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ACKNOWLEDGMENTS

The Minerals Management Service thanks all ITM participants. Recognition goes to the speakers whose timely individual and panel presentations stimulated discussions and exchange of information. We are grateful to the chairs and co-chairs for the many hours spent organizing and chairing the sessions and for spending time gathering presentation summaries. Samantha Burmaster of the Multimedia and Internet Production Section of MMS Gulf of Mexico Region prepared a beautiful and informative exhibit. Contributions of pictures and text were made by Greg Boland, Bill Lang, and Harry Luton. The University of New Orleans, Office of Conference Services, was the contractor responsible for the meeting. The dedicated staff and subcontractors play an integral role in the execution of this meeting and the completion of the proceedings. Their tireless efforts are greatly appreciated. The staff of the Airport Hilton were personable and accommodating to our countless requests. Support funding is provided through the MMS Environmental Studies Program.

INTRODUCTION

This year's Information Transfer Meeting (ITM) again brought together people from all over the country and the world to discuss the various topics funded by the Environmental Studies Program. As always, the ITM provides a forum where interchange on topics of current interest relative to environmental assessments of the offshore oil and gas industry can occur. The accomplishments of the MMS Environmental Studies Program for the Gulf of Mexico and of other research programs or study projects were presented. The ITM is a place to foster an exchange of information of regional interest among scientists, staff members, and decision-makers from MMS, other federal or state governmental agencies, regionally important industries and academia. It is an opportunity for attendees to meet and nurture professional acquaintances and peer contacts.

The 21st ITM focused on several topics from sperm whale research to the history of the oil and gas industry in Southern Louisiana. New information about the movements of sperm whales was shared with an overflow capacity crowd. Interesting stories about the pioneers of the oil industry were shared along with many old photos. Presentations were given on the types of organisms that live on and around the numerous structures in the Gulf of Mexico. Physical oceanographers presented their most recent findings of the movement of currents in deepwater using various models. Two sessions addressed the socioeconomic impacts from the oil and gas industry to Gulf Coast states. The removal of offshore structures was the topic of a full day of presentations that brought together government agencies and industry. The continuing expansion into deepwater with new technologies and issues were discussed. Speakers came from as far away as Mexico and England.

Following are the summaries of the presentations that were given by all the excellent speakers.

SESSION 1A

DEEPWATER

Co-Chairs: Mr. Ed Richardson, Minerals Management Service
Mr. Jim Regg, Minerals Management Service

Date: January 8, 2002

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Compressed Natural Gas: A Key Success Factor for Ultra-Deepwater Developments for the Gulf of Mexico 15
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Mr. David Walker, British Petroleum

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INTRODUCTION

Mr. Ed Richardson
Minerals Management Service

Click here to see Mr. Richardson’s slide show.

G. Ed Richardson is a senior environmental scientist with the Minerals Management Service’s Gulf of Mexico OCS Region in New Orleans. He specializes in National Environmental Policy Act (NEPA) assessments of “new and unusual” technology proposed for use in the oil and gas field. He also coordinates Programmatic Grid Environmental Assessments for the deepwater areas of the Gulf of Mexico. His civilian career spans over 29 years of environmental and regulatory experience in state and federal government agencies and in the oil and gas industry. He is a colonel in the U.S. Army Reserve and serves as a senior environmental science officer. He received his undergraduate and graduate degrees from Clemson University in microbiology, environmental health, and biochemistry.

DEEPSPILL

Mr. Dan Allen
Chevron USA Production Co.

WHY SHOULD THE DEEPSPILL JOINT INDUSTRY PROPOSAL (JIP) BE CONDUCTED?

Little is known about the behavior of liquid and gaseous hydrocarbon releases under deepwater conditions. Several questions have focused the JIP's efforts.

- If hydrates were formed, how would they affect the continued release of the hydrocarbons?
- Would there be any gas phase dissolution? Would gas even come to the surface, of the sea from a release?
- Would the released hydrocarbons eventually come to the sea surface and how far from the release site would this occur?
- Would phase separation occur?
- To what degree would entrainment of oil occur in the water column?
- What about the size distribution of the droplet and bubble from the hydrocarbon release?
- Would "weathering" occur on the liquid hydrocarbons in the water column?

The behavior of the released hydrocarbons could affect potential intervention methods. The formation of hydrates at the release point could limit or stop the release of the hydrocarbons. What kind of cleanup equipment might be needed, if it were needed at all?

Participants in the JIP wanted to optimize their spill response "toolbox." What would work for containment and cleanup of a deepwater spill? Could dispersants be used effectively? Tests were also needed on surveillance technologies to determine their applicability and effectiveness.

Deepwater computer transport models were being developed at two universities. Data from the deepwater release could be used to validate the model and its outcomes. Laboratory data were also generated from elements within the JIP. The release could serve to calibrate these data.

The DeepSpill JIP had some unlikely partners. The MMS contributed funding toward the JIP and was actively involved throughout the process. The Norwegian Pollution Control Authority (SFT) and the Norwegian Clean Sea Association (NOFO), a cleanup consortium, were participants in the JIP. Additionally, 22 oil companies rounded out the JIP partners.

Norway was selected for the test release because it has always been a leader in "field testing" oil release study efforts. Since other releases have been successfully conducted off the Norway, fewer legal complications were expected.

CONDUCTING THE EXPERIMENTAL UNDERWATER HYDROCARBON RELEASE

Table 1A.1 depicts a summary of the four experimental discharges to be conducted during the study.

Table 1A.1. Summary of the four experimental discharges.

Experiment	Duration (minutes)	Gas Rate (Sm^3/s)	Water/Oil Rate (m^3/hr)
Nitrogen and dyed sea water	40	0.6	60
Marine diesel and LNG	60 (oil)	0.6	60
Crude oil and LNG	50 (oil)	0.7	60
LNG and sea water	120	0.7	60

A variety of instruments were used during the experimental release to monitor the characteristics and movement of the expelled fluids. Some instruments were selected to determine if they could accurately detect the released hydrocarbons within the water column. The following is a listing of some of the instruments used during the tests.

- Echosounders at 18, 38, 120, and 200 kHz
- Radar
- ADCP
- CTD, rosette sampler, PAH fluorimeter
- ROV videos

Figure 1A.1 shows a diagrammatic representation of the deployed equipment for the experimental hydrocarbon release.

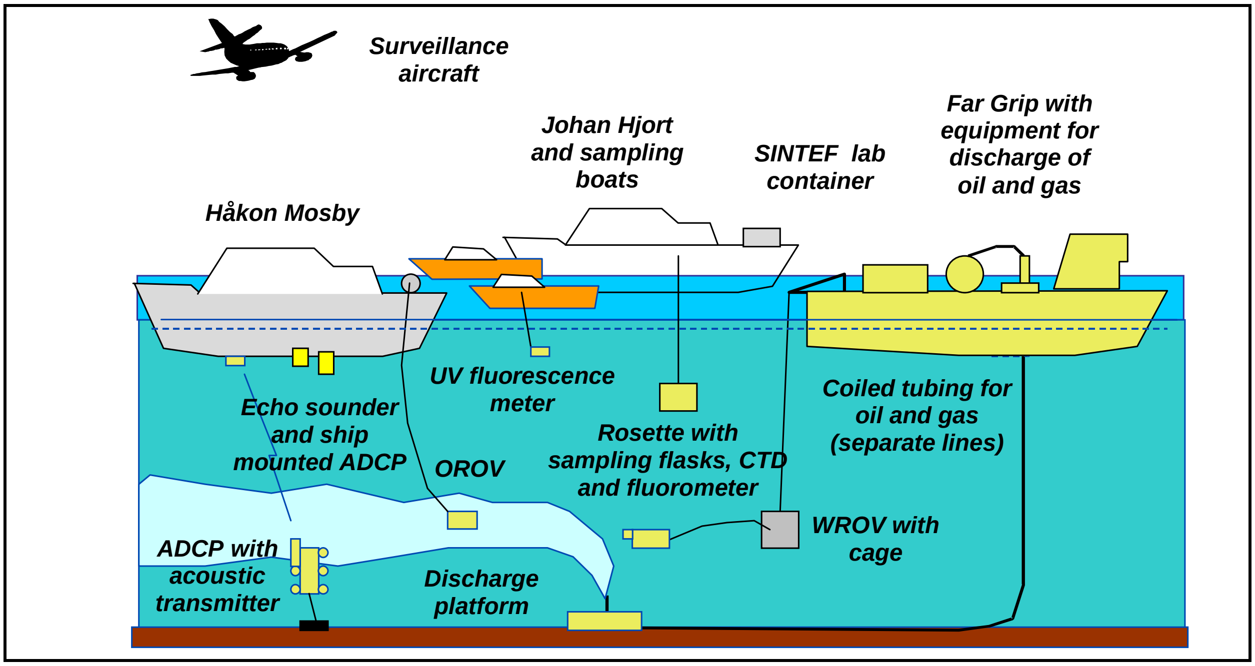

Figure 1A.1. Diagrammatic of the deployed equipment for the hydrocarbon release experiment.

The experimental hydrocarbon release was to take place in the Norwegian sector of the North Sea at a location know as Heland Hansen. The map in Figure 1A.2 shows this area and its relationship to the Norwegian coast.

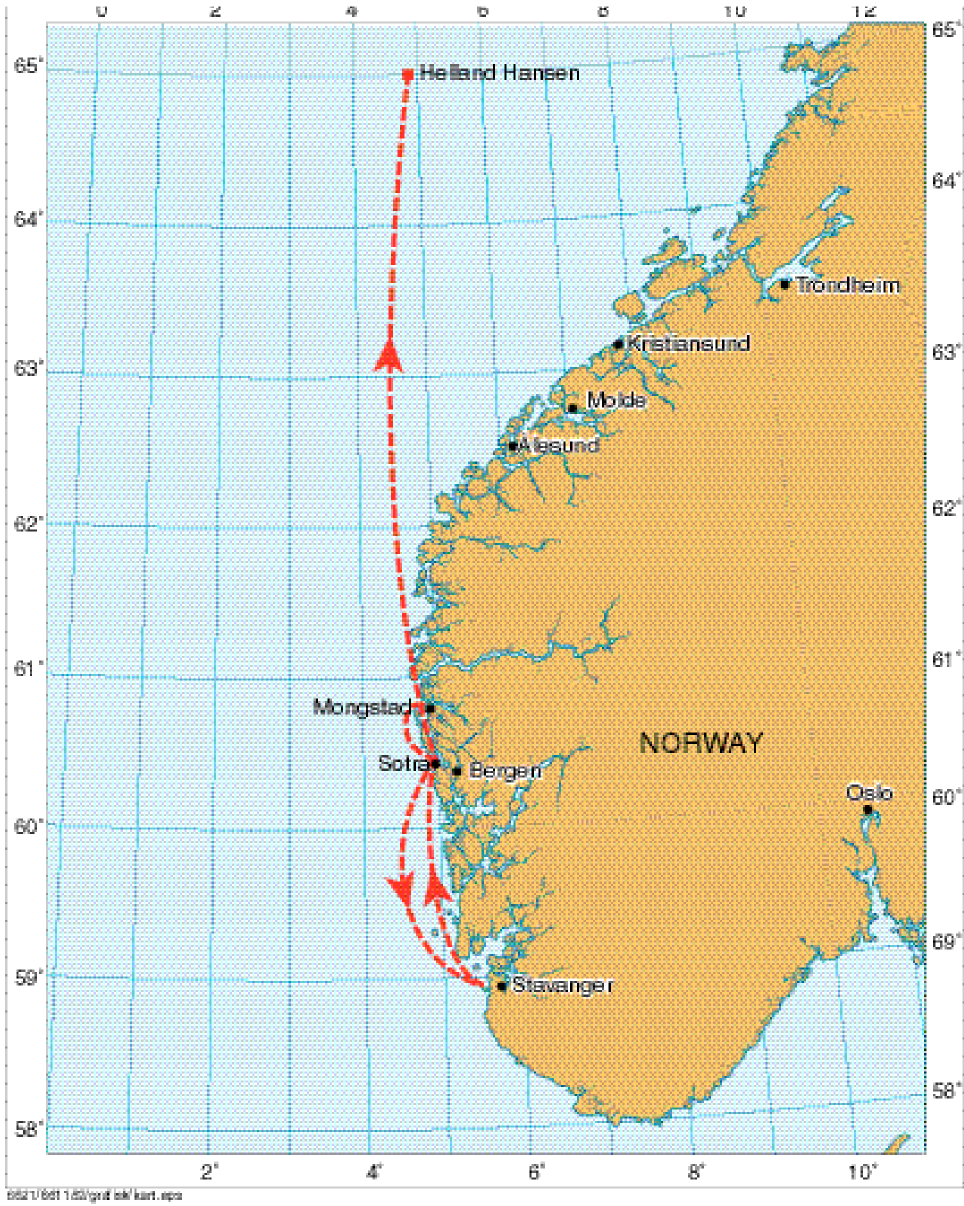

Figure 1A.2. Relationship of experimental hydrocarbon release site to the Norwegian coastline.

Figure 1A.3 shows the surface slick that developed during one of the experimental releases. Note the survey vessels working in the slick.

Figure 1A.3. Surface slick that developed after a hydrocarbon test release.

Figure 1A.4 shows an underwater gas release from the subsea manifold during one of the tests.

FINDINGS FROM THE EXPERIMENTAL DEEPWATER HYDROCARBON RELEASE.

The following list summarizes the major findings from the hydrocarbon release:

- While the temperature and pressure at the underwater release site were well within the ranges for stable hydrates to form, none were observed.
- The gas/oil plumes were clearly detected by echosounder equipment.
- No gas was observed at the sea surface.
- The oil surfaced near the underwater manifold site as thin films within about one hour after its release.
- Oil spill model results roughly agree with the observation at the test site.

Figure 1A.4. Underwater gas release from the subsea manifold.

Mr. Allen is a coastal and marine ecologist working for Chevron Production Company's Deepwater Business Unit in New Orleans. Since joining Chevron in 1981, he has coordinated contingency planning, spill responses and spill research and development programs in all regions of the U.S. and in several locations abroad. He is a member of the Louisiana Applied Oil Spill Research and Development Program Advisory Committee, the API Spill Science and Technology Committee, the OOC Deep Water Sciences Subcommittee, and chairs the OOC Deep Water Spills Working Group. In addition, he serves as an advisor and company representative to a number of other trade associations and spill response cooperatives.

GOM DEEPWATER TRANSPORTATION: JAC SHUTTLE TANKERS

Mr. Chuck Steube
CONOCO Marine

Click here to see Mr. Steube's slide show.

Delivery of crude oil from offshore installations by water borne transportation (oil tankers) to a delivery point to the onshore U.S. market is now an alternative for the Gulf of Mexico (GOM) given the recent Record of Decision issued by the MMS. Most major exploration and producing companies are expanding their search for oil in the GOM and with technology improvements are moving further from existing offshore infrastructure and into deeper water (5,000 ft to 10,000 ft). Alternatives need to be developed for the transportation of these deepwater production volumes to market. Oil transportation via shuttle tanker has been an accepted off-take solution in other major producing areas of the world and is now a viable alternative for oil off-take for future developments in deepwater GOM.

The vessels required for transporting crude oil from the GOM are far from the traditional crude oil tanker. Because of the Jones Act, these vessel will have to be built, flagged and manned in the U.S. Meet OPA-90 requirements, meet stringent technical, commercial, public perception requirements and be cost-effective to compete with pipeline tariffs. Vessel construction will require a non-traditional approach to conventional shipbuilding. The two key criteria that will drive construction are timing and budget.

The needs of the oil producers require that the vessels meet certain specifications to provide a reliable transportation system. Vessel cargo size should be 500,000 BBLS, which equates to an arrival draft of 40 ft. This size is suitable for most Gulf Coast ports and is a typical refinery size. DP-2 systems should also be considered for the vessel to improve turn-around times and vessel uptime that in turn can eliminate any field shut in. The vessel also needs to be OPA-90 compliant and should be double hulled.

The shuttle vessel operator must also decide on the type of vessel to be used for shuttle service: either a tug/barge unit or a tanker. Tankers have a proven track record of shuttle service operating in the North Sea while critical technical issues must be addressed before the tug/barge units should be used for shuttle service.

Only seven U.S. shipyards can build 500 M bbl tankers or larger. Within this group, Avondale, National Steel and Shipbuilding and Kvaerner Philadelphia Shipyard are most interested in securing new building commercial contracts. Avondale is currently constructing commercial tankers for Polar Tankers, and NASSCO has been awarded a contract from BP to construct commercial tankers both for the Alaska WC service.

A non-traditional solution is needed for this non-traditional GOM shuttle transportation service. The solution we have come up with is to bring together different companies with the right technical

background, business expertise, yard facilities and willingness to make a significant step change in the traditional U.S. maritime construction market.
This non-traditional approach we believe can meet the customers' time requirements, can compete with pipelines on a tariff basis, and provide a safe, efficient transportation alternative for the GOM.

Now that we have looked at the Shuttle tanker we also need to look at the interface systems that will move the oil from the deepwater offshore facility to the tanker. These systems can vary depending on the type of facility. Off-take systems can be configured to adapt to a variety of field infrastructures with or without storage. As the industry moves to deeper water, new technologies will emerge that will allow more efficient transfer of crude oil and gas from the process facilities to the shuttle tanker.

Chuck Steube has been employed by Conoco for over 28 years in both project and field management positions ranging from onshore, artic, offshore marine operations to field development. He was part of the Project Team that installed Conoco's first FPSO in Nigeria and was the offshore superintendent for that installation. In his current position as Manager of Production Operations in the Floating Systems Division of Conoco Marine, Chuck is involved with a wide range of projects including shuttle tankers for the Gulf of Mexico and FPSOs and FSO for worldwide deployment. He holds a BA degree from Texas Tech University and an MBA degree from Tulane University.

DUAL GRADIENT DRILLING

Mr. Ken Smith
Conoco Inc.

Click here to see Mr. Smith's slide show.

Ken Smith is an engineering professional with Conoco. He is a graduate of Texas A&M and has 23 years of experience in rig supervision, drilling engineering, drilling technology, and drilling management, both domestically and overseas. For the last six years, he has been working as project manager for the Subsea Mudlift Drilling Joint Industry Project, which recently finished drilling the world's first dual gradient well.

COMPRESSED NATURAL GAS: A KEY SUCCESS FACTOR FOR ULTRA-DEEPWATER DEVELOPMENTS FOR THE GULF OF MEXICO

Mr. Charles White
EnerSea Transport, L.L.C.

Click here to see Mr. White's slide show.

Why does the U.S. need marine CNG transport solutions?

- Long-term conversion to gas is ongoing
  - Growth of gas-fired power generation
  - Evolution of fuel cells
  - Current low price ⇒ decreased land exploration
- CNG can economically transport GOM, Alaska, Canadian, Caribbean, and South America gas to U.S. markets
- A CNG marine transport option for the GOM will facilitate commerical development of smaller (especially gas) discoveries and open the ultra-deep for gas exploration
- CNG transport conserves natural gas compared to LNG, GTL (much less CO_2 production)
- CNG transport limits dependence on supply from the Middle and Far East

There is little incentive to find or develop gas reserves in the ultra-deep GOM. Unless a gas shuttling is allowed as a means to help operators unlock remote gas, a vast resource will remain beyond commercial reach for many years.

Critical success factors for ultra-deep GOM service:

- Clear economic incentive as compared to pipeline export to offset perceived risks
- Approval of oil shuttling for GOM
- Operators' perception of positive government alignment for gas shuttling initiatives (a clear picture of which entities are involved and their commitment to a "facilitation role")
- Rational timeline to approval
- At least one operator focused on "value creation" instead of "risk reduction"
  - Or cooperative operator groups (enhancing opportunities for aggregating marginal fields through one service provider)

What are gas handling alternatives?

- Pipeline export
- CNG
- LNG
- Gas to liquids (GTL)
- Gas to wire (electric power generation & transmission)
- Gas to commodity (bulks, ores, chemicals, etc.)
- Re-injection
- Flaring

Only CNG shuttling, pipelines, and re-injection are receiving any serious consideration as viable options for handling gas in the ultra-deep. Both pipeline export and gas shuttling appear to provide commercial options for gas disposal. However, gas shuttling provides flexibility and re-deployment opportunities not available with pipelines.

Key system design/cost elements for CNG:

- Produced gas characteristics and preparation for storing
- Gas loading systems (hydrate management)
- Gas containment concept (CNG tank design)
  - Materials
  - Wall thickness (base and allowances)
  - Wall wetness
  - Gas behavior in and during loading/unloading operations ("heat of compression" losses)
- Ship design (for efficient carriage of CNG cargo tanks)
- Gas delivery systems
- Safety and risk management
  - Demonstrate hazards no greater than LNG through hazard risk studies

Total system commercial effectiveness:

- Environmental value/challenges
- "New technology" label vs. industry acceptance
- Regulatory approval hurdles
- Economic incentives

CNG marine transport alternatives:

- VOTRANS™
- Coselles™ (coils of small diameter pipe captured in "cans" that may be stacked on barges or in ships)
- Lorica (container-sized carbon/fiber composite pressure vessels)
- TransCanada pipelines (composite reinforced large diameter pipe tanks)
- Knutsen OAS (a CNG ship design with vertical large diameter pipe tanks)

All of the above except VOTRANS™ store gas a very high pressures, depending on blowdown and scavenging to offload their cargo. High storage pressures and scavenging require costly compression facilities. Higher pressures also demand more costly gas containers. VOTRANS™ is not just a new gas container or gas ship idea. It is a total gas storage and delivery system.

WHAT IS ENERSEA TRANSPORT?

EnerSea Transport L.L.C. is a Texas start-up that is building an international presence through new business development and strategic partnerships. EnerSea offers a highly efficient compressed natural gas marine delivery system called VOTRANS™ or Volume Optimized Transport and Storage. VOTRANS™ optimizes the relationships between the compressibility and storage temperature of gas and the weight of steel containment pipes. Depending on the gas make-up, Paragon Engineering Services Inc. (PES) projects that VOTRANS™ will store from 60% to over 100% more gas per pound of steel than competing CNG concepts.

The VOTRANS™ cargo package, or Z-Pack, is comprised of a multitude of tanks or long, large-diameter pipe structures manifolded together in tiers. The steel, though high strength, is commercially available and has been proven in gas transportation service at similar temperatures and pressures. VOTRANS™ Z-ships are inherently scalable and can be designed to carry from 100,000MCF to 2 BCF per ship. In order to maintain temperature and pressure over time and distance, the pipe structures are contained within an insulated coldbox.

The independent engineering, naval architecture, and economic analyses performed over the last two years by PES, Alan C. McClure Associates, Inc., and Groppe, Long & Littell have confirmed the technical and economic viability of VOTRANS™. Naval architects have assessed the viability of newbuild and ship conversion options leading to preliminary class and regulatory reviews. The team has created highly efficient cost-estimating tools that model the entire delivery system (from compression inlet at gas supply point through receipt facilities at market access point). These tools have been used to confirm economics for a wide range of case studies. Dr. Michael Economides reviewed EnerSea's technology and came to some interesting conclusions in an interview with Energy News Live (Williams Webcast). This interview, along with other general information, is available on our website, *www.EnerSeaTransport.com*.

Ongoing communications and sanctioned work efforts with ABS and DnV and government agencies (e.g., Transport Canada, U.S. Coast Guard, and U.S. Minerals Management Service) confirm that a reasonable pathway to regulatory approval exists.

Pre-project engineering is planned in Phase III to begin January 2002, advancing system definition to ensure that a commercial project can be sanctioned for a specific application. The primary focus will be to establish ship design and construction plans and to achieve "class approval in principal" for a Z-ship, with a goal to have "gas on ships" by 2005.

EnerSea's principals have extensive experience with marine systems, naval architecture, deepwater/frontier pipeline development, natural gas storage, energy trading, and finance. Key team members have enjoyed over 30 years with major E&P companies. Others have founded and built profitable energy and logistics businesses with over $800 million in annual sales.

———————

Charles N. White, P.E., has worked for over two decades in the offshore oil industry, focusing on technologies for deepwater development. He was an internal marine systems engineering consultant and project manager with Conoco for 18 years prior to joining Statoil as lead for the deepwater field and technology development (U.S. Gulf of Mexico). Prior to joining Conoco, he worked in technical approval of ships and major approval of ships and major offshore equipment for the American Bureau of Shipping. Mr. White has been a leader in the U.S. and international marine and offshore community for many years, including roles as regional chairman for the Society of Naval Architects and Marine Engineers, as chairman of API and DeepStar workgroups for development of international standards (RPs) for floating production systems and risers, and as originator and champion of several major joint industry projects. Mr. White has also authored many technical papers and been granted a number of patents and engineering awards (U.S. and international).

THE TECHNICAL CHALLENGES OF DEEPWATER PIPELINES

Mr. David Walker
British Petroleum

Click here to see Mr. Walker's slide show.

INTRODUCTION

This presentation summarizes the technological challenges associated with the design, construction, and operation of deepwater pipeline systems that are currently being built in the Gulf of Mexico (GOM). The primary focus is on export lines, both oil and gas, with a brief discussion of flowline issues. The paper's intent is to focus on what is new and challenging for pipelines as the oil and gas industry moves production activities out to the 1,829 m (6,000 ft) water depth contour.

In terms of the history of offshore pipelines, we can trace an evolution from the GOM in the 1960s, through the 1970s, and 1980s in the North Sea and on the Norwegian Shelf culminating in gas export systems such as Asgard, and then back to the GOM in the 1990s with deepwater projects such as Mars. The current pipeline industry benchmark is probably the Hoover-Diana 20-in export system in approximately 1,371 m (4,500 ft) of water. However, during the first half of this decade, we shall see the boundaries being extended in the Black Sea (Blue Stream) and here in the Gulf where plans are underway to construct 28-in lines in over 1,829 m (6,000 ft) of water.

A DEEPWATER PIPELINE SYSTEM

Deepwater pipelines are part of a pipeline system, which often will embrace shallow water sections. Most importantly, pipelines to floating production systems will incorporate dynamic risers linking the pipeline on the seabed to the surface. Traditional pipeline design methods barely address movement and dynamic environments. Typically, guidance is given on how to avoid unsupported spans that are subject to dynamic loading. We need to recognize that in deepwater, spans of over 1.6 km (1 mi) in length in the form of steel catenary risers are an integral part of the pipeline system and have to be considered in great detail in their design, construction, and operation.

The issue of subsea tie-ins, although not unique to deepwater systems, needs to be considered. Expensive deepwater pipeline infrastructure needs to be fully utilized, and subsea is likely to be an attractive option for managing tie-ins, given the weight and expense of trying to hang off multiple risers from floating production facilities. This raises the possibility of multi-diameter pipeline systems – particularly if we seek to minimize riser diameter—which then brings in the question of multi-diameter pigging as a possible requirement.

DESIGN CHALLENGES

For the vast majority of the world's pipelines, their wall thickness is a function of internal pressure concerns. However, this is not true in deepwater environments where external pressure can govern – in particular during installation – where, in the sag bend close to the seabed, the pipeline will be subject to its most severe loading condition combining high external pressure, axial load, and bending. These loadings interact; i.e., the more a pipe is bent, the less external pressure it can sustain. For added assurance of design with very heavy wall pipelines, some operators have chosen to conduct full-scale bending trials where samples of pipe are subject to combined loadings in a pressure vessel to determine the safety margin against collapse. Collapse may not be localized and to limit the extent to which it can propagate along a pipeline, buckle arrestors or extra heavy wall sections are generally incorporated in the deepest sections of the pipeline.

Pipe manufacture is also an issue. Soon we will find ourselves testing the limits of what the world's steel mills can produce as we seek to move into deeper water. Again I mention the question of multi-diameter pipelines, because if we seek to construct fully piggable systems, we need to pay great attention to pig design and to what changes in diameter can be incorporated.

Seabed issues are not confined to deepwater, but we do need to recognize that gathering survey data to assist in route selections will be expensive, especially if traditional "towed fish" technology is utilized rather than the newer autonomous underwater vehicles (AUV) for the surveys. In parts of the Gulf, we encounter seabed escarpments at around the 1,219-1,829 m (4,000- 6,000 ft) depth range, and great care is needed in route selection through these areas. The industry has accumulated a lot of experience in the Norwegian shelf in dealing with difficult and uneven seabeds – potentially a major cost issue. Soft seabeds associated with marine sediments are generally welcomed, but we do need to pay particular attention to any differential settlements that might arise relative to fixed objects such as end manifolds or tie-in sleds.

Steel catenary risers are a challenging part of the pipeline design. Critical areas concern vessel motion prediction and our ability to predict vortex induced vibration (VIV) (in the same way that telephone wires can "hum" in the wind) since marine risers can be "excited" by transverse currents. Fortunately for the pipeline designer, the deepwater drilling community has been deploying long, slender drilling risers from floating systems for many years, and there is a considerable body of research from which we can draw for knowledge. Catenary risers differ in their end conditions from vertical drilling risers, but the analogue is still a good one. For catenary risers, what is likely to govern design criteria is fatigue life considerations, and that has profound consequences the way we must address integrity issues.

A critical component on the export riser will be the top connection to the floating production facility. Generally, to limit stress concentrations at the hang-off point beneath the "floater," some kind of stress joint (a tapered section) or flex joint will have to be incorporated into the design. The mechanical integrity of such a device is of critical importance. In the paper's accompanying slides, a plot is shown of "severity of duty" that is a measure of pressure, temperature, and motion versus the diameter of pipe. Since flex joints incorporate elastomeric materials, temperature rating and production fluid compatibility are also important considerations.

Pipeline fluids are always a key design driver, irrespective of water depth. We just have to recognize that in some instances, there may be high levels of uncertainty which have to be accommodated at the design stage (depending on how well the reservoir fluids have been characterized). We also need to deal with depressed seabed temperatures and high hydrostatic heads in the pipeline fluids that can accelerate the propensity to form wax and/or hydrates.

CONSTRUCTION ACTIVITIES

There are two key drivers in pipeline construction activities: wall thickness and weight of the pipe. Large pipelines installed in deepwater by “J-lay” vessels are heavy. For example, a 28-inch pipeline in 1,829 m (6,000 ft) of water requires top tensions of approximately 350 tons. Should we ever need to recover a “flooded” pipeline of that size to the surface, lifting capacities of close to 1,000 tons will be needed. This severely limits the choice of vessels for these operations. We also need to recognize the huge amount of elastic energy stored in such a system during installation. This has to be a key consideration in our approach to safety management. The drilling community is already dealing with a similar challenge. We just need to recognize that as we step out into deeper water with pipeline installation, the potential hazard associated with any form of failure is significant. Where new vessels are commissioned to operate in this challenging deepwater environment, it is common practice to conduct full-scale pipe laying trials to demonstrate their performance and safe operations.

Thick pipelines require multiple pass welding and careful inspection. The fatigue driven design of catenary risers makes them particularly sensitive to material defects, thus raising the standards required during inspection. Extensive welding trials and fatigue testing of sample welds is routinely required.

Another challenging aspect of risers is their installation. Generally, they will be installed as a part of the pipeline string, but there always remains the tricky operation of passing over the end from the lay vessel to the host platform and securing it to the facility.

Many deepwater pipelines will contain mechanical components, in particular flex joints at their point of origin, and connectors and valves that have to installed on the seabed. Access to these seabed components is hugely expensive in deepwater and therefore, the highest possible standards of mechanical integrity are required.

Subsea tie-ins may be required in deepwater. Careful design of minimum weight tie-in sleds supporting piggable “Y’s” is important to allow their installation as a part of the pipeline string. Critically, there is the question of making diverless tie-ins – not a new technology, but one where we are seeking to make advances in terms of increasing diameter and water depth. The same is true of the ball valves incorporated into a pipeline.

OPERATIONS AND LONG TERM INTEGRITY

The potential for operating a multi-diameter pipeline system in deepwater may generate the need for new types of pigs for operational reasons such as commissioning and wax removal.

When thinking about long-term integrity, there are choices to be made concerning how we should operate and inspect both the riser and the pipeline. If intelligence pigging is the selected technology for corrosion monitoring, then it is likely that development work will be needed to allow the pigs to handle the high internal pressures and the high wall thicknesses, as well as having multi-diameter capability. Crack detection technology that could be applied to riser systems is also evolving rapidly. What is important is our system's design to facilitate its inspection, and that we are well placed to take advantage of the improvements in inspection technology that undoubtedly will happen over the next 20 years. We also need to recognize the value associated with dynamic monitoring simply to allow better designs in the future.

PIPELINE REPAIR

On the question of pipeline repair, there are perhaps two points to be made. First, deepwater pipelines are immensely strong structures. As already pointed out in the design section, their wall thickness in the deepest sections is driven by installation considerations. This means that during normal operations on the seabed, stress levels will be lower than in equivalent sized pipelines in shallow water. Differential pressures (the difference between internal and external pressures and the driving force for any leakage) are generally less than in shallow water. Indeed, in some deepwater natural gas pipelines, we can have situations where external pressure exceeds internal, creating the novel situation of any leak resulting in sea water entering the pipeline. This could have very serious operational impacts if it led to hydrate formation inside the pipe. Potential for third-party interference from vessel anchoring and other bottom disturbing activities is generally very low in the deepwater environment.

However, even in these relatively benign environments, we still need to demonstrate to ourselves that we have a comprehensive repair capability. We are not looking at radically new types of repair technology, but it is clear that much of the equipment we need and the vessels from which it will be deployed will be bigger than we see today to accommodate the heavier wall and greater depths of the pipelines.

FLOWLINE TECHNOLOGY

With flowline, we are less likely to find external pressure governing its design as is the case with export pipelines in the deepwater environment. Indeed, some deepwater GOM reservoirs are both high temperature and high pressure, and these factors can have a more profound effect on the design than simply the water depth.

With untreated hydrocarbons, temperature control to avoid wax and/or hydrate formation will be critical. Frequently, flowline design may require insulation. In some instances, the requirement is driven by steady-state flowing conditions, but more frequently, insulation needs are driven by shutdown conditions. During shutdown of a subsea system, we need to displace the "live crude" to prevent hydrate formation on cool down. The pipeline insulation gives us the time necessary to carry out this operation. Most insulating materials lack the high mechanical strength required to resist external pressure in deepwater, hence, we find solutions such as pipe-in-pipe technology being adopted.

Multiphase flow (often characterizes flowline operations and long vertical risers) will exacerbate any slugging propensity in the system, leading to greater hydraulic instability as water depth increases.

Finally, we have the question of transporting potentially corrosive fluids in risers subject to fatigue—a combination than in some cases will lead us to take special precautions, such as the use of corrosion resistant materials.

CONCLUSIONS

Despite the added demands of pipeline systems in 1,829 m (6,000 ft), there is little if any technology we should categorize as breakthrough. In general, nearly everything can be viewed as extensions from where we are today and this is an important consideration in undertaking this step. We do need added assurance, and we shall see this manifest in three ways:

- a rigorous application of prototype testing,
- a scrupulous attention to detail in design and planning, and
- an enhanced monitoring capability.

David Walker has been with British Petroleum since he started in the oil industry over 30 years ago. He has a degree in mechanical engineering from Cambridge University. His career has been mainly concerned with pipelines and offshore construction. In 1997 he was transferred to BP's Houston office to manage the company's deepwater research and development program. His current job is to act as a senior consultant to BP's deepwater Gulf of Mexico projects.

QUESTIONS AND ANSWERS
SESSION 1A, DEEPWATER

Dan Allen, ChevronTexaco
DeepSpill

Q – How much oil made it to the surface during the Deep Spill test release?

A – The exact result is in the test release final report; ballpark estimate is that about 50% of the oil released reached the surface. Oil released reached the surface about one hour after its release at the seabed (844 meters water depth) and the resulting sheen was a thin film about 0.5 km from the site.

Q – Regarding the oil at the surface, was it weathered? Could the oil at the surface be chemically dispersed?

A – There was considerable stripping of the high-end components of the oil as it migrated through the water column. The study did not investigate chemical dispersion of the resulting oil sheen.

Chuck Steube, Conoco Marine
GOM Deepwater Transportation: JAC Shuttle Tankers

Q – Have you investigated gas transport?

A – There is a paper later in this session to address options for the transportation of gas. Conoco's efforts to develop shuttle tankers for the GOM have not focused on gas transport by ship.

Q – What is the status of the Hi-Load Deepwater Offloading System?

A – This system is currently in a detailed design phase. Feasibility and conceptual designs have been completed.

Q – Have you investigated the drivers for the high cost of a Jones Act shuttle tanker?

A – Jones Act tanker is about twice the cost of a shuttle tanker built in Korea. Labor rates have some impact on the high cost.

Ken Smith, Conoco Inc.
Dual Gradient Drilling

Q – (No questions)

Chuck White, EnerSea Transport, L.L.C.
Compressed Natural Gas: A Key Success Factor for Ultra-Deepwater Developments for the Gulf of Mexico

Q – Have you investigated the resulting release of CNG in the event of a collision?

A – This has been addressed in hazard analyses to date but there has not been much modeling of impact scenarios.

Q – Would the CNG shuttle tankers be required to comply with the Jones Act?

A – This has not been addressed in detail with the U.S. Customs office. Economic studies conducted by EnerSea Transport have assumed that the CNG shuttle tankers would be Jones Act.

David Walker, British Petroleum
The Technical Challenges of Deepwater Pipelines

Q – How sensitive are deepwater pipeline designs to currents?

A – Deepwater pipeline designs are not sensitive to extreme events. They are most sensitive to long term fatigue.

Q – How do you address uncertainty in deepwater pipeline designs?

A – Uncertainty is addressed through safety factors and monitoring of the pipeline.

Q – Do you see deepwater pipelining technology as a step change or an extension of existing design and techniques?

A – BP believes designing, installing and operating deepwater pipelines is an incremental technology that does not require a massive step change. Deepwater pipelining is not fundamentally different from what is going on in the GOM now.

SESSION 1B

PLATFORM STUDIES I

Chair: Mr. Greg Boland, Minerals Management Service
Co-Chair: Ms. Susan Childs, Minerals Management Service

Date: January 8, 2002

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Mr. Rick Kasprzack, Louisiana Department of Wildlife and Fisheries

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Dr. Mark C. Benfield and Dr. Richard F. Shaw, Coastal Fisheries Institute, Department of Oceanography and Coastal Sciences, Louisiana State University
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Dr. Randy E. Edwards, U.S. Geological Survey, Biological Resources Division, Florida Caribbean Science Center and University of South Florida, College of Marine Science
Dr. Kenneth J. Sulak, U.S. Geological Survey, Biological Resources Division, Florida Caribbean Science Center

MOLLUSCS AND BENTHIC FORAMINIFERS OF CHEVRON ST23: PRELIMINARY BIOTIC SURVEY AND EVALUATION OF BIOTECHNOLOGY POTENTIAL

Dr. Laurie C. Anderson
Dr. Barun K. Sen Gupta
Department of Geology & Geophysics
Louisiana State University

Ms. Lorene Smith
Museum of Natural Science
Louisiana State University

INTRODUCTION

This report of preliminary results concerning benthic Foraminifera and Mollusca is part of a larger study evaluating oil and gas platforms on the Louisiana continental shelf for organisms with biotechnology potential (Task Order 17809). Dr. Larry Rouse is the project director and other principal investigators include Drs. Fred Rainey (Bacteria), Russell Chapman (Algae), Michael Hellberg (Bryozoa), Barun Sen Gupta (benthic Foraminifera), Laurie Anderson (Mollusca), and David Foltz (genetic analyses of Mollusca and Foraminifera).

The project was developed in response to MMS's recognition that offshore oil and gas platforms may serve as a harvestable source of organisms with pharmaceutical or other commercial applications. The project also addresses recommendations in the National Ocean Conference Report to (1) increase support for sustainable harvesting and testing of marine compounds by both government agencies and commercial pharmaceutical companies as possible treatments for AIDS, inflammatory or infectious diseases, and cancers; and (2) support research on the environmental effects of extracting marine organisms for biotechnology purposes.

In this initial effort, we are addressing three research questions. (1) What organisms make up the biofouling communities on platforms? (2) Are any of these organisms potential sources of pharmaceuticals or other natural products? (3) What is the distribution and relative abundance of these organisms, and how does this distribution vary geographically, with depth, and over time?

FIELD COLLECTIONS

Our sampling goal in year one was to sample six to nine platforms, at least two each from the shallow, middle, and outer continental shelf. Because of delays and inclement conditions associated with tropical storm Allison, only one platform, Chevron South Timbalier-23 (here referred to as ST-23) was sampled in the first field season (on 9 June 2001). The platform is in approximately 16 m of water at 29º 01.40 N, 90º 10.17 W off of Timablier Island, Louisiana.

At the platform we sampled two legs (east vs. west). Wave conditions did not permit sample collection near the water surface, but samples were collected from the platform legs at 10 m and one meter above the seafloor (here referred to as the 20-m sample). Three replicate samples (scraped from 25 cm^2) were obtained at the 20-m level on both legs, and at the 10-m level on the west leg. Because of time constraints, only two replicate samples were collected at the 10-m level on the east leg. Before scraping, loose sediment associated with the biofouling community was collected using large syringes to retrieve any unattached microorganisms. Syringe samples examined thus far are barren of foraminifers and will not be discussed further.

Two bottom sample localities (with three replicate samples taken at each) were also collected. Divers collected replicate bottom samples consisting primarily of barnacle fragments adjacent to the west platform leg. The other locality, consisting primarily of mud, was sampled from the ship using a grab sampler, and was located about 12 m away from the east leg.

SAMPLE PREPARATION

Samples scraped from platform legs were frozen in the field. Each sample was thawed in the lab and preserved in 95% ethanol. Large pieces (approximately > 4 mm) were retained in ethanol, and finer sediment and biota were screened using 63 micron, 0.5 mm, 1 mm, and 2 mm sieves. All fractions were dried, and molluscs and/or foraminifera were picked from the > 63 micron fractions. Prior to drying, the two finer fractions of ST23-W-10-B and W-20-A were stained with Rose Bengal. ST23-E-10-A was not stained and ST23-E-20 samples have not yet been processed.

Bottom samples were preserved in alcohol in the field and were later treated with Rose Bengal. Samples were screened in the lab, dried, and molluscs and/or foraminifers were picked from the > 0.5 mm and > 63 micron fraction respectively.

PRELIMINARY RESULTS: BENTHIC FORAMINIFERA

Live-collected benthic Foraminifera were present in both seafloor samples—ST 23-E-bottom-A (soft- bottom) and ST23-W-bottom-C (hard-bottom), and in samples scraped from platform legs, in spite of putative bottom-water hypoxia at the time of collection. At the present stage of the work, the focus is on foraminiferal taxonomy, but some distinctions have emerged between the assemblages found in seafloor mud and those from the 20-m and 10-m levels on the platform legs.

20-m Platform Sample

Thus far, one replicate from the 20-m level of the west platform leg has been examined (ST 23-W-20-A). Several species were found in both this platform sample and the seafloor mud sample (ST 23-E-bottom-A, collected about 12 m from the east leg). These species include *Nonionella basiloba*, *Buliminella morgani*, *Bolivina* spp., and *Ammonia parkinsoniana*. All are grazers, and thus, the similarity between a soft-bottom and a hard-bottom assemblage separated by about a meter of water column is not surprising. However, one common grazer of the seafloor, *Bulimina* sp. cf. *B. spicata*, which was found living in spite of bottom-water hypoxia (as were the species named above), is present only as a single occurrence in ST23-W-20-A. In contrast, many miliolid individuals (porcelaneous taxa, mainly *Miliolinella* and *Quinquelouclina*), which are motile grazers, were much more abundant in the 20-m sample than in the mud. The presence of *Dyocibicides*, a sessile form with an irregular, dorsal attachment surface, in W-20-A (but not in the bottom mud) constitutes the most exclusive element of this hard-bottom foraminiferal fauna. *Trochammina* (agglutinated, motile), *Cibicides* (hyaline, sessile), and *Rosalina* (hyaline, possibly sesssile) are dominant constituents of this fauna. Also present were the agglutinated species *Bigenerina irregularis* and *Spiroplectammina* sp.

10-m Platform Samples

One replicate each from the 10-m level of both east and west platform legs was examined (ST 23-E-10-A and S 23-W-10-B). In contrast to the 20-m sample, these shallower assemblages have very few species in common with the seafloor assemblage, except that *Bolivina lowmani* are common in both. *Bolivina lowmani*, however, is a meroplanktonic species and, therefore, its distribution is not substrate controlled. Grazing taxa found at 10-m include species of *Elphidium, Discorbis, Neoconorbina, Miliolinella, Quinqueloculina*, and *Trochammina. Planorbulina, Cibicides,* and *Rosalina* represent the sessile component of the assemblage.

SIGNIFICANCE: BENTHIC FORAMINIFERA

This is the first report of benthic foraminifers living on Gulf of Mexico (GOM) platform legs. Further, the taxa found on the platforms are not limited to those found on surrounding soft sediment, but include hard-bottom species not typically reported from this part of the GOM.

For benthic foraminifers, the organisms collected thus far with the greatest biotechnology potential are those that produce various bioadhesives, including both agglutinated species (*Trochammina, Bigenerina, Spiroplectammina*) and attached calcareous species (*Dyocibicides, Rosalina, Cibicides*). However, high densities of large specimens (>1 mm) that could be exploited to extract these bioadhesives have not been recovered to date.

PRELIMINARY RESULTS: MOLLUSCA

Molluscs were identified from the same samples examined for benthic foraminifers, with the exception of the bottom sample. For molluscs, a replicate from the locality adjacent to the west leg was examined (ST23-W-bottom-B). Live bivalves are present on platform legs, and typically are found nestled within a substrate created by barnacles, which dominate the macrofauna. At the 10-m level, *Isognomon* sp. and *Barbatia domingensis* are common, and *Chama macerophylla* and *Modiolus americanus* also occur. In addition, a variety of unidentified post-larval gastropods and bivalves were found in the samples. At the 20-m level, Barbatia *domingensis* remains common, but *Modiolus americanus* replaces *Isognomon* as a common bivalve. Overall the composition of the bivalve assemblage is similar to those of shallow-water platforms off Texas (e.g., Fotheringham 1981; Gallaway and Lewbel 1982).

Molluscs recovered from a bottom sample (ST23-W-bottom-B), which was collected by divers adjacent to the platform's northwest leg, contained no live molluscs. The death assemblage included the remains of both sessile epifauna derived from the platform, and indigenous shallow infaunal taxa. Unlike the platform samples, a number of recognizable gastropod species were present including *Stramonita* and *Nassarius*.

SIGNIFICANCE: MOLLUSCA

As with benthic foraminifers, the molluscs collected thus far with the greatest biotechnology potential are those that produce bioadhesives. These taxa include the byssate bivalves *Modiolus*, *Isognomon,* and *Barbatia*. The byssus is a bundle of proteinaceous threads secreted by a bivalve that attaches to a substrate by an adhesive plaque (Rzepecki and Waite 1991; Burzio *et al*. 1997). These adhesives are of biotechnology interest because they provide strong, durable adhesion to wet surfaces (Rzepecki and Waite 1991, 1995). In addition, some of the proteins in the adhesive can chelate metal ions (Martell 1982; Deming 1999). The most widely studied byssal protein is mussel adhesive protein (MAP) from *Mytilus edulis*. This compound is used as an attachment factor for cells and tissues in culture (Waite 1991; Deming 1999); as an immobilization agent for antigens, antibiotics, and enzymes (Burzio *et al*. 1997); and as an anticorrosive coat for metals and metal sequestering reagent (Burzio *et al.* 1997; Rzepecki and Waite 1995). Additional potential uses are as medical and dental adhesives and fillers; as microencapsulating agents; as sizing agents for textiles; and as water-resistant inks (Rzepecki and Waite 1995; Burzio *et al*. 1997).

Because byssal composition is highly variable among taxa (Waite 1983), an examination of other byssate bivalves (including those found on Louisiana platforms) may lead to the extraction of a new variety compounds with similar applications. Shallow-water platforms, however, may not be a viable commercial source for these compounds because molluscs are neither large nor abundant on the shallow water platform examined. However, synthetic analogs of MAP are in production (Deming 1999) and the molecular composition of byssi from a variety of platform bivalves may serve as new molecular models.

CONCLUSION

Preliminary results indicate that many species of benthic Foraminifera and Mollusca have colonized offshore Louisiana oil and gas platforms. Some of these, especially the sessile species, may have biotechnology potential.

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COMPARISON OF THE FISHERIES VALUE OF STANDING, TOPPLED, AND PARTIALLY REMOVED PLATFORMS IN THE NORTHERN GULF OF MEXICO

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PROJECT SUMMARY

Artificial reefs have been embraced as a management tool by a wide range of user groups (commercial, recreational, and federal and state resource managers). While these groups view artificial reefs positively, little information exists on associated nekton assemblages, particularly at deepwater artificial reefs. The northern Gulf of Mexico (GOM) boasts the largest artificial reef complex in the world; despite platform acceptance and use as artificial reefs, little is known about the ecological importance of these structures. Previous researchers have documented species compositions and abundance of fishes at several platforms and estimated that standing platforms can seasonally serve as critical habitat for 10,000-30,000 fishes; many species were of recreational and commercial importance. However, similar estimates of fish abundance at platforms reconfigured as artificial reefs are not available.

The purpose of this research was to examine the effect of artificial reef profile on the associated fish community. This research project was designed to effectively sample and compare the fish resources associated with a standing platform and two artificial reefs located in a similar geographic region in the northern GOM off the Texas/Louisiana border (Figure 1B.1 and Table 1B.1). Standing, toppled, and partially removed platforms are generally referred to as artificial reefs, as they are man-made habitat that support living marine organisms.

Dual beam hydroacoustic surveys (Stanley and Wilson 1997) were conducted in June 1999 and 2000 and were accomplished with a stationary array of four transducers at the standing platform (HI 350A) and a mobile survey with a single transducer mounted on a v-fin tow body (towfish) at the partially removed (HI A355) and toppled sites (WC617A). The original plan was to conduct stationary acoustic sampling at each of the two artificial reef sites; however, the research vessels were unable to anchor effectively. The artificial reef surveys were subsequently redesigned as mobile surveys.

Measurements and comparisons were made of the abundance, species composition, and size frequency distribution of fishes associated with a toppled platform, a partially removed platform, and a standing production platform. Digitized hydroacoustic data were processed with a Biosonics' Visual Analyzer 4.02. Ten-meter depth strata were assigned for processing data from each site. We

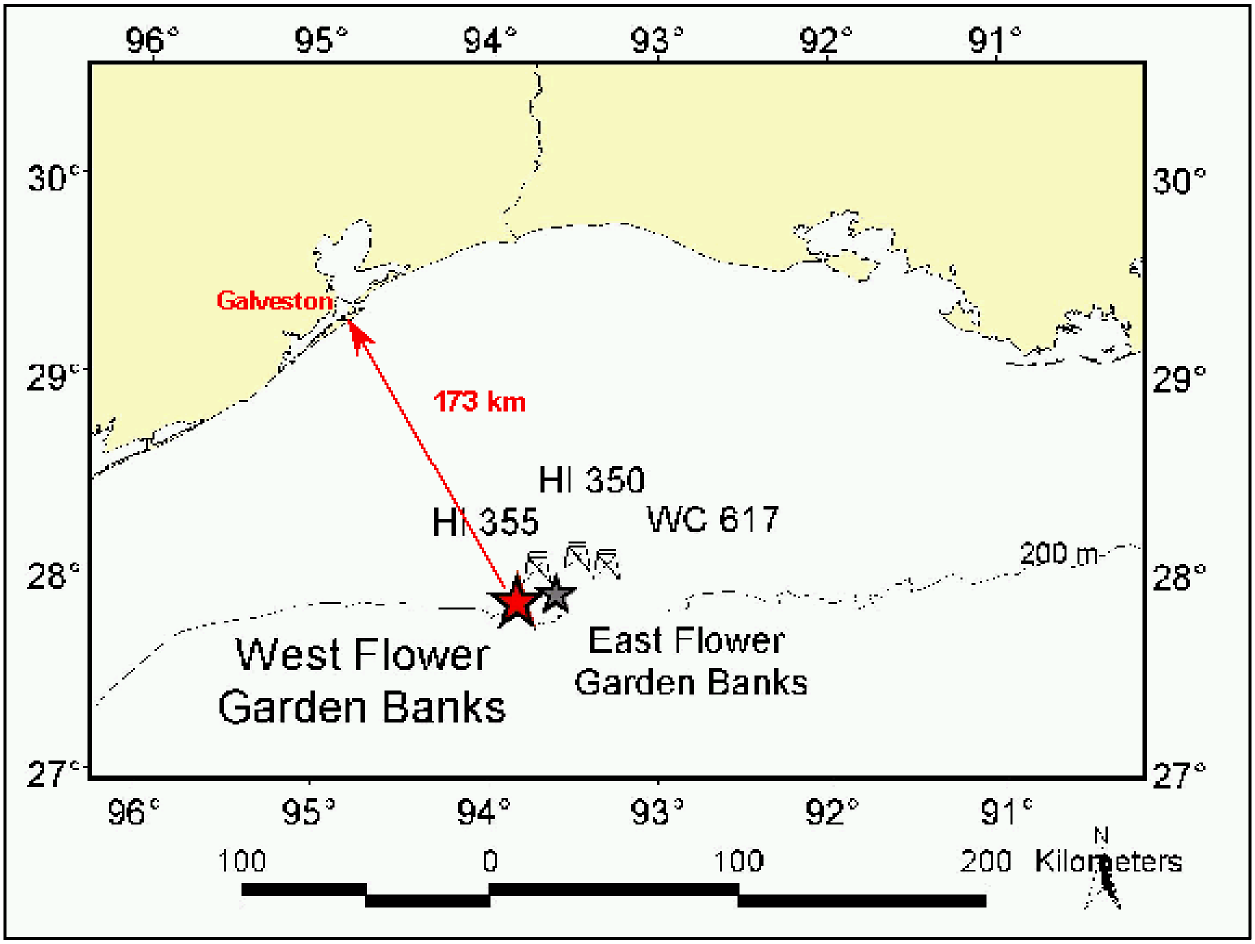

Figure 1B.1. Map of the sites surveyed in June 1999 and 2000.

Table 1B.1. General information about the oil and gas structures surveyed in June 1999 and 2000 with stationary or mobile dual beam hydroacoustics.

SITE	COMPANY	LATITUDE	LONGITUDE	DEPTH	PILES	INSTALLED	REMOVED	REMOVAL METHOD
HI A350 (standing)	SHELL	28.01884N	93.4585W	89	8	1976		
HI A355 (partially removed)	OXY USA	28.04152N	93.70919W	88.4	8	1978	1/15/1996	NON-EXPLOSIVE
WC617A (toppled)	MOBIL	28.06107N	93.31342W	97.5	8	1976	7/16/1992	EXPLOSIVE

determine simultaneous estimates of sigma (target strength) and mean volume backscatter (reflected acoustic energy) for each depth strata. These parameters are used to estimate fish density and fish size. The standing platform data were analyzed in 5-minute blocks for each side as in previous studies (Stanley and Wilson 1997). Analyzer outputs for the standing platform included volume backscatter/m^3, fish density/m^3, and mean target strength/m^3. A Visual Basic program was used to extract the data of interest from analysis outputs and to compile the results into a site specific database for statistical analysis (Stanley and Wilson 1997).

Mobile transects were analyzed at one second resolution (@ 2 meters linear distance) to determine the volume backscatter and target strength within each depth stratum along the transect. Analysis of each one second block of data provided geographic position and mean volume back scatter. Individual target strength information was acquired by extracting ping specific data, which could be selectively output as a text file. A Visual Basic program was used to calculate an average target strength for each target, by strata, and location.

Statistical analysis of these data included the reported reflected acoustic energy as volume backscatter (SV), a proxy for fish biomass, as a dependent variable in our analysis. The second dependent variable in our analysis was density, which was generated from the Visual Analyzer analysis for HI A350 and calculated for the mobile surveys of two reef sites. A randomized block analysis of variance was used to examine the main effects at HI A350 and TS at all sites as described by Stanley and Wilson (1997). Due to the larger number of zero values in the mobile survey, logistic regression (Trexler and Travis 2001) was used to analyze the mobile data.

Statistical tests were reported as significant at the alpha < 0.01 level. The use of logistic regression in ecological sampling was described by Trexler and Travis (2001). It has been shown to be useful with data that have a large proportion of zero values when error is usually not normally distributed. Analysis consists of converting the dependent variable into a discrete form (e.g. presence/absent, agree/disagree, etc). The regression model then assumes a binomial distribution of errors (Trexler and Travis 2001, Garrison *et al*. 2000). Class variables for HI A350 include time of day (TOD), depth bin (stratum), platform side, and all two-way interactions. Class variable for WC 617A and HI A355 include TOD, stratum, reef side, horizontal 10 meter distance intervals away from the reef structure (away), and all two-way interactions. Tukey's standardized range tests (Ott 1982) were used to compare the means of significant variables. Statistical tests were reported as significant at the alpha < 0.01 level. The total fish abundance estimates at each site were calculated by determining a 20m near-field area of influence of each reef site or platform, then multiplying mean density values by stratum and side (number of fish/m^3) by the volume of water on each side of or over the platform (Stanley and Wilson 1998).

Many factors play an important role in determining fish biomass, density, and species composition for any fish habitat, and oil and gas platforms are no exception. The standing platform, HI A350, was characterized by the same type of community of fish that Stanley and Wilson (2000a) observed at other structures in similar water depths such as GI 94. Time of day and depth stratum affected the fish community as had been reported previously (Stanley and Wilson 2000a); however, the density patterns exhibited at different times of day do not follow a predictable pattern and are likely site-specific. We continue to see fish density and size being greater near the surface than the bottom and of standing oil and gas platforms. Our results revealed approximately 7,000 fish around HI A350, which is consistent with the estimates of fish communities reported by Stanley and Wilson (2000b, 1997) for platforms in similar water depths. They reported 10,000 to 20,000 fish inhabited each of the four oil and gas platforms they had studied. Species composition at HI 350 was also similar to that reported by Stanley and Wilson (2000a) and included important to recreational and commercial species such as amberjack, red snapper, creole fish, trigger fish, and almoco jack. Like the results reported herein, Stanley and Wilson (2000a) also found a significant pelagic community at these high vertical profile sites.

The two reef sites were surveyed in 1999 and 2000. By using the same collection technique at all three sites we are better able to compare the results. Previous acoustic studies at platforms, as in our study of HI350 employed a stationary array of transducers. Hence data collection techniques were different. However the acoustic data are averaged on a per ping basis so data collected in five-minute blocks as in HI350 in this study and previous studies by Stanley and Wilson (2000a, 2000b) and Stanley (1994) are comparable to the mobile acoustic data collected in 1 sec blocks.

There was a general pattern at both sites of a higher probability in finding a fish in 1999 when compared to the 2000 survey. We offer no explanation for the between-year difference in these results other than it supports Stanley and Wilson (1997) that fish densities vary month to month.

Density at the two artificial reef sites ranged from 0 to 0.7 fish/m^3. The partially removed platform had a slightly higher fish density than the toppled platform with overall mean values (within 20m of each site) of 0.002 vs. 0.0015 respectively. Both sites had highest fish densities near the bottom, which is opposite the pattern at the standing platform. However, the partially removed platform, HI A355, also had higher estimated densities near the surface resembling fish distribution at a standing platform. There was little difference in species composition between the two reef configurations. ROV surveys of HI A355 in June 1999 and in June 2000 indicated that red snapper and amberjack were the two most abundant species both years, and together they made up over 70% of the fish community. Similarly, the survey of WC 617A, conducted in June 1999, indicated that amberjack, almaco jack, and red snapper were the most abundant species. Species composition at the two reef sites were similar to species composition at the lower portion of HI A350 and to previous studies by Stanley and Wilson (1997, 2000a). It is of interest that the red snapper and amberjack populations at the two reef sites were similar in number to the populations estimated to be at the standing platform in similar water depths. These artificial reef sites, like their platform predecessors, have significant fishing value since majority of the species associated with these reef sites are targeted by commercial and recreational fisherman. When a standing platform is converted into an artificial reef site, it appears that the pelagic planktivores make up the greatest biomass that is lost; the more desirable recreational species are retained.

Target strength data revealed information on the size distribution of fishes associated with these sites. In general, slightly larger fish are associated with a standing platform, particularly near the middle water column, compared to a partially removed or toppled platforms, where they are larger over the reef sites and near the surface (Stanley 1994). The larger species were shown to be pelagic planktivores and piscivores by Stanley and Wilson (1997).

We found significant effects of orientation and distance at both artificial reefs. The probability of finding a fish at WC 617A was highest over the platform and within 30 m of the reef; which is similar to the survey of EI 366 done by Stanley and Wilson (Unpublished). This is similar to a reported 16 m area of influence by Stanley (1994) at platforms from 50-100m depths. Platforms appear to have a finite reef effect that does not extend beyond visual range of the associated species. The probability of finding a fish at HI A355 was highest around the sides of the platform and within 30 m of the structure, although fish biomass, and therefore density, were highest directly over the reef site. Stanley and Wilson (Unpublished) reported higher numbers of fish directly over another artificial reef (EI 366), and reported the same high fish densities within 30 m of the artificial reef. The difference in orientation (north, south, east, ands west) at HI A355 could be related to a section of the jacket being placed roughly 30m away from the partially removed platform on the southeast side. It is also possible that the small foot print of HI A355 confounded analysis.

According to survey results from HI A355 and WC 617A, we estimate a loss of approximately 50-80% of the fish population when a standing platform is converted (toppled or partially removed) into an artificial reef site in 100 m of water. Each artificial reef site harbored approximately 2,500 fish compared to 7,000 fish around the HI A350 and the 10,000- 20,000 reported by Stanley and Wilson (1998). This decline of fish numbers was also observed during the survey of EI 313 and EI 367 done by Stanley and Wilson (Unpublished). Artificial reef configuration and orientation definitely influence the size of and species composition of the associated fish community.

This project again demonstrated the utility of dual beam hydroacoustics coupled with visual survey techniques to study fish assemblages associated with standing platforms, artificial reefs, and most recently natural reefs. The choice of survey sites, which are in close geographical proximity, provided us an opportunity to use stationary and mobile acoustic survey methods to compare species composition, fish biomass, and fish densities within and among a standing platform and two artificial reef configurations of retired oil and gas platforms. Dual beam hydroacoustics coupled with video surveys afforded the best combined method for assessing fish resources at these sites.

Our results provided direct evidence that fish densities and biomass around standing oil and gas platforms are the highest per unit of artificial and natural sites studied to date. In particular, they are higher than artificial reefs or natural reefs in the northern GOM. Fish were not only more abundant around platforms, but also they were larger than those found in the open water habitats or over natural reefs. Our results are in support of the findings reported by Stanley and Wilson (2000a), that when a platform is converted into a artificial reef by toppling in place or by partial removal, it loses a significant portion of the fish community. Most of this “lost” portion is pelagic planktivores such as blue runner and Bermuda chub.

Future refinements in the approach to stationary and mobile acoustic studies will lead to even more accurate assessments of fish habitat. Furthermore, integration of results into a GIS databases will enable improved management of these resources.

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WHAT DO WE KNOW ABOUT THE SPATIO-TEMPORAL DISTRIBUTIONS OF PELAGIC FISHES IN THE DEEPWATER ZONE OF THE NORTHERN GULF OF MEXICO?

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INTRODUCTION

Recent advances in deepwater drilling and deepwater platform technologies combined with new petroleum and natural gas discoveries on the outer continental shelf (OCS) and slope have accelerated platform deployments in previously unexploited waters of the northern Gulf of Mexico (GOM). In spite of preventative measures established by the petroleum industry and governmental regulatory agencies to prevent the accidental discharge of petroleum products, oil spills remain a statistical certainty (e.g. Price and Marshall 1996).

As petroleum exploration expands into and beyond the waters of the OCS, the potential exists, via accidental spills, to adversely impact pelagic recreational and commercial fisheries. Surface petroleum spills in pelagic waters of the OCS will primarily impact those species of fishes and crustaceans that inhabit the epipelagic zone of the open ocean. Members of this group include several species that command a high value (e.g. tunas, wahoos, and billfishes), as well as ecologically important or indicator species (e.g. flying fishes, ocean sunfishes). Spills in the surface waters are also likely to impact floating *Sargassum* communities, which contain a diverse and often unique faunal assemblage of fishes and invertebrates and which also serve as important nursery habitats for many fishes belonging to the families Coryphaenidae, Carangidae, Pomacentridae, and Lobotidae.

Relatively little is known about the susceptibility of pelagic fishes from the GOM OCS to petrochemical spills. The magnitude of any impact will depend upon the spatial and temporal scale of the incident as well as the chemical properties of the spilled material. The spatial scale (location, depth and extent) of the spill combined with the temporal scale (timing and duration) will combine to determine the species and life history stages that are likely to be present in the impacted area. Unfortunately, information on the spatial and temporal distributions of pelagic fish stocks in the OCS is not readily available and is generally scattered throughout the peer-reviewed and non-peer-reviewed technical literature and databases. This study was undertaken to synthesize what is known about the spatio-temporal distribution patterns of selected pelagic fish species. We have attempted to provide an estimate of what life history stages of these target species are likely to be present within the OCS waters on a seasonal basis.

METHODS

Study Area

At the inception of this study, most of the active leases within the deepwater zone of the OCS lay within the 200-2,000m isobaths. Both the Mississippi and De Soto Canyons are encompassed by this region; however, we felt that a strict selection of the area overlying the 200-2,000m depth range would be too restrictive a criterion because some active leases lay outside of that zone in deeper water, and data from the locations of commercial fishing vessels (Maul *et al.* 1984), suggested that fish species such as bluefin tuna range through this zone and further to the south in to the central Gulf. Accordingly, we delineated a study region of the north central GOM that includes waters above the 200-2,000m isobaths south to 26ºN latitude. The study area was divided into four zones: western zone (96.4ºW–92.0ºW, 26.0ºN–28.0ºN), central zone (92.0ºW–88.0ºW, 26ºN–28ºN), eastern zone (88ºW–84.3ºW, 26.0ºN–28.0ºN), and a triangular northern zone with a base from 90.7ºW-84.3ºW at 28ºN, and an apex at 87ºW, 30ºN (Figure 1B.2). The western, central and eastern zones correspond broadly to the MMS western, central and eastern planning areas.

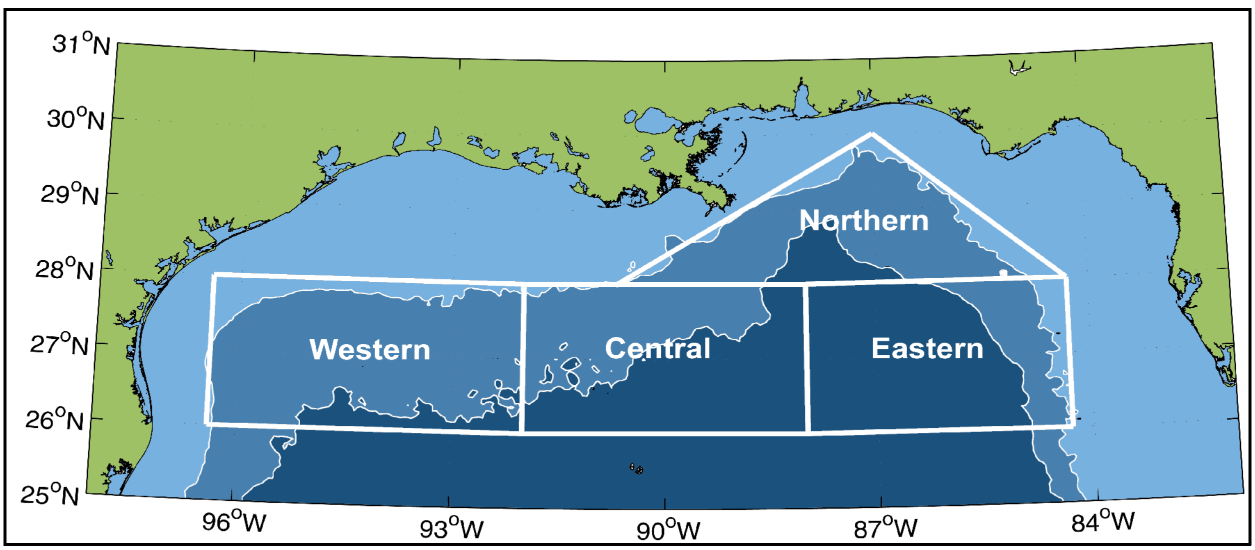

Figure 1B.2. Locations of the western, central, eastern and northern study zones within which we attempted to define the distributions of target species.

Target Taxa

Bluefin tuna (*Thunnus thynnus*) are a large, long-lived species that represents the single most valuable fisheries resource on a value-per-pound basis. Demand for the raw flesh of this fish in the Japanese sashimi market has driven the price of individual fish to over $U.S. 350 per pound (Safina 1993). Fishing pressure for bluefin tuna is intense, and the western Atlantic breeding population appeared to drop by over 90% between 1975 and 1990 (Safina 1993). [At the time of writing this report, the theory that there are two distinct and separate stocks of bluefin tuna in the Atlantic was being questioned.] A long-lining fleet operates in the OCS deepwater region from approximately

January to April (Maul *et al*. 1984). The GOM appears to be the only spawning ground for the western Atlantic stock of bluefin tuna (Clay 1991).

Yellowfin tuna (*T. albacares*) are the second most abundant true tuna in the GOM and represent a valuable commercial and recreational fishery resource that is targeted for human consumption. This is the secondary target species for the domestic and foreign bluefin tuna long-liner fleet and is a popular gamefish for recreational anglers.

Blackfin tuna (*T. atlanticus*) are the most abundant true tuna in the GOM where they are targeted as a popular recreational and commercial resource for human consumption. Blackfin tunas are frequently collected near petroleum platforms on the landward edge of the OCS.

Blue marlin (*Makaira nigricans*) and white marlin (*Tetrapturus albidus*) are highly sought after gamefish in the northern GOM.

Wahoo (*Acanthocybium solanderi*) are a popular gamefish in the OCS.

Dolphin (*Coryphaena hippurus*) also known as mahi mahi is a popular gamefish that is frequently targeted by recreational and commercial anglers. This fish is often found in close association with *Sargassum* rafts, weedlines and flotsam. The same processes that result in the accumulation of flotsam and weedlines may also cause aggregations of oil and tar.

Flyingfishes are potentially important indicator species because of their pelagic distribution, close association with the ocean surface, and their role as prey for many other larger predatory species. Two common species in the northern Gulf are *Cypselurus melanurus* and *C. furcatus* (J. Caruso, University of New Orleans, Pers Comm).

Blue runner (*Caranx crysos*) are small- to medium-sized schooling carangids that are common prey items for larger predators. These fish are frequently associated with offshore petroleum platforms. Although humans seldom eat them, they are popular light tackle gamefish and are commonly captured as live bait.

Sargassum community fauna: two species of pelagic brown algae (*Sargassum fluitans* and *S. natans*) commonly called Gulf weed, form dense floating rafts in the pelagic waters of the GOM. These rafts reproduce vegetatively and can occupy large areas of hundreds to thousands of square meters. Within the *Sargassum* are a variety of fishes and invertebrates adapted to life in the weed through cryptic coloration, morphology and behavior. Common residents include the sargassumfish (*Histrio histrio*), sargassum pipefish (*Syngnathus pelagicus*), planehead filefish (*Monocanthus hispidus*), sargassum triggerfish (*Xanthichthys ringens*), and a variety of invertebrates including shrimp, nudibranchs, hydrozoans, and bryozoans. Rafts of *Sargassum* provide floating nurseries for juvenile carangids, sergeant majors (*Abudefduf saxatilis*) and tripletails (*Lobotes surinamensis*). *Sargassum* communities have the potential to be heavily impacted by spilled oil because patches of *Sargassum* often accumulate in the same areas where physical oceanographic processes are likely to concentrate oil.

The focus of the study was on pelagic organisms. While we are aware that the substantial network of planned and existing pipelines and subsea facilities creates a potential for deep-sea petroleum spills, we chose to focus on taxa that inhabit the upper 50 m of the water column (e.g. depth of the mixed layer) for the following reasons:

1. Most of our target species are highly fecund and produce large quantities of small eggs with limited yolk reserves. The small larvae that hatch from such eggs are dependent on the plankton for food and must forage in the near-surface waters;
2. Few commercially important fisheries resources are currently being exploited in the deepest zones of the waters of the OCS;
3. Oil spilled in surface waters is buoyant and will likely accumulate in the neustonic zone;
4. While the fate of oil released near the bottom under high pressure and low temperature is unclear, naturally occurring surface slicks from deep-sea seeps are a common feature of the GOM suggesting that oil spilled near the bottom may rise to the surface; and
5. It is unlikely that sufficient information exists on the spatial and temporal abundances of deep-sea fishes to make even a well-reasoned inference about the impacts of subsea spills.

Sources of Data

Surprisingly little information is available on the spatio-temporal patterns of abundance of commercially and ecologically important pelagic fishes in the waters beyond the shelf-slope break in the northern GOM. Records of the distributions of target taxa are scattered throughout the peer-reviewed and non-peer-reviewed ‘gray’ literature. In addition to a comprehensive literature search of the available peer-reviewed and gray literature, this report drew heavily on two datasets: the National Marine Fisheries Service (NMFS) long-line database and the Southeast Area Monitoring and Assessment Program (SEAMAP) ichthyoplankton surveys.

The NMFS long-line database contains the reported locations of the ends of surface long-line sets in the GOM. Originally comprised of Japanese vessels targeting adult swordfish, tunas, and other tuna species (Cramer and Scott 1997), today the fleet is largely made up of domestic vessels. The numbers of tunas (bluefin, yellowfin, and blackfin), blue marlin, white marlin, wahoo, and dolphin taken during each set along with the set date are provided for the period 1986-99. Since this fishery primarily targets tunas, the spatial pattern of fishing effort varies among months (Figure 1B.3). Some level of fishing effort occurs during each month in most of the region of interest for the present study. For this reason, the presence of tunas and other pelagic species is a potentially useful indicator of their distribution within the study area. The monthly changes in CPUE (number of fish per long-line set) were used to estimate the distributional range of each species in the area of interest. All landings data for the period 1986-99 were sorted by month. Within each month, the CPUE was estimated within each cell of a 10' longitude x 10' latitude grid (approximately 100 $nmile^2$ or $343km^2$) superimposed on the study area. The values of all cells containing non-zero CPUE estimates were then color-coded and superimposed on the grid.

The NMFS long-line database provided an estimate of the distributions of adults. Determining the distributions of early life-history stages of the target species was more problematic. Data on larval and juvenile abundances are sparse and highly restricted in both space and time. While peer-

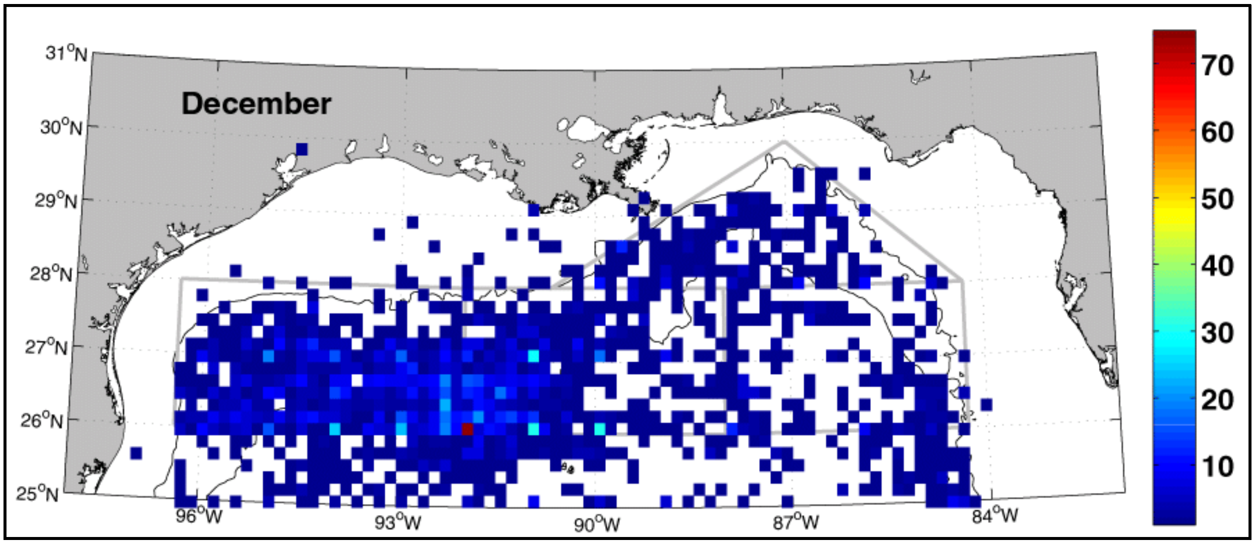

Figure 1B.3. Commercial long-line fishing effort (number of sets) within 10' x 10' grids (approximately 100 nautical mile^2) expressed as mean monthly CPUE (fish per set) based on data collected from 1986-99.

reviewed and non-peer-reviewed literature provided some limited distributional data, the SEAMAP ichthyoplankton database was the most useful source of information on the distribution and abundance of early-life history stages. Data from the SEAMAP spring and fall plankton surveys as well as additional SEAMAP records spanning other times of the year were examined from 1982 to 1996. Data were grouped by month across all available years and assigned to the same 10' x 10' grid as the long-line database. Distributional maps were coded by the presence or absence of larvae and juveniles. Presence or absence was used because it was not always possible to estimate sampling effort from the dataset.

Distributional data were then summarized for adults and larvae (Figure 1B.4). Juveniles are problematic because gear designed to sample ichthyoplankton is generally avoided by the more capably swimming juveniles. This format differs slightly from that proposed at the inception of this study to predict distributions on a month-by-month rather than annual basis. The potential presence of a particular stage in any of the cells within the grid was ranked according to three categories: confirmed, reasonable inference, and unreported. Confirmed presence was assigned when a physical sample of the relevant stage of a particular taxon had been reported in the primary literature as being present within a cell. Given the high mobility of most of the adults of species in this study, we assumed that an individual that was detected in any cell of the study grid could reasonably have traveled a distance of two additional cells around the detection cell within a month of collection. Reasonable inference for adults stages was therefore assigned to any cells within which, there was no confirmed presence, providing the cells were located within a radius of two cell distances (up to approximately 52 km) of a cell with a confirmed presence. It was also assigned to any cells that were bounded by four or more cells also designated with the reasonable inference category. This is probably a conservative estimate of the distances that some of these fish can travel. Reasonable inference was also assigned to any cells that fell within a region where the distribution had been reported in a document that synthesized the results from other datasets. For example, the National Ocean Service (NOS) Strategic Assessment Data Atlas (NOS 1985) contains distributional maps for

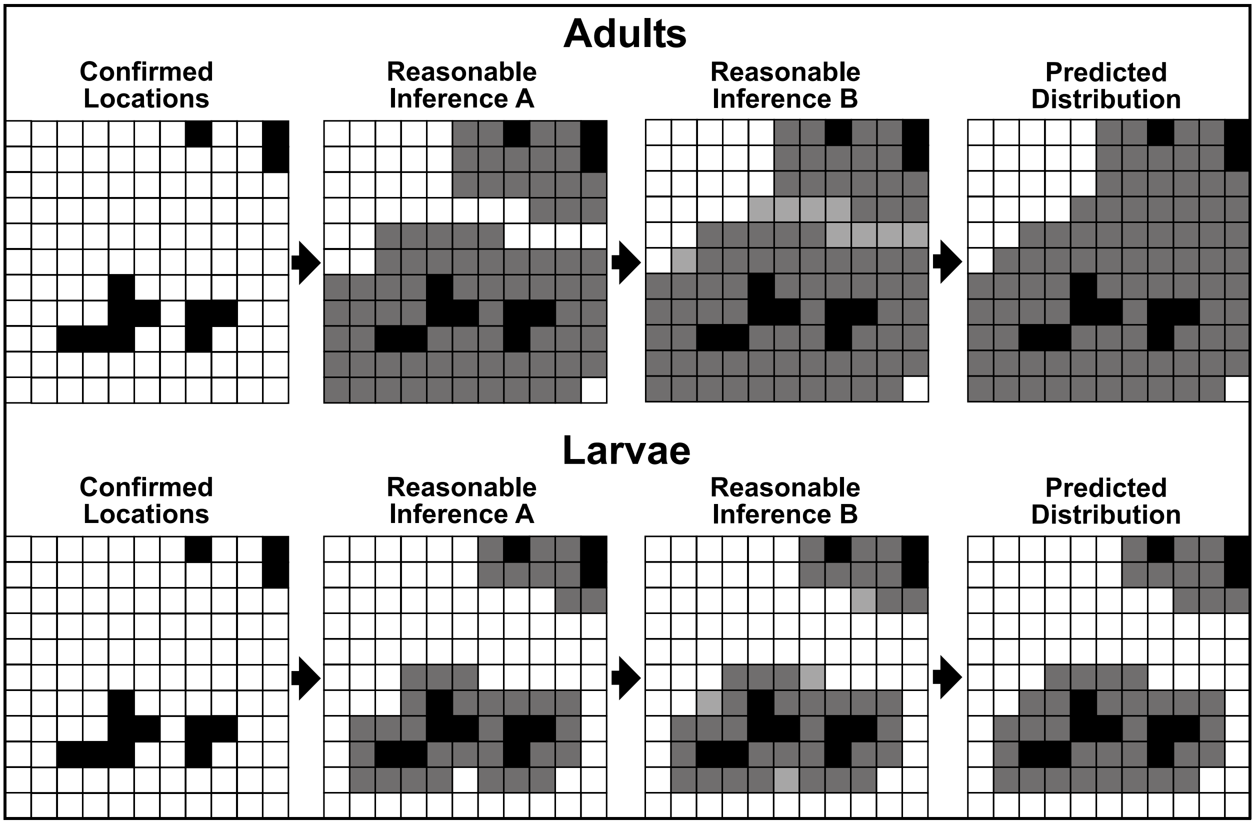

Figure 1B.4. Strategy for classifying distributions of adult fishes (top) and larval/juvenile fishes (bottom). For adults, all cells within two grid squares of each confirmed location () were assigned the reasonable inference category (). Next, any empty cells bounded by four or more reasonable inference cells ()were also assigned the reasonable inference category. For larval/juvenile fishes, all cells within one grid square of each confirmed location were assigned the reasonable inference category, and then any empty cells bounded by four or more cells classified as reasonable inference, were also assigned the reasonable inference category.

several of the target species derived from analysis of other studies. Such maps were digitized and scaled to our study area. Finally, all cells that did not fall into the confirmed or reasonable were assigned an unreported category.

For larvae, reasonable inference was confined to cells from which no physical sample had been reported that were contiguous with confirmed cells. Most larvae are present when the surface waters of the GOM are warm. Thus, growth rates are rapid and the larval duration probably does not exceed 14 d. Assuming that larvae are drifting in slow currents (0.1 knots or less), net advection during a four period should not exceed 33 nautical miles and would likely be considerably less. Therefore, we used a rather conservative distance and assigned the reasonable inference category to any cells within which larvae had not been detected, but which were within one cell of a confirmed cell. As with the adult distributions, all cells that did not fall into the confirmed or reasonable were assigned an unreported category.

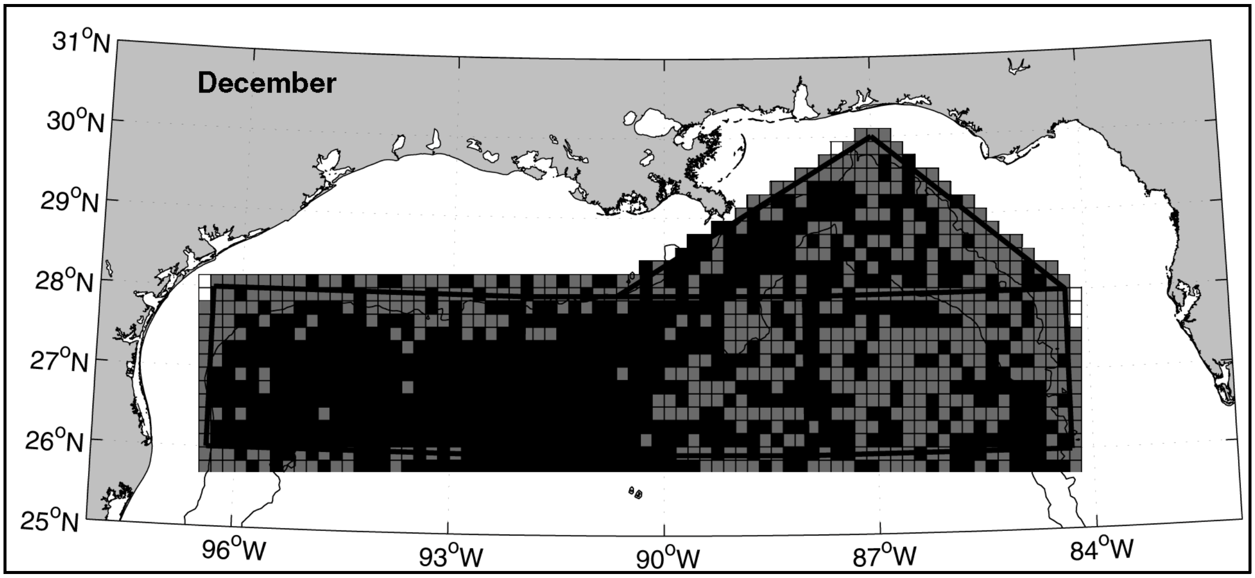

Figure 1B.5. Predictive coverage by the NMFS longline database of the study area during January and February with the spatial coverage of predicted distributions of adult fishes obtained using the decision rules outlined in Figure 1B.4. The decision rules assumed that one fish was detected in each of the grid cell containing a longline record. The presence of individuals in each grid cell is coded as confirmed (■), reasonable inference (■) or unreported (□).

Estimation of spatial distributions based on these decision rules would only work for regions within the study area where sampling effort was sufficiently dense that there would not be any empty zones after the application of our classification strategy (Figure 1B.4). We evaluated the spatial coverage of the NMFS and SEAMAP datasets by assuming that a confirmed sample was collected at each recorded location during each month and then applied our classification strategy. For adult fishes, the results indicated that there were no gaps in our predicted distributions throughout the study area during all months (Figure 1B.5).

Larval and juvenile distributions based on SEAMAP samples were more problematic. These surveys are primarily designed to quantify distributions over the shelf rather than slope water. After application of our classification strategy, with the assumption of detection of at least one individual at every sampling location, there were still large areas of the study zone where there was insufficient coverage to infer larval and juvenile distributions (Figure 1B.6). During January, most of the eastern zone and the eastern half of the northern zone were not covered. In February, coverage was sparse in all zones, but was particularly low in the northern and eastern zones. During March, there was no coverage in any of the study area zones (Figure 1B.6). Coverage improved during April, May, and June although during these months, each zone contained areas where there was no predictive capability (Figure 1B.6). In July, predictive coverage was generally confined to the northern and western periphery of the western and northern zones. This coverage expanded in August and September to include the eastern peripheries of the northern and eastern zones; however, the western, central and eastern zones were generally poorly covered during summer (Figure 1B.6).

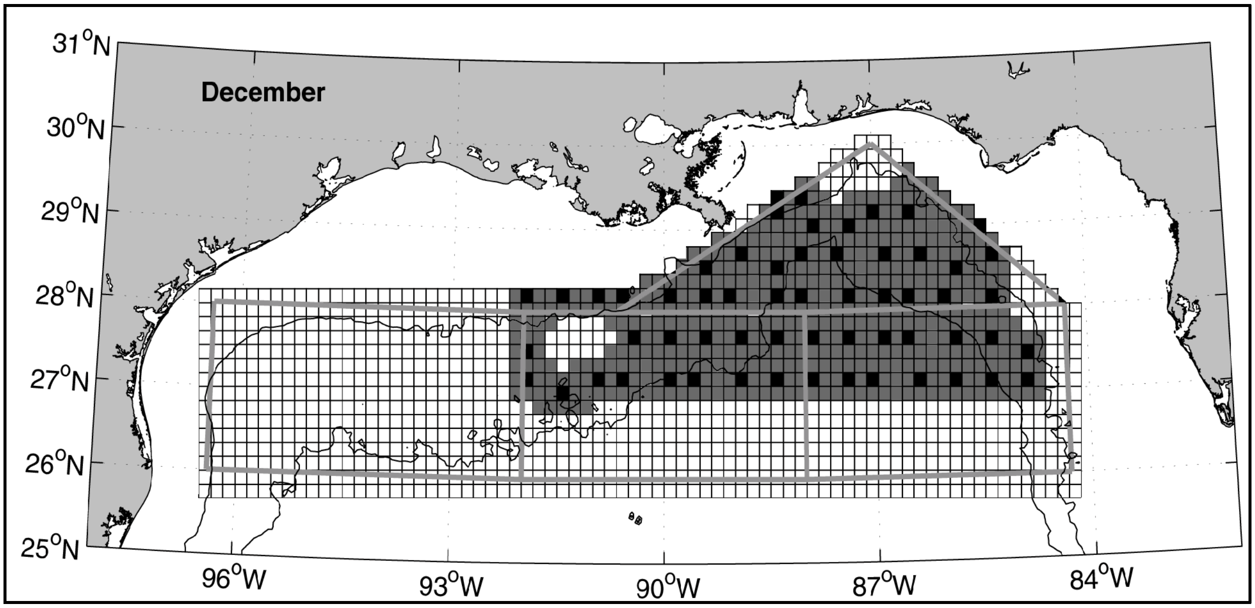

Figure1B.6. Predictive coverage by the SEAMAP database of the study area during May, June, and July with the spatial coverage of predicted distributions of larval and juvenile fishes using the decision rules outlined in Figure 1B.4. The decision rules assumed that one fish was detected in each of the grid cell containing a SEAMAP sample. The presence of individuals in each grid cell is coded as confirmed (■), reasonable inference (■) or unreported (□).

During October and November, predictive coverage was extremely limited. December provided good coverage of the northern zone, and the northern halves of the central and eastern zones (Figure 1B.6). In spite of the gaps that limit the utility of the SEAMAP dataset to predict the distributions of larvae and juveniles in the deepwater zones of this review, most zones were well covered during April-June when the majority of species are spawning in the GOM.

RESULTS

Bluefin Tuna (*Thunnus thynnus*)

Adult bluefin tuna were present in the study region throughout the year with maximal spatial coverage from January through June (Figure 1B.7).

Larval tuna were present in ichthyoplankton samples during April, May, June, and July, which corresponds to the reported spawning period for this species. Peak larval abundance appears to occur in May (Figure 1B.8). In April, larvae are present in all four study zones close to the 2,000 m isobath. By May their abundance spread throughout most of the study area with the exception of the western half of the western zone, and in June their distribution was largely confined to the waters over the continental slope in the northern zone.

Little can be inferred from juvenile bluefin tuna distributions from the SEAMAP data. The maximum length of specimens collected during this period was only 8.2 mm. Tuna grow rapidly and

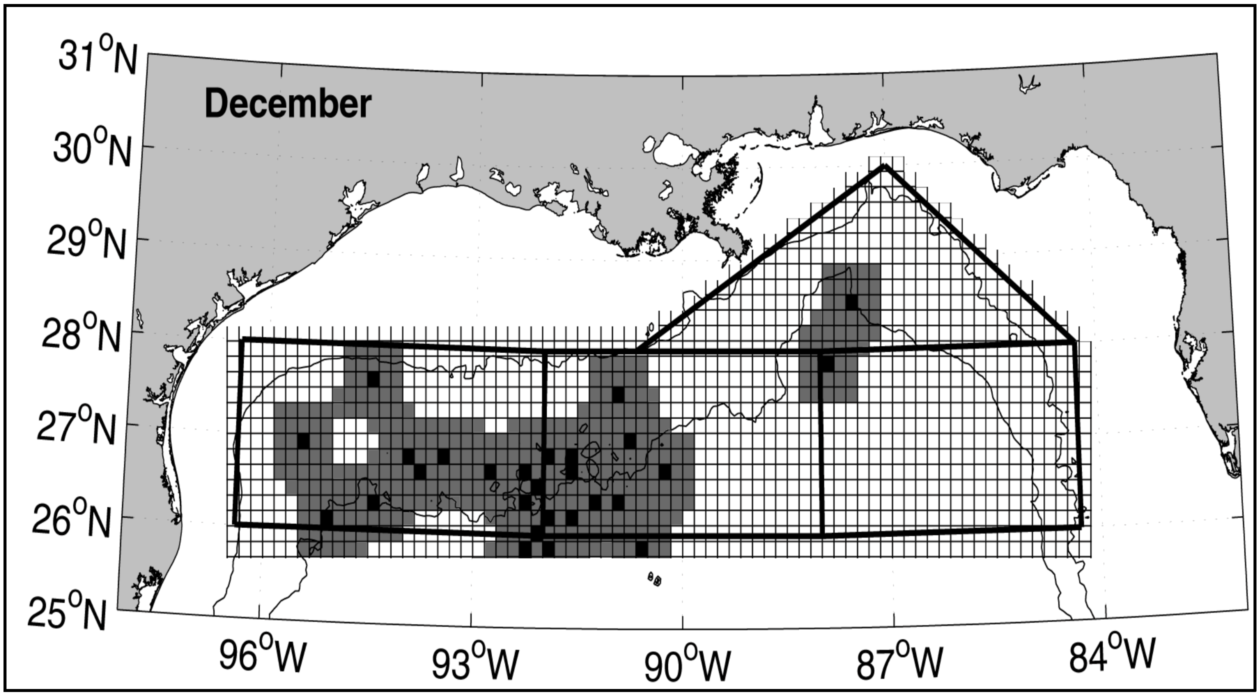

Figure 1B.7. Predicted distributions of adult bluefin tuna in the study area. The presence of individuals in each grid cell is coded as confirmed (▮), reasonable inference (▮) or unreported (▯).

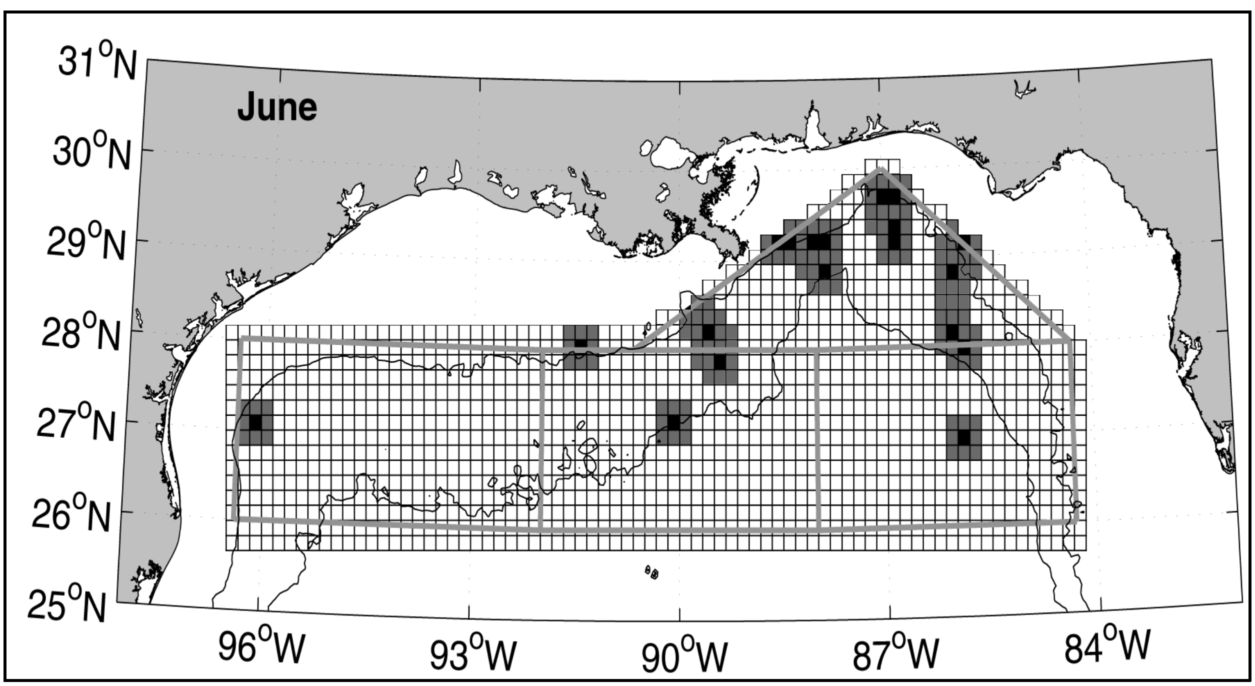

Figure 1B.8. Predicted distributions of larval/juvenile bluefin tuna in the study area during April, May and June. The presence of individuals in each grid cell is indicated as confirmed (▮), reasonable inference (▮) or unreported (▯).

become competent swimmers, which likely contributes to effective avoidance of gear designed to collect ichthyoplankton. Distributions of early juvenile bluefin tunas probably overlap the larvae.

Yellowfin Tuna (*Thunnus albacares*)

Adult yellowfin tuna are likely present throughout the majority of the study area during all months of the year (Figure 1B.9). During winter (January through March), the majority of confirmed landings were in the western and western halves of the central and northern zones. By April, yellowfin expand their distribution in the northern zone towards the northeast and this movement pattern continues through May and June (Figure 1B.9). During April there is also an apparent movement into waters deeper than 200 m in the southeastern edge of the northern zone and the northeastern edge of the eastern zone. In summer, adults are present throughout most of the three zones, and during fall and early winter (September through December), the epicenter of confirmed records shifts back to the western and central zones (Figure 1B.9).

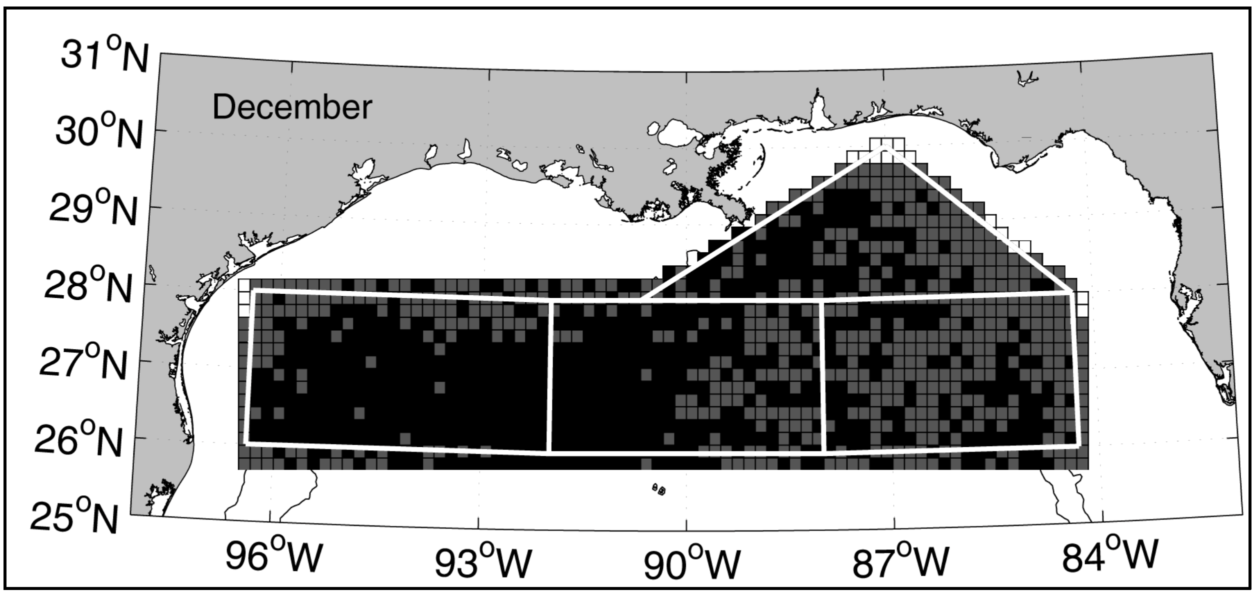

Figure 1B.9. Predicted distributions of adult yellowfin tuna in the study area. The presence of individuals in each grid cell is coded as confirmed (■), reasonable inference (■) or unreported (□).

The SEAMAP dataset contains extremely limited numbers of confirmed yellowfin larvae that were only present during May and June. Predictions of larval distributions based on this dataset (Figure 1B.10) are restricted to the latter two months and do not provide much utility for estimating larval distributions. Additional data from Grimes and Lang (1992) indicated larvae off the Mississippi River plume during September. When the larval distributions predicted from the SEAMAP and Grimes and Lang (1992) data are viewed together, they suggest that most spawning occurs near the Mississippi River plume frontal region with larval and juvenile yellowfin tuna present seaward and downstream (southwest) of the plume along the 200 m (Figure 1B.10).

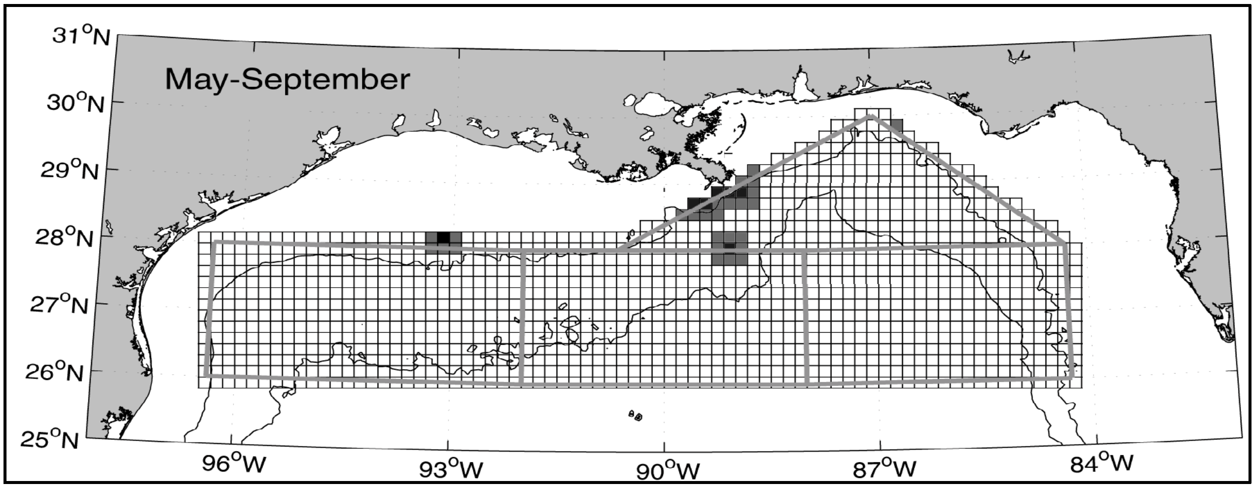

Figure 1B.10. Predicted distributions of larval/juvenile yellowfin tuna in the study area during May, June, and September as well as a composite distribution from all three months (lower right). The presence of individuals in each grid cell are indicated as confirmed (▮), reasonable inference (▯) or unreported (□).

Dolphinfish (*Coryphaena hippurus*)

Dolphinfish adults are predicted to occur throughout the waters of all study zones during January, February, and March with the exception of the shelf waters along the eastern edge of the eastern zone during January (Figure 1B.11). A small void present in the southern part of the eastern zone during February expands in March to cover a large section of the oceanic waters. This void contracts in April and disappears during May. From May through November, dolphinfish are present throughout the study area with the intermittent exception of the northwestern corner of the northern zone (Figure 1B.11). During December they are present throughout the study area except for the shelf waters south of Mississippi and the extreme northwest corner of the western zone (Figure 1B.11).

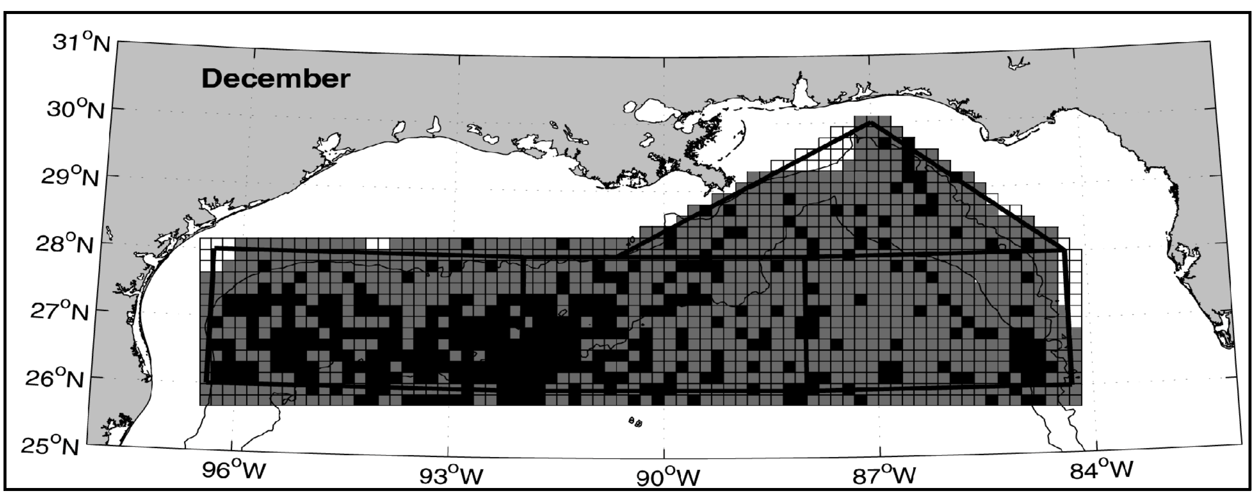

Figure 1B.11. Predicted distributions of adult dolphinfish in the study area. The presence of individuals in each grid cell is coded as confirmed (▮), reasonable inference (▯) or unreported (□).

Larvae are predicted to be present in the study zone throughout the year. During January and February they will be present along the southern edge of the slope water and likely in the oceanic waters to the south (Figure 1B.12). Their distribution during March cannot be reliably predicted in specific cells, but it is likely similar to that of April when larvae are present in the oceanic and slope water regions of the central, eastern, and the southerly part of the northern zone (Figure 1B.12). During May they will be present over the shelf edge, slope water and oceanic waters of the study zone. This distribution will likely persist with a northward expansion onto the shelf during June and July. In August they are present over the slope water; however, there are no sample records to confirm their likely presence in the western, central, and eastern zones. In September larvae are very common along the shelf-slope break (Figure 1B.13). Insufficient data are available to predict their distributions during October and November; however, cooling water in the northern Gulf probably stimulates southerly migration and shifts spawning activities to warmer water in the southern parts of the study area. In December, larvae are present over the mid-slope and oceanic waters of the central and eastern zones and are likely in comparable waters within the western zone as well.

SUMMARY

The use of this approach for mapping the distributions of adults was generally good for those species that are targeted, or captured incidentally by the commercial longline fishery. Far fewer data were available on the distributions of smaller pelagics such as blue runner (*Caranx crysos*) and flyingfishes. The prediction of larval distributions is limited to the spatial coverage of the SEAMAP

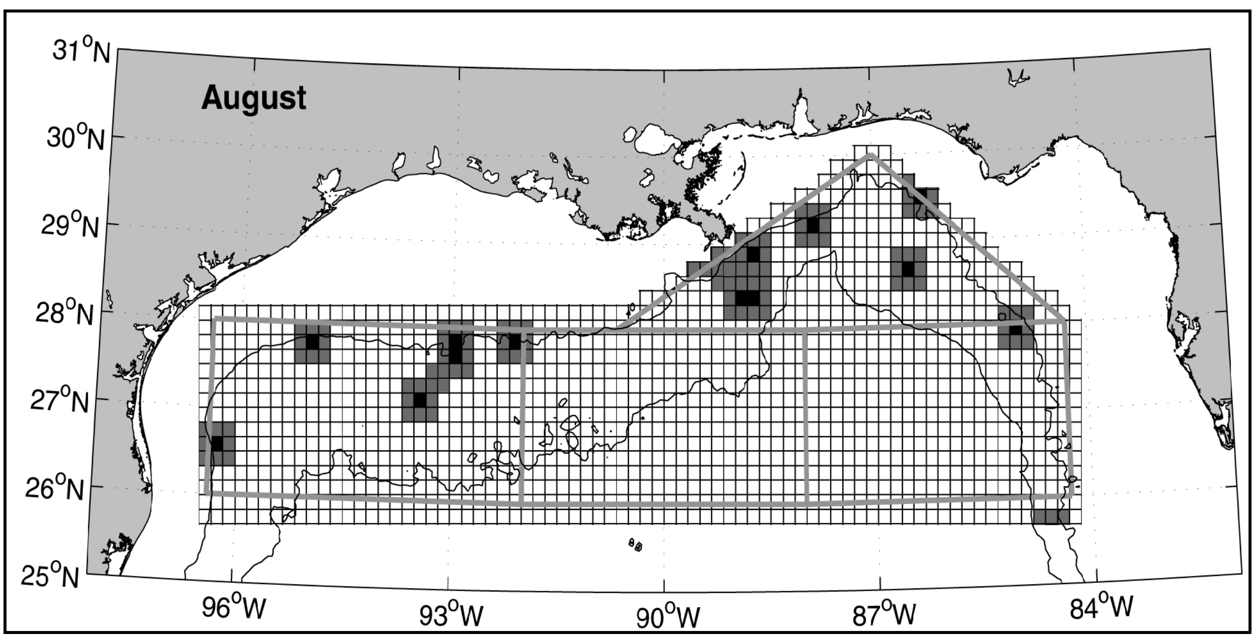

Figure 1B.12. Predicted distributions of larval/juvenile dolphinfish in the study area from January through August. The presence of individuals in each grid cell is indicated as confirmed (▮), reasonable inference (▯) or unreported (□).

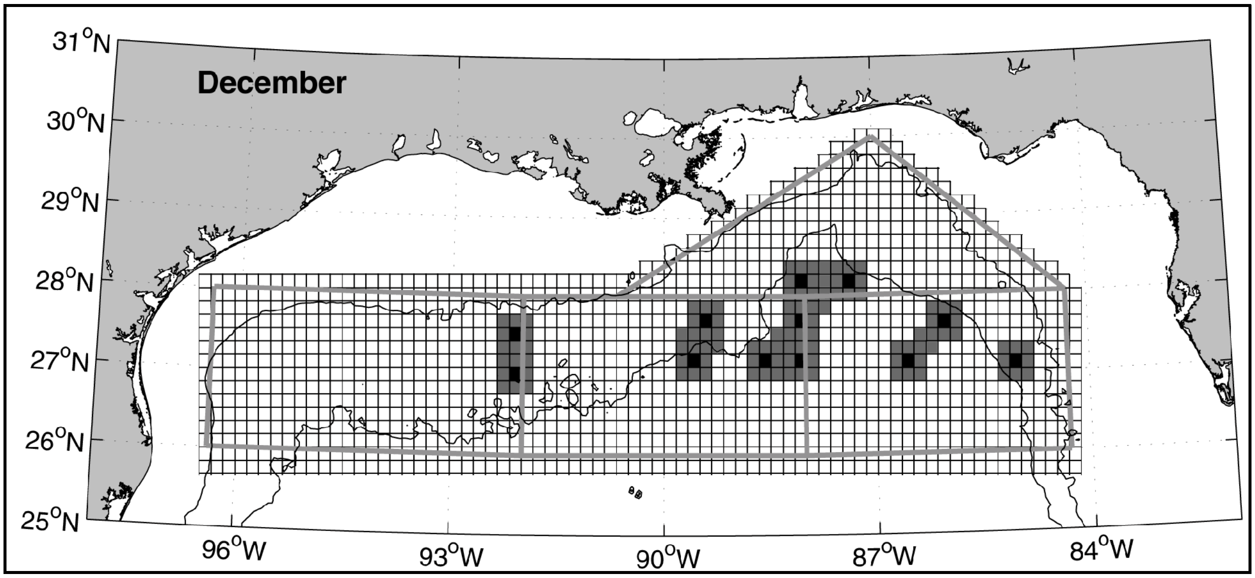

Figure 1B.13. Predicted distributions of larval/juvenile dolphinfish in the study area from September through December. The presence of individuals in each grid cell is indicated as confirmed (▮), reasonable inference (▯) or unreported (□).

database and this database has patchy coverage of the deepwater region during many of the months. Problems with the taxonomy of the larvae of some species (e.g. yellowfin tuna) makes it difficult to predict larval distributions. Prediction of juvenile distributions was highly problematic because they are not well sampled by larval gear and are too small to be collected by commercial gear.

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THE POTENTIAL OF DEEPWATER PETROLEUM STRUCTURES TO AFFECT GULF OF MEXICO FISHERIES BY ACTING AS FISH AGGREGATING DEVICES (FADS)

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INTRODUCTION

Background

The fact that large pelagic fish are attracted to floating objects in the open ocean has been long known, probably since people first began to build boats and make ocean voyages. Although fishermen have long recognized and utilized the propensity for fish aggregate near floating objects (Greenblatt 1979), it was not until the 1970s that floating objects began to be purposely deployed as fish aggregating devices (FADs) (Dickson,1999). Shortly thereafter, the use of FADs grew explosively, first in the eastern Pacific Ocean, then in the western Pacific and Indian Ocean in the 1980s, and finally in the Atlantic in the 1990s (Fonteneau *et al.* 2000) (Figure1B.14). FADs were found to be highly effective in attracting and aggregating a large suite of pelagic fish species, especially tunas. In recent years, more than half of the world commercial tuna catch has been caught from around FADs (Fonteneau *et al.* 2000), thus demonstrating the strength and significance of the phenomenon of fish aggregation to floating objects. As a result, scientific research aimed at explaining FADs' effects and the resultant effects on fisheries has been stimulated and begun. Recently, scientists have raised a large number of questions about potential important negative effects of FADs on fish and fisheries, including ecological as well as fishery effects. The most important negative ecological effects involve changes in movements and migration arising from the strong attraction to FADs.

Relevance

Starting in the mid 1990s, the petroleum industry in the northern Gulf of Mexico (GOM) began to rapidly expand into deep waters (depths greater than 1,000 ft) (Baud *et al.* 2000). The Minerals Management Service (MMS) convened the Workshop on Environmental Issues Surrounding Deepwater Oil and Gas Development (Carney 1997) in 1997. In that meeting, MMS raised the issue of the potential for deepwater petroleum structures (DPSs) to impact (GOM) fish and fisheries by acting as fish aggregating devices (FADs). That workshop also identified the need for examination of existing scientific information pertinent to this issue.

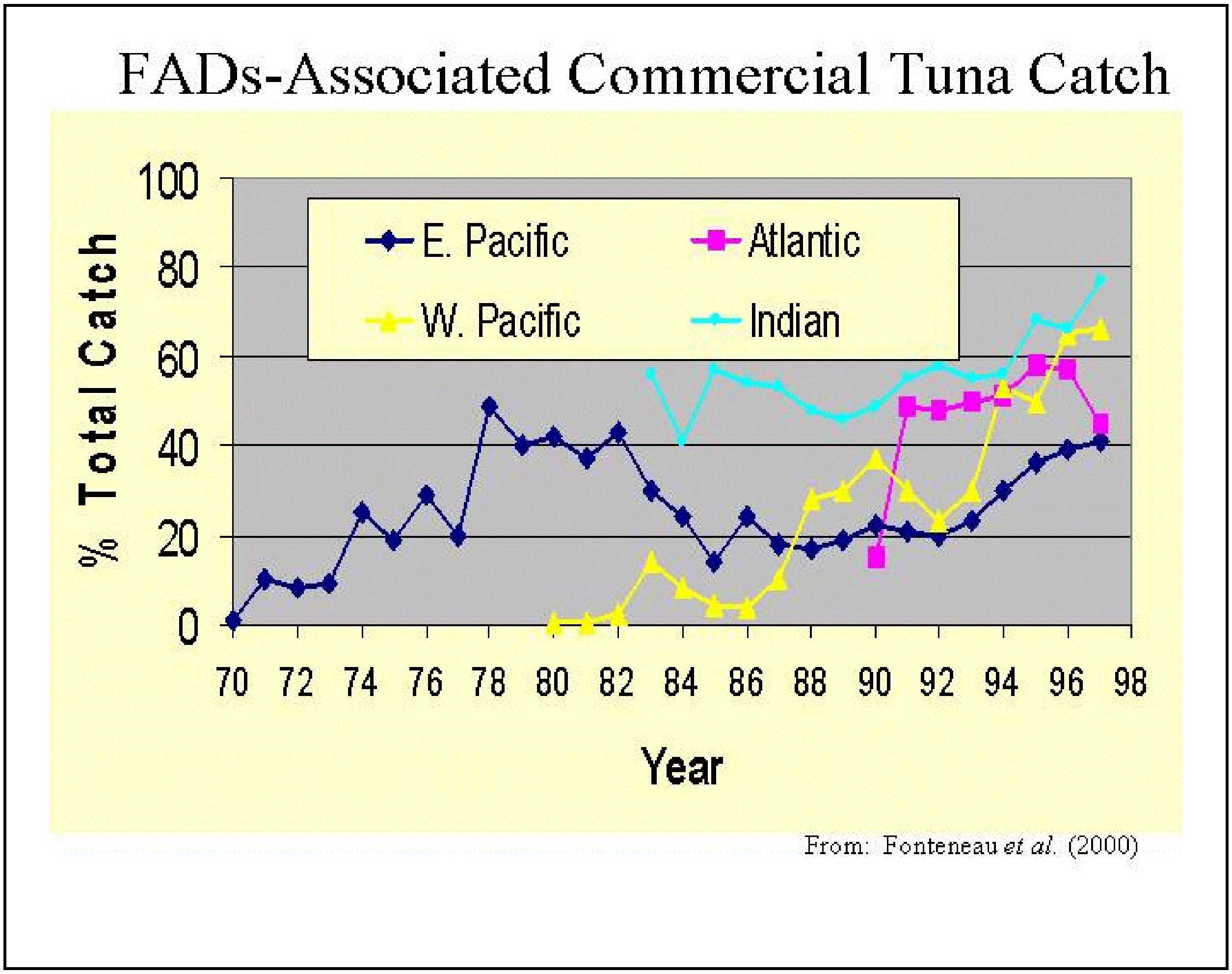

Figure 1B.14. Percent of commercial tuna catch taken from FADs.

Response

The U.S. Geological Survey, Biological Resources Discipline (USGS-BRD), in its role of addressing information needs of MMS, developed a project aimed at finding, examining, compiling and analyzing existing scientific information on FADs and related topics pertinent to the potential FADs' effects of GOM DPSs. The purpose of this project was to provide a tool with which MMS and other involved parties could determine the degree to which existing science could be used to assess the potential fishery impacts of deployment of large numbers of petroleum structures in deep waters of the northern GOM.

Product

The project will provide compilation, synthesis and analysis of scientific information on FADs and fish aggregation from the perspective of potential impacts of deepwater GOM DPSs on pelagic, highly migratory fish species. The nature of the project is mission-oriented, applied (to GOM DPS

FADs issues) and practical, rather than academic. However, it also will provide a detailed compendium of FADs information that should be useful to FADs and resource managers.

METHODS

Bibliographic Data Search and Acquisition

Standard bibliographic methods were used to search for existing FADs literature. Online, computer-searchable databases were searched for references that include FADs-related terms in their title, abstract, or key words. Primary emphasis was placed on published, peer-reviewed journal articles. Conference and symposia proceedings, Internet sources, and popular publications (e.g., magazines) were also thoroughly searched. Where possible, gray literature, including reports and non-journal articles, was included. Literature identified above was read and examined for FADs-related references.

Dissemination

The bibliographic sections along with the report text will be made available and disseminated on CD-ROM in hypertext markup language (.html), Adobe Acrobat (.pdf) and rich text (.rtf) formats (on the same CD). The bibliographic database will be made available as a separate CD. The first CD will be distributed and made generally available as a USGS Open-File Report.

FADs Technical Session

To ensure that scientific literature, information, and understanding of FADs had been thoroughly researched, information exchange with prominent FADs scientists was developed. This was accomplished by convening a technical meeting bringing important FADs scientists together to discuss GOM DPS FADs issues. The meeting was held as a special session of the American Fisheries Society (AFS), Southern Division (SD) Midyear Meeting, 22-25 February 2001, Jacksonville, Florida.

RESULTS

Bibliographic Database Composition

The bibliography includes 466 references. Of these, only 125 (27%) are either books (4), peer-reviewed, journal articles (95), or published as symposia in peer-reviewed journals (26) (Figure 1B.15). The rest are non-peer-reviewed, unpublished reports or other gray literature or references to information available from the Internet, or popular articles. Most FADs literature is recent. The earliest reference (Kojima 1956) was the only reference earlier than the 1960s, for which period only five references were identified. There were only 19 references from the 1970s, 106 from the 1980s, 250 from the 1990s and 82 from 2000 or later (Figure 1B.16).

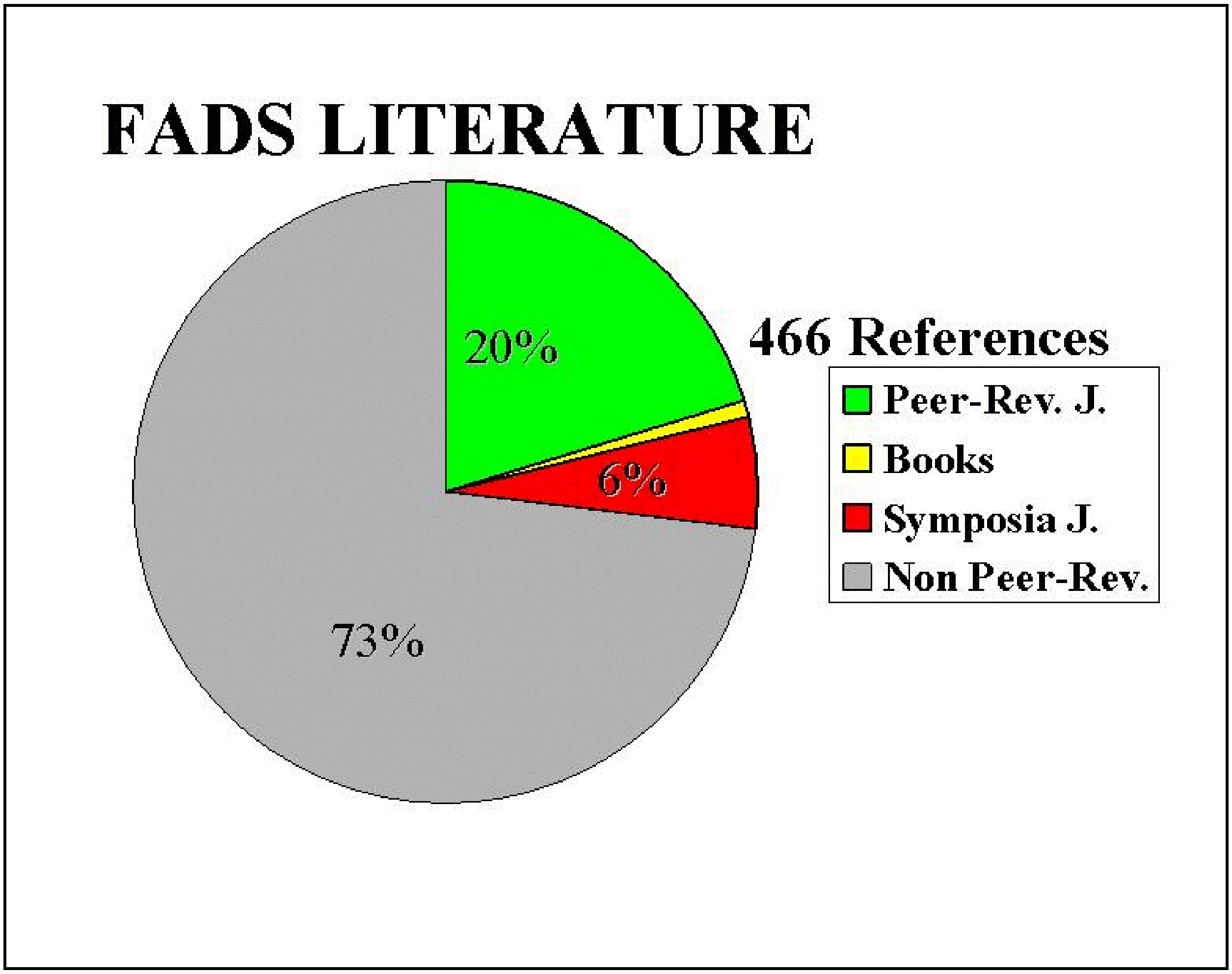

Figure 1B.15. Composition of FADs literature in categories of (1) peer-reviewed journal articles, (2) books, (3) proceedings of symposia published in peer-reviewed journals (although the proceedings articles are often not peer reviewed), and (4) all other documents that have not been peer reviewed.

FADs Information Availability and Character

A large body of information about FADS exists. Most of the FADs references are focused on specific FADs fisheries or fishery applications, and most of these have little pertinence to scientific understanding how FADs function or how GOM petroleum structures may function as FADs.

Information on phenomena and processes related to attraction and aggregation of fish to objects was limited, and the bibliography included only 314 such key word entries of all 2,205 technical key word entries (excluding bibliographic key words). This proportion (14%) is a measure of the limited degree to which existing FADs literature has value or application with regard to understanding

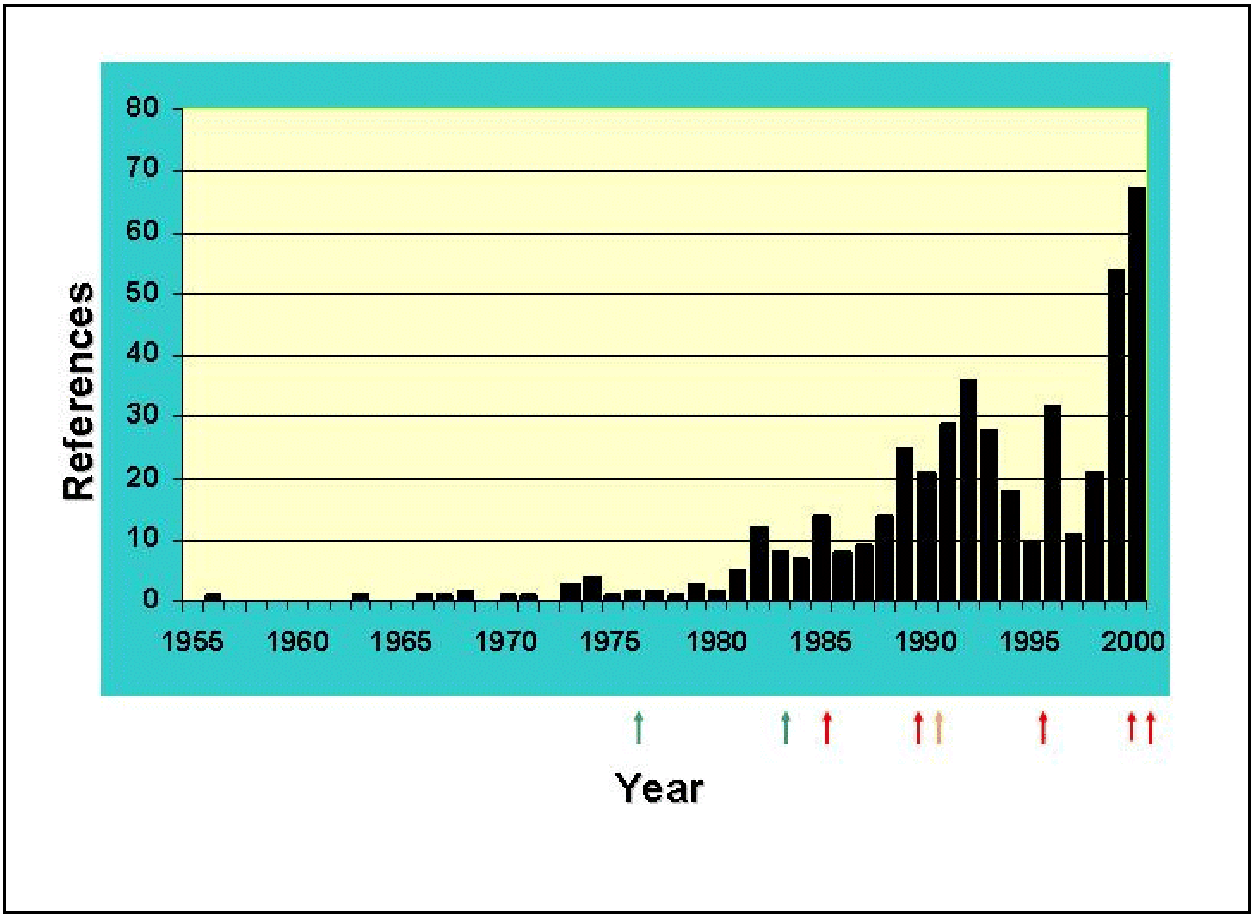

Figure 1B.16. Histogram of FADs bibliography references by year of publication. Green arrows indicate first utilization of FAD in artisanal fisheries in the Philippines (Dickson 1999) and their introduction into the Indian Ocean (Fonteneau *et al.* 2000). The yellow arrow indicates the adoption of "dolphin-safe" tuna fishing in the eastern Pacific fisheries. Red arrows indicate major conferences or symposia on FADs or related issues.

potential impacts of GOM DPSs. Although the information directly useful for understanding GOM DPS FADs issues is limited, a few areas that are of clear utility for understanding and predicting DPS FADs impacts exist and are summarized below.

Types of FADs

The literature separates FADs into two main categories: 1) drifting FADs and 2) moored (anchored) FADs. Drifting FADs include natural floating objects such as trees, floating algae, and even whale carcasses as well as man-made objects such as shipping containers, pallets, and floating structures specifically designed and constructed to attract and aggregate fish. Moored FADs (Figure 1B.17) usually are designed and deployed to aggregate fish, although some large moored buoys (e.g., weather buoys) aggregate fish and are exploited by fishermen (McPhaden *et al.* 2000). GOM DPSs

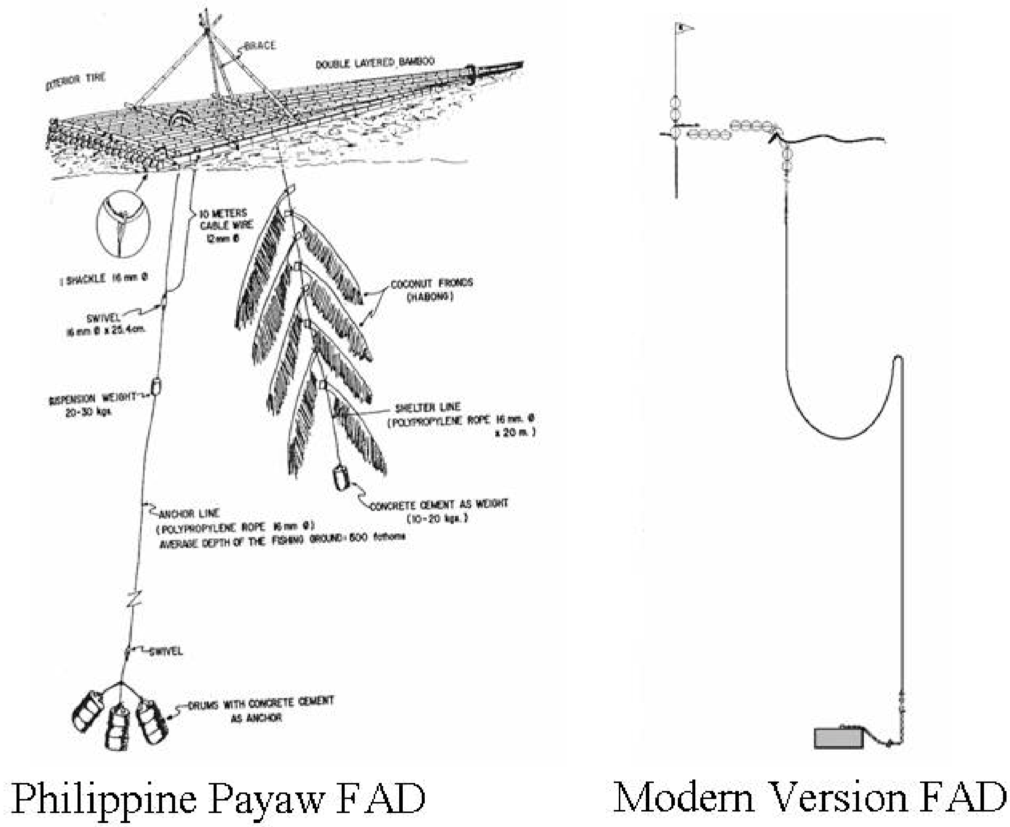

Figure 1B.17. Examples of moored FADs (from Malig *et al.* 1991 (Payaw); Anderson and Gates, 1996 (Modern)).

include a variety of types of structures and components (Baud *et al.* 2000), so it is uncertain whether they would function more like drifting FADs or moored FADS. It is unknown whether fish aggregate for the same reasons around drifting FADs and moored FADs (Freon and Misund 1999).

Species

The three species that are most aggregated by FADs and most important to FADs fisheries throughout the world oceans are the tuna species: yellowfin tuna (*Thunnus albacares*), skipjack (*Katsuwonus pelamis*), and bigeye tuna (*Thunnus obesus*). These three species are listed as keywords in 63, 47, and 29 references respectively, and are mentioned prominently in many other publications in which they are not listed as a keyword. All three are found in the GOM and are commercially harvested, although not as intensively as in most other oceans or seas. These three species, due to their great affinity and attraction to almost all objects in the open sea, can be expected show some attraction and aggregation to GOM DPS. Yellowfin tuna are already known to concentrate around and are caught by recreational fishermen near GOM DPSs (Sloan 2001). Skipjack have been caught in commercial quantities from around FADs deployed near Cuba (Martin 1999).

Information available to predict whether bluefin tuna (*Thunnus thynnus*) may aggregate around GOM DPSs is sparse. Bluefin tuna are attracted to FADs in the Mediterranean (Pipitone *et al.* 2000) and Pacific (Anon. 1983). An important recreational fishery exists off Cape Hatteras, North Carolina, where many large bluefin aggregate near wrecks. The GOM is the only known spawning grounds for the Western Atlantic stock of bluefin tuna (Nemerson *et al.* 2000), and it has been suggested that if they are attracted to and aggregated to DPSs during their spawning season, they may spawn in sub-optimal environments, causing important negative effects on reproduction and recruitment (Lamkin *et al.* 2001) of a species that is already considered to have been reduced to near-extinction population levels (Safina 1993).

Dolphin (AFS common name, also called dolphinfish, dorado, or mahi-mahi in some places) (*Coryphaena hippurus*) is another species that aggregates around moored and drifting FADs in abundances high enough to support commercial fisheries. Given its well-known tendency to aggregate and be caught around floating objects, and because the species is abundant in the GOM, dolphin can be expected to be attracted to GOM DPSs.

Other important GOM species known to aggregate and be caught around FADs include blackfin tuna (*Thunnus atlanticus*), amberjack (*Seriola dumerili*), wahoo (*Acanthocybium solandri*), rainbow runner (*Elagatis bipinnulata*, and marlins. Blue marlin (*Makaira nigricans*) are targeted and caught by recreational anglers fishing near GOM DPSs (Sloan 2001).

Coastal pelagic species, such as king mackerel (*Scomberomorus cavalla*) and cobia (*Rachycentron canadum*), will also be attracted and aggregated to DPSs, but their presence would be expected to be less than that reported for shallow rigs (Franks 2000) that are present in their inshore, primary habitats. Coastal pelagic species are outside the main focus of the report and bibliography.

Benthic fish and invertebrates may utilize DPS structures as artificial substrate and habitat, as has been well documented for petroleum structures in shallower waters. Since the focus of this project is aggregation of pelagic species, this project did not include the extensive literature on benthic species relationships to artificial structures.

Hypotheses

A number of hypotheses have been put forward to explain FADs. The hypotheses explaining the association between fish and floating objects (Freon Misund 1999) include

- Concentration of food supply hypothesis* (Kojima 1956).
- Schooling companion hypothesis* (Hunter and Mitchell 1968).
- Substitute environment hypothesis * (Hunter and Mitchell 1968).
- Cleaning station hypothesis* (Gooding and Magnuson 1967).
- Shelter from predator hypothesis (Gooding and Magnuson 1967).
- **Spatial reference hypothesis** (Klima and Wickham 1971).

- Comfortability stipulation hypothesis* (Batalyants 1992).
- **Generic-log hypothesis (and related hypotheses)** (Hall 1992).
- **Meeting point hypothesis** (Dagorn 1994).

Review of the hypotheses (Freon and Dagorn 2000) has eliminated concentration of food as obviously invalid for schooling fish around FADs and has combined or eliminated several others (*), leaving four major hypotheses (bold).

These remaining hypotheses can be summarized as follows (Freon and Dagorn 2000): the shelter from predator hypothesis proposes that fish aggregate around objects because they can be used by prey as a refuge; the spatial reference hypothesis proposes that fish aggregate around objects because objects provide spatial reference points to which fish can orient in the otherwise unstructured pelagic environment; the generic or indicator log hypothesis is based on the fact that natural floating objects are often indicators of productive areas (*e.g.*, Langmuir cells); and the meeting point hypothesis suggests that objects can be used to increase encounter rate between isolated individuals or small schools and other schools.

The fact that such disparate and possibly interacting hypotheses and processes exist and are as yet untested, indicates how relatively little is understood about fish attraction and aggregation to objects. It further shows that in-depth understanding of how GOM DPSs may attract and aggregate fish is not possible from present scientific understanding of FADs.

Spatial/Temporal Relationships

Spatial relationships between tunas and moored FADs is another area in which scientific consensus exists. Tuna remain close, within 1.8 km to moored FADs during the day and move away from FADs during the night (Marsac and Cayre 1998, Holland 1996). The attractive influence of a FAD for adult yellowfin tuna disappears at around 9 km (Marsac and Cayre 1998), and the radius of influence of a FAD for juvenile yellowfin tuna and juvenile bigeye tuna is about five nautical miles (Holland 1996). These conclusions were obtained through acoustic tracking studies. They agree with modeling studies that find that presence of four or five FADs in a 50 km x 50 km area reduces movement of skipjack out of the area by 50% (Kleiber and Hampton 1994). These findings are of direct value in projecting or estimating the effects of GOM DPSs.

Object Characteristics and Size

Little is known about how an object's characteristics affect the degree to which fish aggregate to it, and only three references (Inoue *et al.* 1968; Hall *et al.* 1992; Hall, *et al.* 1999,) addressed this topic directly. No clear relationships were found between aggregation (as measured by catch) and object characteristics including material, shape, color, surface area, volume, and epibiota (Hall *et al.* 1992; Hall *et al.* 1999). Only two references addressed the topic of the effect of object size (Akishige et al. 1966; Hall *et al.* 1992). Size of drifting objects was found to be unimportant as long as the minimum dimension was greater than about 1 m (Hall *et al.* 1992). Effects of object characteristics and size have not been evaluated for moored FADs.

Rigs and FADs Technical Session

The daylong session included 13 technical presentations by U.S. and international experts. A panel discussion followed and included participation of representatives from regional (Gulf of Mexico Fishery Management Council) and federal (National Marine Fisheries Service, Highly Migratory Species Division) fishery management agencies, the GOM oil and gas industry, recreational fishing interests, invited speakers and session attendees.

Follow-up responses from FADs experts indicated that the session had been well received, and that the preliminary bibliography had no major omissions or deficiencies. A few, mainly peripheral, citations were offered and added.

Some of the significant follow-up comments included

- It is critical to determine the potential impact on migrating/spawning adult bluefin tuna.
- It would seem that information on FADs effects of petroleum structures in other parts of the world should be available, but the experts do not know of any.
- More emphasis on fishery management issues particular to GOM DPSs impacts is needed in any subsequent meetings.
- Information on GOM tuna movements is needed; if it is not available, tagging studies should be conducted.
- More information on types and distribution of GOM DPSs (present and future) is needed.
- More information on existing GOM commercial and recreational fisheries is needed.
- Directed studies are needed to determine FADs' effects of DPSs.

Most of the contacted participants were enthusiastically in favor of a follow-up meeting and were interested in one as a way to develop research plans that, in their opinions, were needed and could provide many answers to FADs issues surrounding GOM DPSs. A number of FADs experts expressed opinions that techniques and methodology for direct assessment of GOM DPS FADs effects have been developed and are available from FADs research conducted previously. These approaches could be directly and effectively applied applied to answer many of the important questions. The nucleus of interest and support from government agencies, academia and others could make a follow-up meeting productive and effective. In that light, USGS-BRD is continuing to explore the possibility of organizing such a meeting.

CONCLUSIONS

Projections from Existing Knowledge

Existing scientific information, from published studies of FADs elsewhere or from fundamental understanding of fish aggregation and attraction, phenomena and processes, is not sufficient for understanding or predicting potential FADs effects of GOM DPSs. However, some valuable conclusions can be made from the existing body of knowledge.

The existing information on FADs indicates that several commercially and recreationally important species will be or are already being attracted to GOM DPSs. The main species are yellowfin tuna (*Thunnus albacares*), skipjack (*Katsuwonus pelamis*), and bigeye tuna (*Thunnus obesus*).

Based on FADs research and experience around the world, it may be subjectively inferred that GOM DPS FADs effects are likely to occur and possibly could be substantial. However, the existing information is inadequate for scientifically predicting the degree to which such aggregation will occur, let alone for predicting impacts on populations or fisheries. Aggregation of other species such as billfish, wahoo, dolphin, sharks, and coastal pelagics also may occur.

Similarly, the existing information is insufficient with regard to understanding the phenomena or processes involved in fish attraction to objects. Thus, it is impossible to make scientific projections as to the degree to which different structures or DPS components would attract large pelagic fish. Existing information is completely inadequate for analyzing factors such as size, color, shape, lighting, etc.

There is a strong consensus of scientific opinion that open-ocean fish are not attracted to objects for trophic reasons (Lehodey 1966; Brock 1985; Holland 1996). That is to say that they are not attracted due to the presence of prey species around the object, as has been reported for coastal FADs (Klima and Wickham 1971; Wickham and Russell 1974). Instead, pelagic fish (particularly tunas) are attracted to objects for other intrinsic reasons that are yet to be fully understood (Batalyants 1992; Hall 1992; Edwards *et al.* 2000; Freon and Dagorn 2000; Edwards *et al.* 2001). It is possible, however, that some less-abundant species like blue marlin and wahoo are attracted by small tunas and other small fish that aggregate around FADs.

Spatial and temporal relationships between yellowfin, bigeye and skipjack tunas and FADs have been reasonably well studied and probably could be applied to DPSs. Similarly, knowledge of tuna movement patterns between and among FADs probably could also be applied to GOM DPSs.

However, it appears that tuna relate to drifting FADs differently than they do to moored FADs. Tuna aggregate under drifting FADs at night (Hall 1992; Hall and Garcia 1992), whereas they aggregate near moored FADs during daylight hours (Holland *et al.* 1990; Josse 1992; Cilaurren 1994; Holland 1996; Josse *et al.* 2000), perhaps utilizing moored FADs as extensions of the reef dropoff zone (Holland *et al.* 1990). They move away from moored FADs to deep waters during the night, perhaps to feed on vertically migrating squid and shrimp (Holland *et al.* 1990).

Neither reef dropoffs nor open-ocean depths exist immediately near GOM DPSs. Therefore, it is unknown whether diurnal and spatial distributions around DPSs would be more like those for drifting FADs or those for moored FADs. The situation may be further complicated due to lights on DPSs. Lights are often deployed on drifting FADs to attract tuna and other species at night. However, the responses of fish to various kinds of light and intensity are complicated (Bullis and

Roithmayr 1972; Beltestad and Misund 1988; Freon and Misund 1999) and largely unknown for tunas and other FAD species. Thus, the effects of DPS lights cannot be evaluated from the literature.

Potential Ramifications of DPS FADss Effects

There are a number of possible ramifications that should be considered. These may include primary ecological effects including: a) changes in distributional patterns (particularly due to aggregation and concentration in areas with DPSs), b) changes in movement and migration patterns, c) changes in spawning and larval survival/recruitment (due to a and b above).

Under some circumstances, FADs may act as an "ecological trap" that can have serious negative effects by retaining fish in unfavorable environments (Marsac *et al.* 2000). Locations of primary spawning grounds of yellowfin tuna and bluefin tuna in the GOM are not well understood. FADs' effects could have important consequences on bluefin tuna spawning and larval survival (Lamkin *et al.* 2001). Thus, effects of DPS FADs on distribution and spawning of GOM tunas cannot be directly estimated from existing information.

A number of possible secondary, indirect effects of DPS FADs should be considered. They include: a) increased catchability and fishing mortality due to aggregation around DPSs, b) changes in population age structure due to increased or changed age-specific mortality due to fishing, c) changes in commercial and recreational fisheries due to aggregation, concentration and location predictability, e) changes in fisheries bycatch due to changes in fishing gears and techniques utilized around DPS FADs, and f) changes in fishery management required by new situations due to DPS FADs. Indirect effects may be either positive or negative.

Important and valuable recreational fisheries may spring up in areas of DPS deployment. In Hawaii, for example, a network of FADs has been established around the islands (Figure 1B.18) to enhance recreational and hook-and-line artisanal fisheries, primarily targeting yellowfin tuna and blue marlin (Holland *et al.* 2000). A similar "network" of DPSs already exists in the northern GOM (Figure 1B.19). Concentrations of and enhanced fishing for yellowfin tuna and blue marlin have already been reported around some of these structures, including Exxon "Hoover/Diana" rig and other structures over 100 miles offshore (Sloan 2001). Because prey biomass around FADs has been shown to be inadequate for supporting aggregated tuna biomass (Freon and Dagorn 2000), the impact of DPSs will be primarily due to attraction, as opposed to the alternative explanation of increased production.

Information Needs

If FADs' effects of GOM DPSs are to be assessed and quantified, it will have to be done through direct studies, instead of by extrapolation or inference from existing scientific literature. If GOM DPSs are to be directly studied, it is important that such studies be done immediately, before so many DPSs have been deployed that natural distributions and movements will already have been significantly altered (Kingsford 1999).

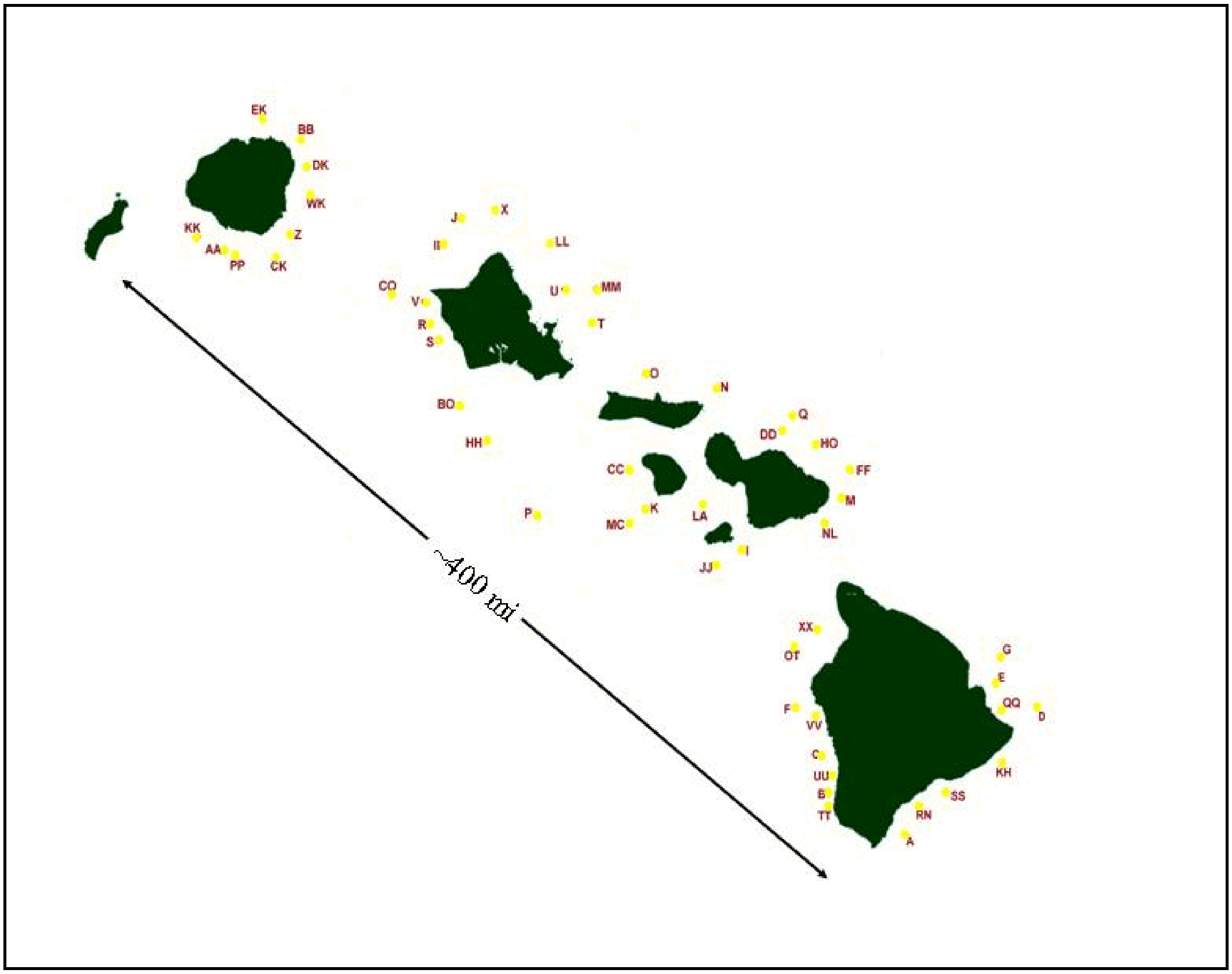

Figure 1B.18. FADs network in the Hawaiian islands.

There are a number of effective, proven ways that assessment of GOM DPS FADs effects can be made. Much of the existing information about FADs' effects on tunas has been obtained through acoustic telemetry and tracking. Automatic acoustic monitoring stations have been used to detect return and evaluate site fidelity of tunas to structures. This technique could be very easily applied at DPSs. Hydroacoustic techniques also have been found to be useful in assessing presence and distributional patterns of tunas around FADs. Combination of acoustic tracking and hydroacoustic survey has provided important information (Josse *et al.* 1997, 1998) and, with the development of sophisticated new hydroacoustic instruments (Gerlotto 2001), offers great promise for assessing FADs' effects of GOM DPSs.

Other techniques that have been used to assess and understand FADs include tag/recapture studies and fishery-dependent monitoring. Both of these approaches are contingent on presence of active large fisheries, which may not yet exist in the deepwater petroleum development areas of the GOM. Fishery-independent techniques and exploratory fishing could be used to preliminarily assess DPSs. Modeling has provided valuable insights into tuna-FADs relationships and could be expected to do

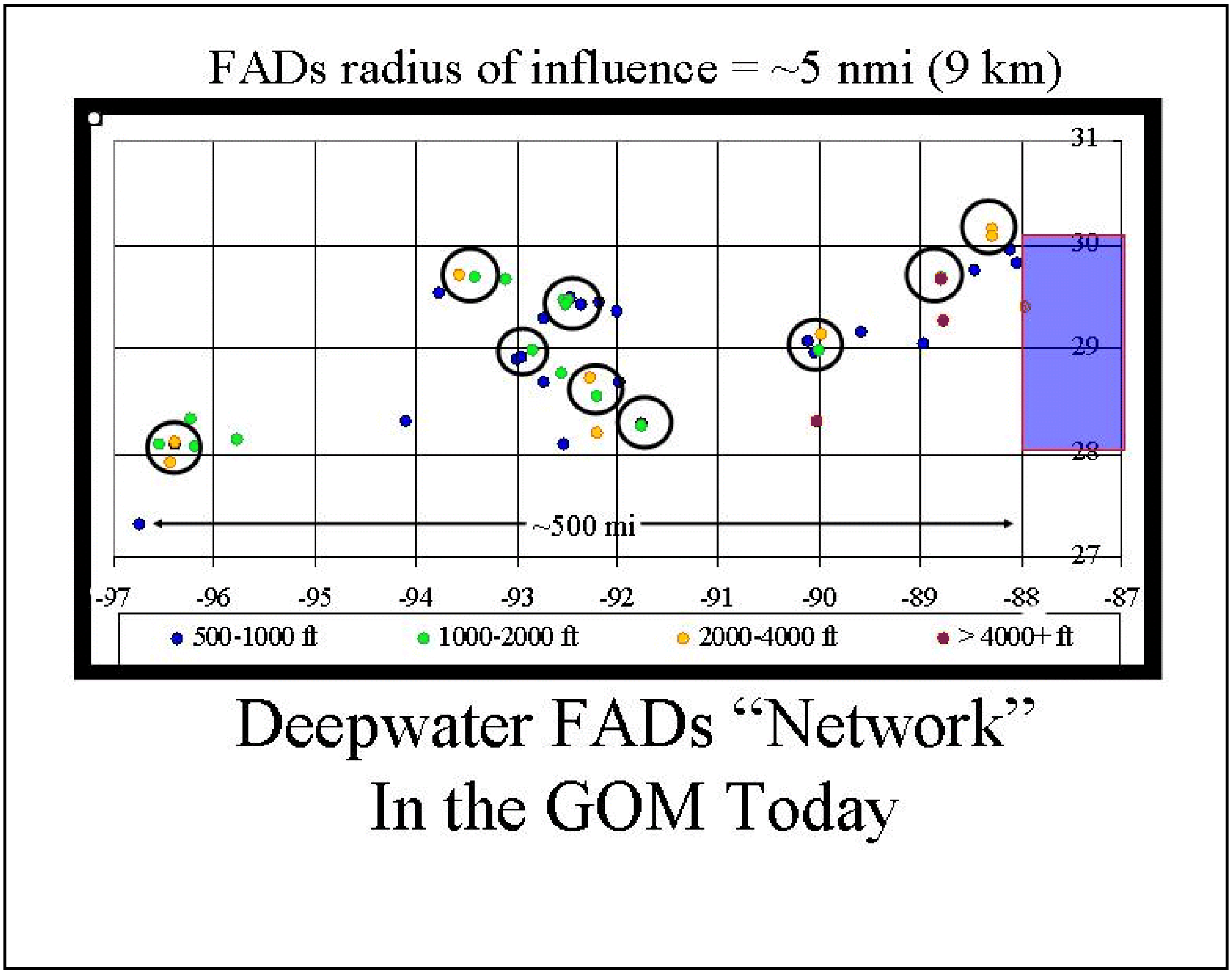

Figure 1B.19. Existing network of deepwater petroleum structures in the northern Gulf of Mexico. Groups of structures within 5 nmi radius of influence are shown in black circles.

the same for GOM DPSs. Given the great depths to which FADs-associated tunas are found (Cayre and Marsac 1993, Josse *et al.* 2000, Holland, *et al.* 1990), aerial-visual or LIDAR (light detection and ranging) surveys (Oliver and Edwards 1996) are unlikely to be fully effective; but they may still be useful, especially to determine presence of bluefin tuna or large schools of yellowfin tuna.

Due to uncertainties inherent in rapidly developing and evolving deepwater technology, the future numbers, types and distributions of deepwater structures cannot be accurately predicted or projected. Therefore, it is likely that most future consideration, management, or mitigation of DPS FADs effects on fisheries will have to be tactical rather than strategic. MMS could help efforts to assess these effects by providing scenarios and estimates of future deepwater development.

For the reasons of uncertainty about how GOM pelagic fish will be aggregated by DPSs, how DPS technology will develop, how fisheries will change, etc., it is unlikely that the issue of DPS FADs effects can be immediately resolved. It probably will have to be studied and monitored over time. On the other hand, if direct studies and assessments of DPS FADs were initiated, and if direct aggregation affects on important pelagic fish were to be documented as small or minimal, resource managers could have reasonable confidence that deepwater development would not have major negative impacts on GOM pelagic fisheries.

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SESSION 1C

DEEPWATER MARITIME SITES: A NEW CHALLENGE FOR ARCHAEOLOGY UNDERWATER

Co-Chairs: Dr. Rik Anuskiewicz, Minerals Management Service
Mr. David Ball, Minerals Management Service

Date: January 8, 2002

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INTRODUCTION

Dr. Richard J. Anuskiewicz
Minerals Management Service
Gulf of Mexico OCS Region

This session focuses on two facets of archaeology underwater: the discovery and management of resources underwater. The discovery process can be either accidental or the result of exhaustive research and planning with hypotheses formulated and tested via rigorous application of the scientific method during survey and fieldwork. Once archeological resources are found, managing and protecting these underwater resources can be a significant challenge. Two papers in this session focus on the accidental discovery process. The authors address some of the management challenges and provide insight on the resource management strategies of these two deepwater shipwrecks sites. Other papers in this session look at remote-sensing instrumentation as a tool for both refining archaeological sites and for marine prehistoric and historic maritime model building.

Richard (Rik) J. Anuskiewicz was awarded his B.A. in 1972 and his M.A. in 1974 in anthropology, with specialization is archaeology from California State University at Hayward. Rik was employed with the U.S. Army Corps of Engineer Districts of San Francisco, Savannah, and New England Division from 1974 to 1984, as a terrestrial and underwater archaeologist. In 1980 he began work on his doctorate. In 1984 he accepted his present position with Department of the Interior, Minerals Management Service, Gulf of Mexico Region as a marine archaeologist. Rik received his Ph.D. in 1989 in anthropology, with specialization in marine remote-sensing and archaeology from the University of Tennessee at Knoxville. Rik's current research interest is focused on using remote-sensing instrumentation as a tool for middle-range theory building through the correlation of instrumental signatures to specific observable archaeological indices.

DISCOVERY AND MANAGEMENT OF A DEEPWATER HISTORIC SHIPWRECK IN THE GULF OF MEXICO

Dr. Richard J. Anuskiewicz
Mr. David A. Ball
Dr. Jack B. Irion
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INTRODUCTION

In February 2001, archaeologists with the Minerals Management Service, Gulf of Mexico Region, were notified of the accidental discovery of a wooden-hulled, copper-sheathed shipwreck lying in approximately 2,650 feet of water. The vessel, believed to be from the late eighteenth or early nineteenth century, had been discovered during a post-lay survey for a newly installed 8-inch pipeline by ExxonMobil. This was a groundbreaking discovery in many ways. It was the first opportunity we have had to study in detail a 200-year old wooden hulled shipwreck in over a half a mile of water in the Gulf. The discovery also afforded a chance to review the effectiveness of our program with respect to protecting archaeological resources (Anuskiewicz *et al.* 2001)

Although no archaeological assessment was required for this pipeline, a hazard survey was conducted. However, a review of the remote sensing data prior to construction did not identify any potential hazards in this area. One question that is continuously asked is “how could this happen?” That was exactly MMS’s question as well, and we believe we have a reasonable answer. Both the pipeline route and deep-tow side-scan used for the survey contributed to the problem. The pipeline route was predetermined taking into consideration engineering constraints, physical geography and geology, and the surrounding underwater environment to select a safe pipeline route. At this particular water depth the requirement for a magnetometer survey, one of the two standard remote sensing tools used for identifying shipwrecks, is typically waived. The side-scan sonar, then, became the primary instrument for possible shipwreck identification. Since the side-scan sonar instrument scans out at a slight angle when surveying and the survey line just happened to pass directly over the center of the wreck, the only image that appeared on the data was an anomalous smudge in the center of the sonar record, as indicated in the figure below (Figure 1C.1).

An even smaller image appeared at the extreme edge of the sonar record on an adjacent survey line. Again, this area of the Gulf did not require an archaeological assessment and no shipwrecks were known to have wrecked in the area. The main problem then, was that the survey lane spacing and the instrument setting were such that they allowed a blind spot directly below the acoustic sensor. The smudge that appeared was simply evaluated as not being a hazard to pipeline construction. Once the pipeline was in place, the survey company ran an ROV (Remotely Operated Vehicle) across the pipeline route to ensure proper installation. It was at this point that the historic shipwreck was discovered lying some 2,650 feet below the surface.

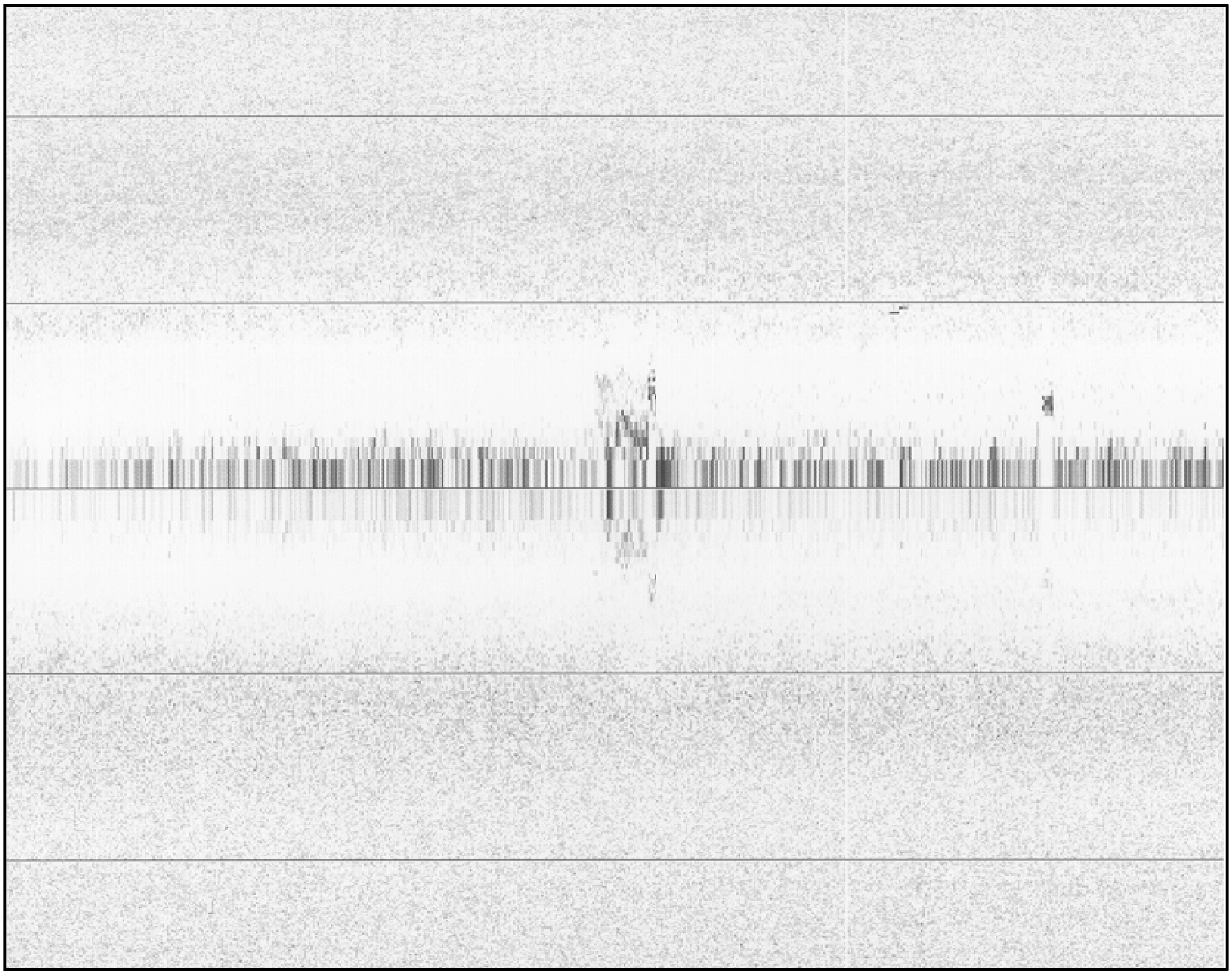

Figure 1C.1 Sonar image of shipwreck.

INITIAL INVESTIGATION

After notifying MMS archaeologists, ExxonMobil agreed to send the MMS GOMR Marine Archaeologists out to the site to direct a preliminary ROV investigation of the wreck in an attempt to determine what this vessel might have been. A total of about six hours of videotape was collected and reviewed by the archaeologists (Figure 1C.2).

The remains of the vessel are approximately 60-65 feet from bow to sternpost. It is approximately 20-25 feet wide. Most of the inner works of the ship are gone, but there is about six feet of relief at the bow and about nine feet at the stern. As it sits on the seafloor, all that remains appears to be a shell of the hull from the area below the waterline. The inside of the vessel is filled with sediment and may yet contain several diagnostic artifacts that can possibly help us determine its name, age, and perhaps even points of origin and destination. However, very few artifacts were visible in the video survey.

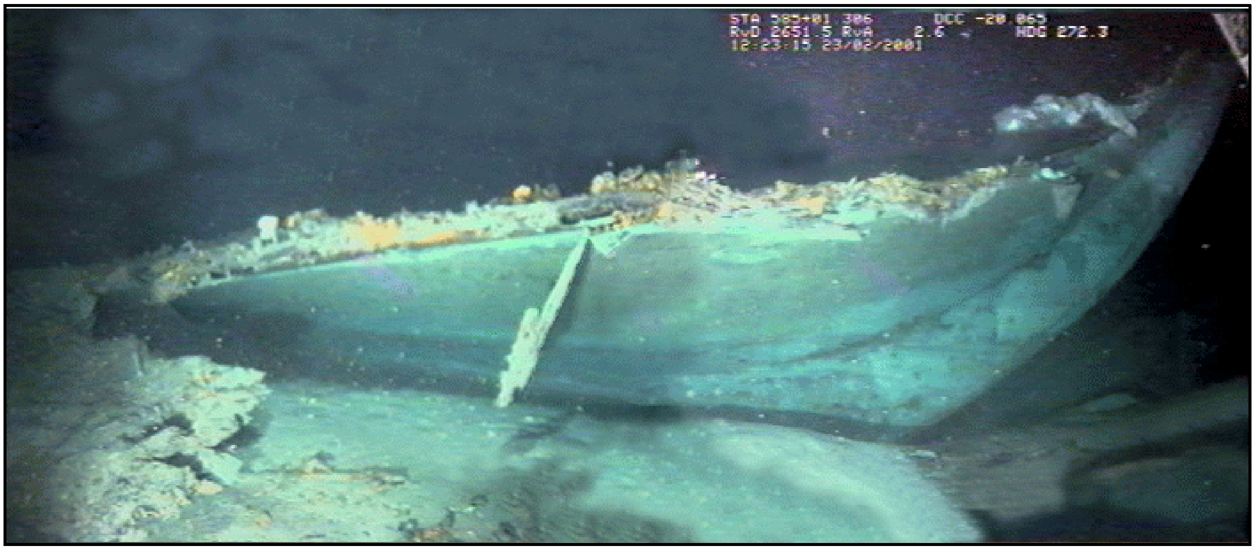

Figure 1C.2. Composite image of starboard bow section of the shipwreck.

During our preliminary investigation, two artifacts were removed from the vessel in an attempt to identify its age. The first artifact removed (Figure 1C.3) was recovered from the port side bow section of the vessel, prior to MMS notification. It was a lead tube approximately 45-cm long, 15-cm

Figure 1C.3. Hawsepipe, recovered from bow of vessel.

in diameter, 2-cm thick and weighed about 6.8 kilograms (15 lbs.). Initially we thought the lead artifact might have been part of the bilge pump system or perhaps one of the decking scuppers used to drain water from the decks. After further research, we now believe this artifact is a hawsepipe. A hawsepipe is an inclined tube which leads from the main deck to the outside of the vessel. An anchor cable or rope is passed through the hawsepipe holding the anchor. We believe the hawsepipe was subjected to the heat of a fire because of the folding of what would have been the interior end of the pipe (Anuskiewicz *et al.* 2002).

Trying to avoid as much disturbance to the shipwreck as possible, but also wanting to get an estimate as to the age of the vessel, we decided to recover one other artifact from the site: one of the loose pieces of sheathing that had fallen away from the vessel along its port side. Sheathing on historic vessels was an expensive undertaking, implemented as an anti-fouling method to keep marine growth and wood-boring organisms from weakening the wooden hull. It is known that pure copper was used from the mid 1700s through the mid 1800s. It is also known that a copper alloy, known as Muntz metal, replaced pure copper. Therefore, by obtaining a sample of the sheathing and having it assayed, we could narrow down the time period of this vessel. The sample that was collected turned out to be pure copper, which therefore gives us a date range of mid eighteenth to early nineteenth century. The sheathing also had a few pieces of wood planking fastened to it with small copper nails. The wood planking, which was approximately ½ inch thick, leads to an interesting hypothesis. Wood planking on vessels of this time period would typically have been oak, several inches thick. Therefore, we believe that the wood planking was most likely attached to the vessel as sacrificial planking (Stem to Stern 2002:5), prior to the copper sheathing. We sent the wood to two separate labs for sourcing and almost identical results came back to us. The wood was classified as white pine (*Pinus strobus*) which is native to the northeastern United States and Canada. The wood sample also showed evidence of charring, which leads us to believe that there was a fire on the vessel, which most likely led to its sinking.

MANAGEMENT OPTIONS

Since it was clear that we were dealing with an historic shipwreck, our next task was to determine an appropriate management strategy that best protected the resource. The four options we developed were as follows:

1. Lift and re-route the pipeline around the wreck
2. Construct a sandbag bridge over the wreck
3. Cut and re-route pipeline around the wreck
4. Leave in-place, conduct a limited data recovery program

After we collected available deepwater engineering data and cost figures for all four options it became obvious that, due to the extreme depth of this wreck, the most feasible option was a data recovery program, option 4. We therefore developed a research design incorporating a data recovery program that would contract for the use of a suitable ROV or submersible to excavate a representative portion of the interior of the wreck, recover a limited number of diagnostic artifacts, excavate up to 15 test units outside the wreck to determine if a scattering of artifacts exists outside the wreck, and obtain high quality video and digital images.

Funding for the project was supplied by the pipeline operator under the Moss-Bennett Act, which permits government agencies to accept private funds for the purpose of conducting archaeological salvage. The MMS subsequently entered into a cooperative agreement with Texas A&M University's Department of Oceanography and the Institute of Nautical Archaeology to perform this study, which is expected to be carried out sometime during summer 2002.

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Richard (Rik) J. Anuskiewicz was awarded his B.A. in 1972 and his M.A. in 1974 in anthropology, with specialization is archaeology from California State University at Hayward. Rik was employed with the U.S. Army Corps of Engineer Districts of San Francisco, Savannah, and New England Division from 1974 to 1984, as a terrestrial and underwater archaeologist. In 1980 he began work on his doctorate. In 1984 he accepted his present position with Department of the Interior, Minerals Management Service, Gulf of Mexico Region as a marine archaeologist. Rik received his Ph.D. in 1989 in anthropology, with specialization in marine remote-sensing and archaeology from the University of Tennessee at Knoxville. Rik's current research interest is focused on using remote-sensing instrumentation as a tool for middle-range theory building through the correlation of instrumental signatures to specific observable archaeological indices.

Dave Ball received his Bachelor of Arts degree in anthropology from Sonoma State University in 1992 and his Master of Arts degree, which focused on marine archaeology, from Florida State University in 1998. He has conducted fieldwork in archaeology for over 10 years and has directed field research on both land and underwater archaeological sites from Florida to Washington State. Some of the more notable sites that Dave has worked on include an inundated prehistoric site at Little Salt Spring, Florida, dating back about 10,000 years; a 1533 Spanish shipwreck in the Dry Tortugas; a Confederate Ironclad shipwreck in Mobile Bay, Alabama; and the 1686 French shipwreck *la Belle*, which wrecked in Matagorda Bay, Texas. Dave has been employed with the MMS as a Marine Archaeologist since October 1999.

Dr. Jack B. Irion received his doctorate in archaeology from The University of Texas in 1990. He has over 27 years' experience in underwater archaeology and has participated in or directed archaeological expeditions in England, Mexico, Belize, Turkey, Italy, Puerto Rico, and throughout the United States. Prior to joining the MMS in 1995, Dr. Irion served as a private consulting marine archaeologist working under contract to both private industry and state and federal agencies. His work has resulted in the discovery and documentation of numerous historic sites and shipwrecks, including the Confederate Harbor Obstructions in Mobile Bay and the wreck of the steamship *Columbus* in Chesapeake Bay. Since joining the MMS, Dr. Irion has directed the Seafloor Monitoring Team, composed of a group of diver/scientists with the MMS, in the documentation of several historic shipwrecks on the Outer Continental Shelf. These have included the Civil War gunboat U.S.S. *Hatteras* and the 19th century coastal steamers *New York* and *Josephine*, the latter of which was added to the National Register of Historic Places in 2000. In his free time, Dr. Irion also works as a volunteer diver with the Audubon Aquarium of the Americas.

REFINING AND REVISING THE GULF OF MEXICO OUTER CONTINENTAL SHELF REGION HIGH PROBABILITY MODEL FOR HISTORIC SHIPWRECKS

Dr. Charles E. Pearson
Coastal Environments, Inc.

Mr. Stephen R. James, Jr.
Panamerican Consultants, Inc.

For over 25 years, the Minerals Management Service has required cultural resources assessments for federal oil and gas leases in the northern Gulf of Mexico Region or GOMR (Figure 1C.4). These assessments reflect the obligations of the MMS relative to the identification, protection and management of prehistoric and historic properties on federal lands in this area. Over this time, the MMS has funded several studies to collect data on the cultural resources of the northern Gulf of Mexico (GOM) to aid in their effective management. The results of these studies have been used to develop survey guidelines, equipment requirements, and analytical procedures deemed most appropriate for identifying submerged and/or buried cultural resources. Two of these studies have dealt specifically with historic shipwrecks in the GOM; they have resulted in lists of wrecks and statements about their distributions and preservation potential. In June of 2000, MMS awarded a contract to Panamerican Consultants to refine and revise the work of the previous studies on historic shipwrecks in order to enhance their management. Coastal Environments, Inc., of Baton Rouge, is participating with Panamerican in this study.

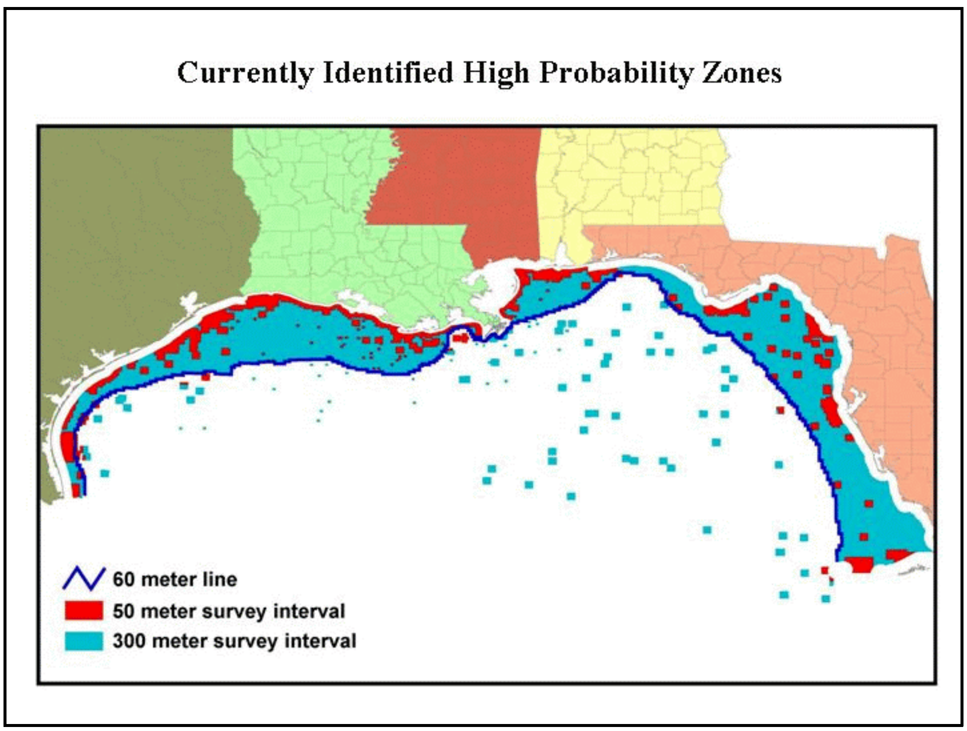

Figure 1C.4. Currently identified high probability zones.

This study has involved several tasks. (Figure 1C.5) One is the reevaluation and expansion of previously collected data on shipwrecks. Another is the correlation of these shipwreck data with other sorts of data on submerged objects from the GOM, such as reported snag and hang data. This second task involved diving on selected offshore targets to determine their identity. The third task focuses on using current offshore survey approaches via a magnetometer survey at selected target locations with differing equipment and survey strategies. The final task is the synthesis and consolidation of all of the collected information into a report for the MMS. Coastal Environments has been involved principally in Tasks 1 and 2, the reevaluation of shipwreck data and correlation with other data sets.

TASKS

1. **Archival Data Collection**
2. **Correlate Collected Data on Shipwreck Locations with Lease Block Survey Data, Reported Hang Locations, Etc.**
3. **Compare Marine Magnetometer Technologies and Survey Line Spacing**
4. **Synthesize Collected Data:**
    - **Develop Predictive Model from Shipwreck Data**
    - **Assess Results of Magnetometer Survey Tests**

Figure 1C.5. Tasks.

At the outset, we decided to gather all of the collected information on wrecks and other offshore objects into an electronic data base and to incorporate it into a Geographic Information System (Figure 1C.6) to make the information accessible to MMS personnel involved in cultural resources management. The database we are using is Access, and an example of a page of the 3-page entry form is shown here. The GIS system is ArcView.

The data on shipwrecks, objects, and hangs came from a variety of sources. We used MMS data, including wreck information from the two earlier studies, data from offshore lease block surveys, and snag data from the government's fisherman compensation fund. We also used data from the U.S. Coast Guard, NOAA, the National Imagery and Mapping Agency, U.S. Fish and Wildlife Service, and similar agencies from each of the Gulf states. We obtained hang and obstruction data from Texas A&M University and the Louisiana Department of Natural Resources. One of our advantages over previous studies is that many of these data sets are now in digital format. In addition, we examined the records at all of the state archaeologist's offices of the Gulf states to collect information on offshore remote-sensing surveys or shipwreck work previously done. Most of these studies dealt with state waters, but often they provide information on losses in federal waters. We also examined pertinent publications dealing with shipwrecks, including historical and

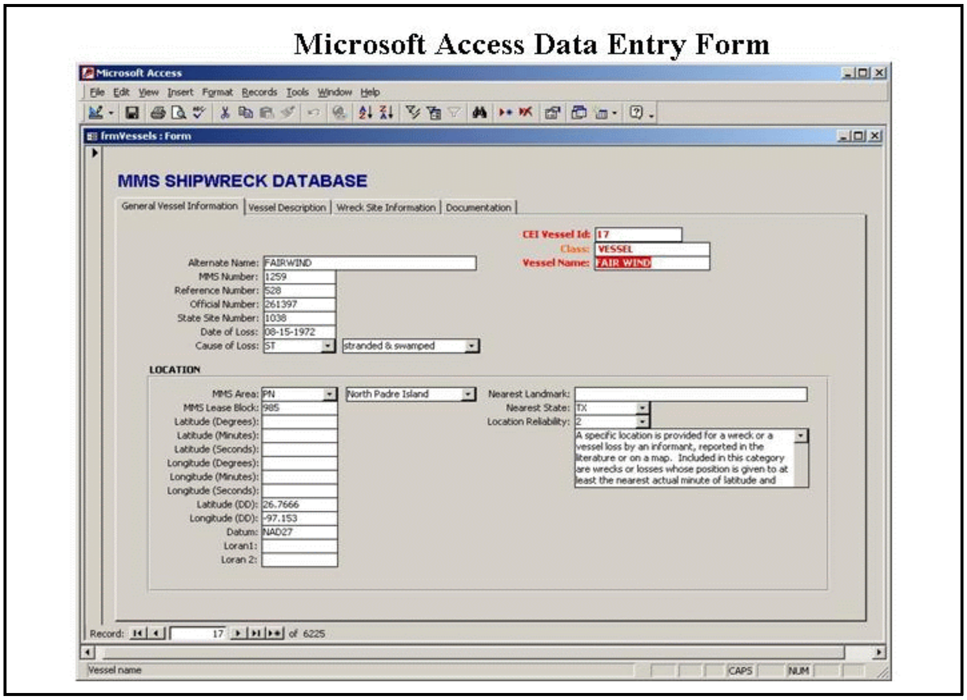

Figure 1C.6. Microsoft Access data entry form.

archaeological works. Some of the sports divers publications proved to be particularly useful for obtaining information on wrecks in offshore Florida, Alabama and Mississippi. Figure 1C.7 shows all of the reported and identified wrecks in the study area derived from these sources.

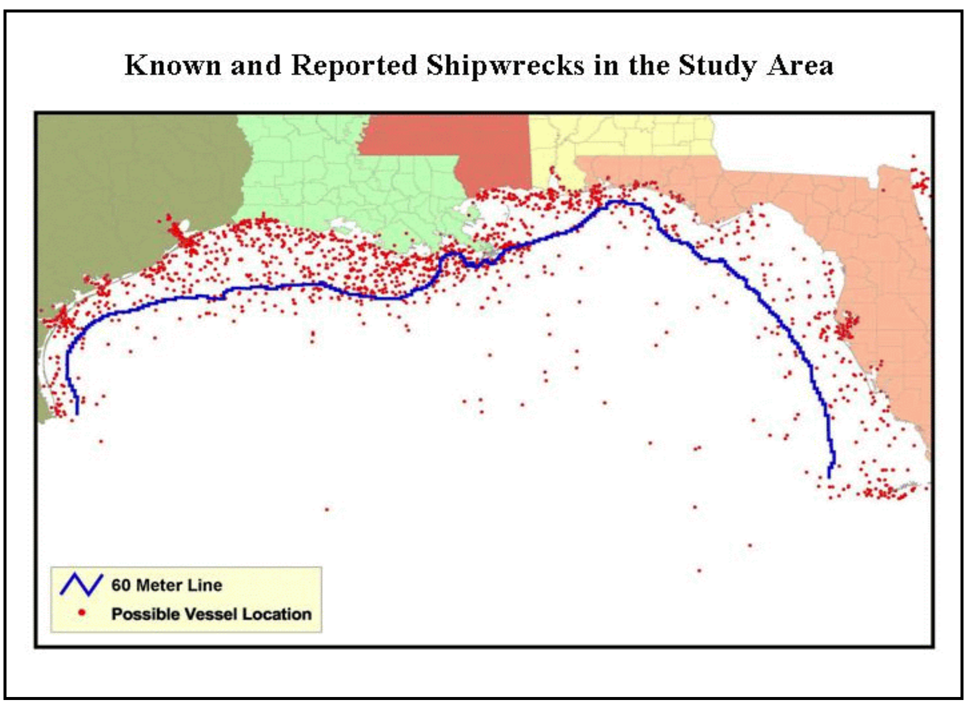

Figure 1C.7. Known and reported shipwrecks in the study area.

Many of the shipwreck data sets now available are in digital form. However, these data sets do have problems. There are numerous errors, duplications, and inaccuracies within these sets; some, but not all of which, can be resolved. One of the principal difficulties with these data sets relates to the reliability of the location of loss information provided. Some of the data sets do include evaluations of the reliability of the positions provided, but many do not. Additionally, reliability assessments vary across data sets and reliability assessments change over time. This forced us to go back to original wreck reports where they were available. Among the most useful of these proved to be the lists of Merchant Vessels of the United States, published by various agencies since the late nineteenth century. In referring to these lists we found numerous instances where the original wreck report contained imprecise information on the position of loss that had miraculously become very precise in recent data bases. Typical examples would be where a vessel might have originally been reported lost “about 50 miles east of Main Pass,” or even more vague “75 miles off Mobile,” with no direction at all given. These locations have been converted into geographic coordinates and, over time, incorporated into various wreck lists and databases where locations are often given to the nearest tenth of a second. It is obvious that developing statements about historic wreck occurrences and distributions using this type of information is fraught with difficulties. Of course, these problems are most prevalent with older wrecks, but even on recent losses, the reliability of the position of sinking can be poor. To address this problem, we have assigned locational reliability assessments to wrecks in the database, with reliabilities ranging from 1, very precise, to 4, very vague.

At present our data set of wrecks and objects includes 6,223 entries. This number does not include over 7,000 reported snag, well site locations, and the like, that we are including in the data sets we are examining. Of these entries, 3,260 are classified as vessels identified from the various sources used. This number is an increase of about 2,000 over the number of offshore wrecks given in the MMS list of wrecks developed in 1987. This increase is due to some losses since that date, but more so to the incorporation of many unidentified vessels from offshore survey work and various databases not used in the earlier study. Of these 3,260 wrecks, only 276 have been assigned a location reliability factor of 1 and 985 a factor of 2 (Figure 1C.8). These 1,261 wrecks constitute about 38% of the total and represent those that we feel are most useful in making statements about patterns of wreck distribution, except in the very broadest sense.

The distribution of known and reported wrecks in an area of offshore Louisiana and Texas is shown in Figure 1C.9 to give some idea of the type of information provided in ArcView. As can be seen, and as expected, the density of wrecks is highest in inshore Federal waters, generally corresponding to the high probability areas now identified by the MMS. Some wrecks in state waters are shown here, although our concern is only with those in federal waters. Moreover, some of the positions of the wrecks shown here in state waters are so unreliable that we are not sure whether they actually fall in state or in federal waters. These will be maintained in the final data set. Figure 1C.10 shows the same area that includes only those wrecks given location probabilities of 1 and 2. As mentioned, these are those that we feel can most reliably be used to make statements about vessel distributions and occurrences.

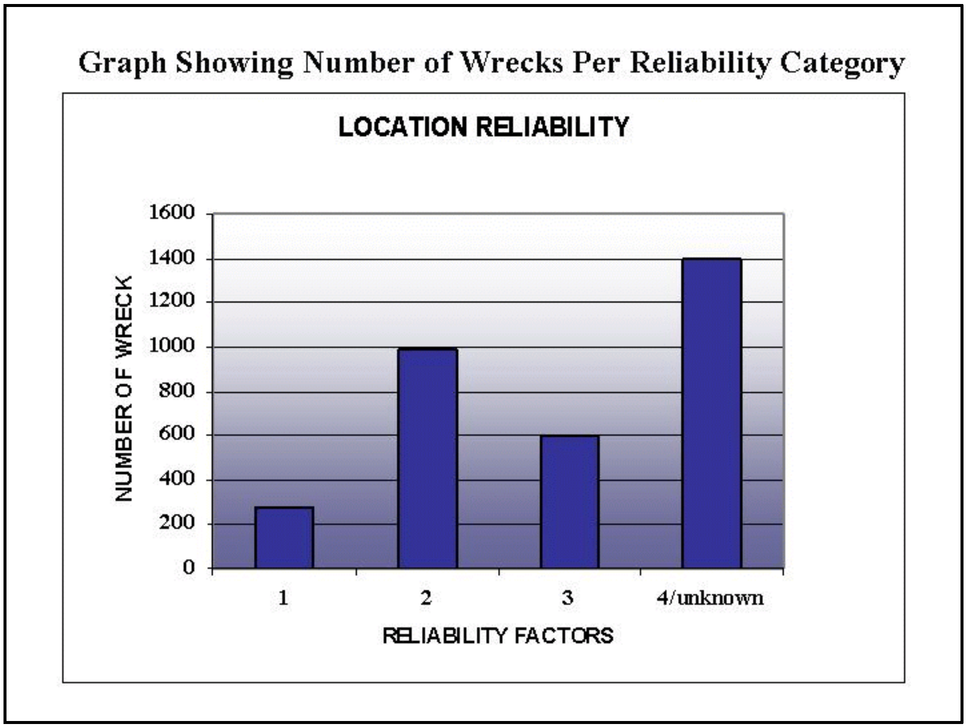

Figure 1C.8. Number of wrecks per reliability category.

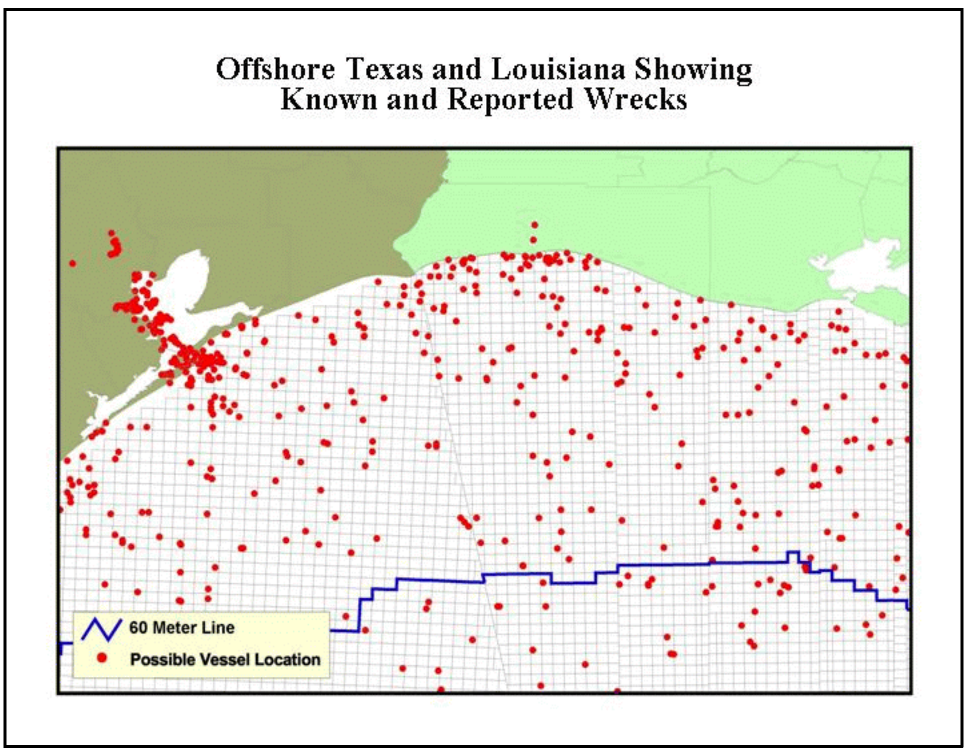

Figure 1C.9. Offshore Texas and Louisiana showing known and reported wrecks.

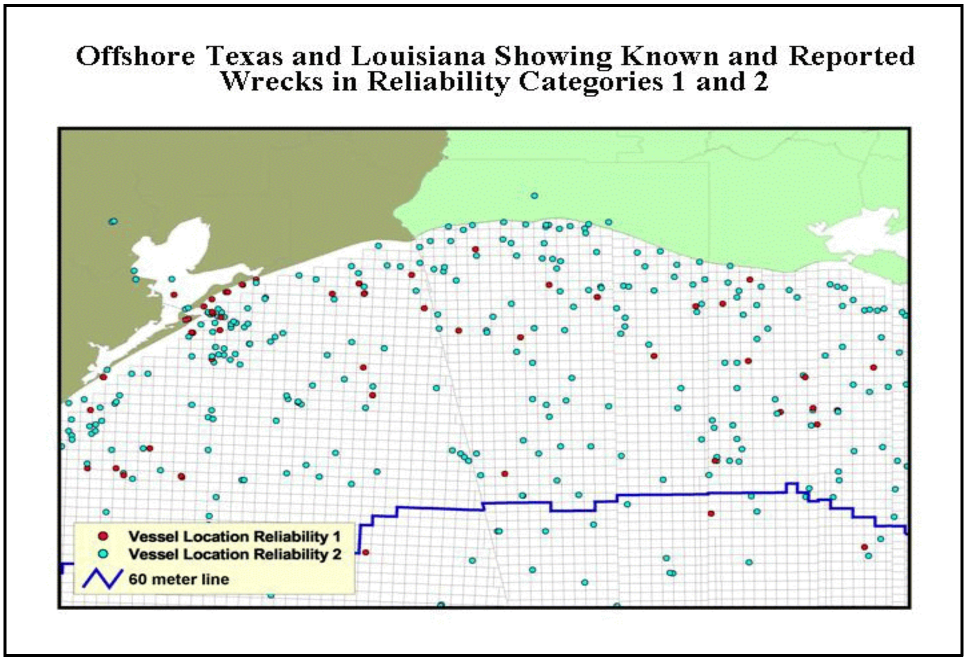

Figure 1C.10. Offshore Texas and Louisiana showing known and reported wrecks in reliability categories 1 and 2.

One of the objectives of this study was to assess reported hang locations with reported wreck locations to see if correlations exist, the assumption being that many of the reported net snaggings have caught exposed wreckage, based on findings at the small number of historic wrecks now known in the GOM. Figure 1C.11 shows a smaller area of offshore Louisiana with reported wrecks

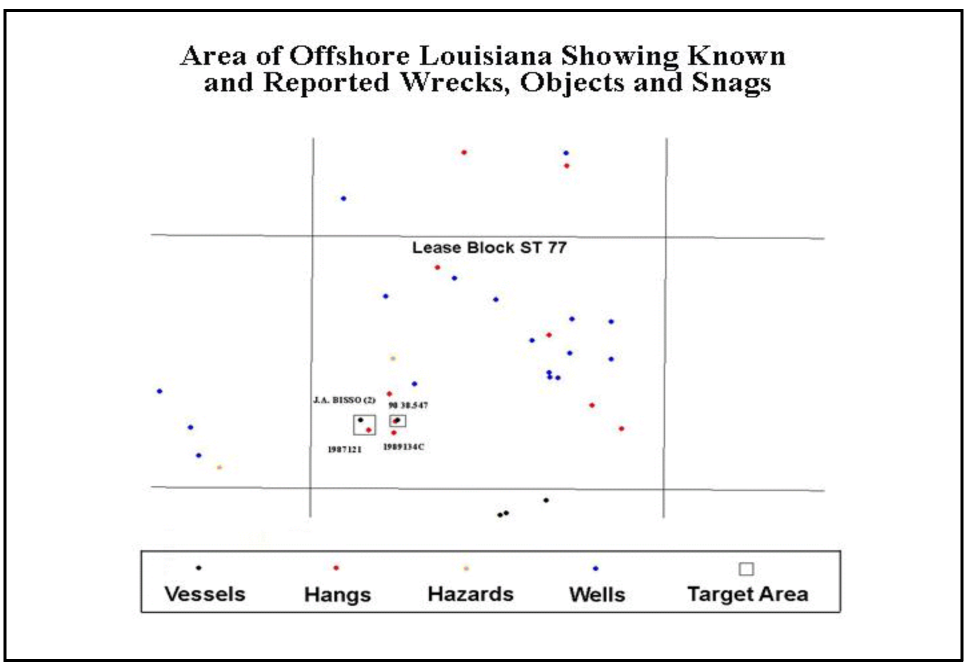

Figure 1C.11. Areas of offshore Louisiana showing known and reported wrecks, objects and snags.

and reported hangs shown. As can be seen, there are clusters of snags around some reported vessel loss locations and there are, also, clusters of hangs by themselves. The question is, do these clusters of hangs constitute undiscovered shipwrecks? One of the objectives of the diving operations was to examine this question.

We are still assessing the collected wreck data and have no final conclusions. The collected data add to our understanding of the occurrence, distribution, and preservation of shipwrecks in the GOM, but, also reveal a number of shortcomings that need to be considered and addressed. Of particular importance is the demonstration that GIS systems like ArcView can provide MMS personnel with a powerful and useful tool for managing these shipwreck resources.

The second phase of Task 2 was to conduct diving on approximately 20 targets identified in the hang and obstruction data to determine if hangs correlated with or represented shipwrecks. Twenty targets or target areas were chosen for selection for survey and subsequent diver investigation, this map showing their lease block locations (Figure 1C.12). All targets situated in less than 100 feet of water chosen for further investigation had the following characteristics:

- Group of hangs which correlated spatially with unidentified objects noted during previous hazard surveys.
- Group of hangs which correlated spatially with a reported wreck location.
- Group of hangs which correlated spatially with only themselves, the cluster suggesting the presence of an object. And/or

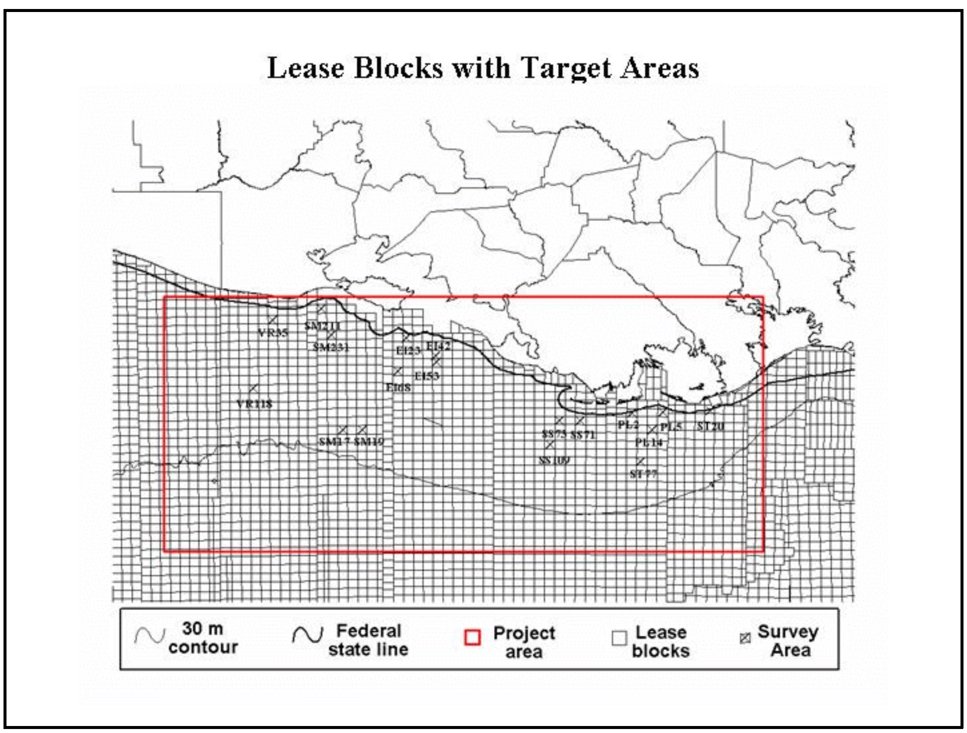

Figure 1C.12. Lease blocks with target areas.

- Precisely located unidentified objects located during previous hazard surveys, regardless of association with hangs.

As indicated by each target area's lease block map, the majority of target areas enclosed multiple targets composed of hangs, vessels, obstructions, etc. (Figures 1C.13 and 1C.14) With the exception of those targets precisely located during previous oil industry-related hazard surveys, we elected to

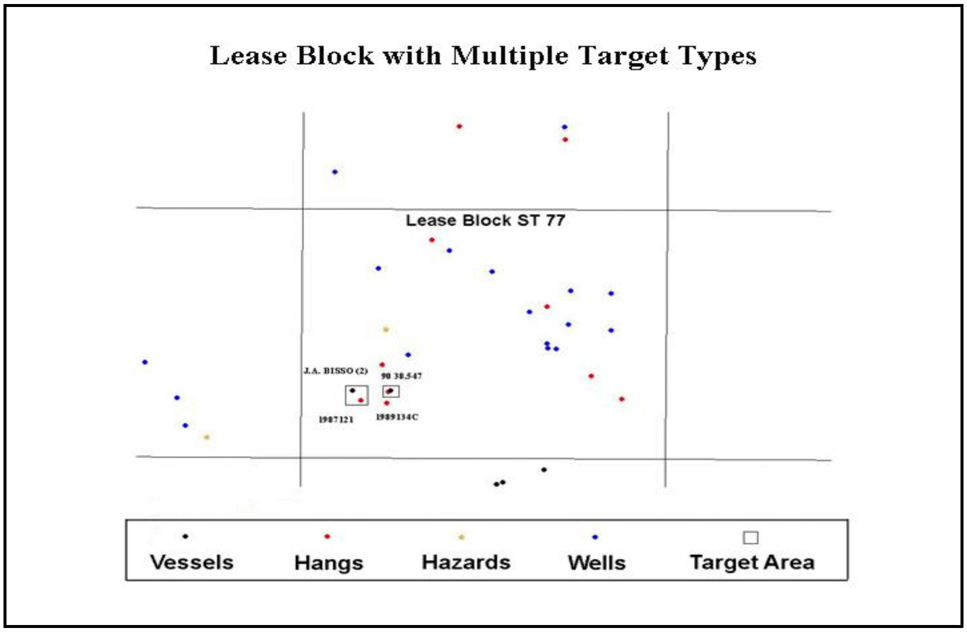

Figure 1C.13. Lease block with multiple target types.

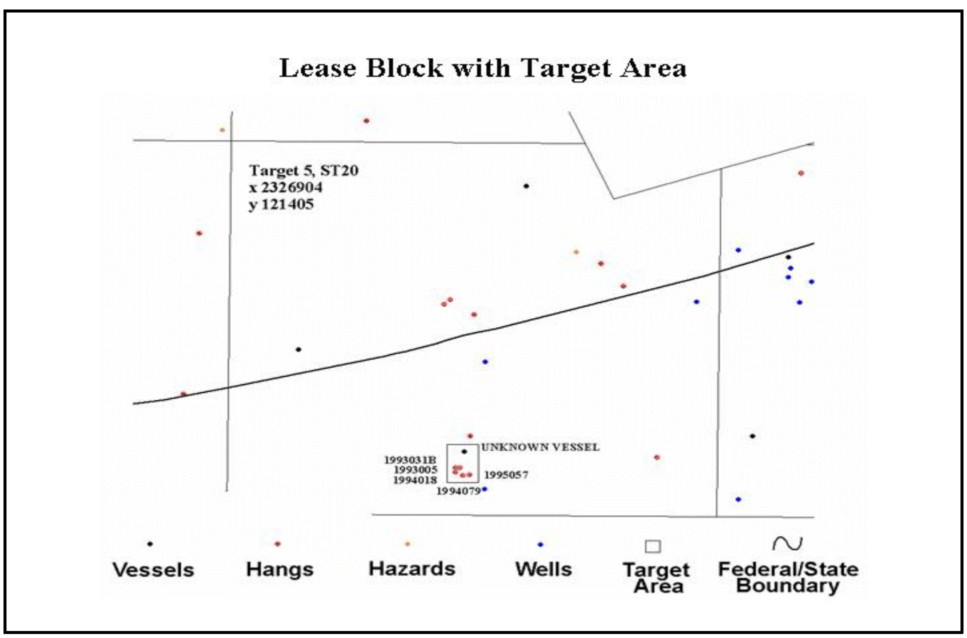

Figure 1C.14. Lease block with target area.

survey a large block around multiple hangs, objects, or unknown vessels in a cluster calling the survey block a single target, rather than investigating the specific coordinate of each hang or obstruction and calling that specific location a separate target (Figure 1C.14). This was implemented on the belief that closely clustered hangs or obstructions could represent the same object with slightly different coordinates because of the inaccuracy of the Loran system used to position most of them. Furthermore, we believed that calling each hang in a cluster a separate target would have offered the study only minimal correlation data. As opposed to 20 separate single targets our survey areas offered a much larger sample by investigating 51 recorded locations that included 29 hangs, 12 unknown vessels, 9 unknown objects, and 1 obstruction.

The initial examination of each of the 20 target areas involved a remote-sensing survey using a marine magnetometer, side-scan sonar, fathometer and DGPS for positioning. Of the 20 targets, only ten target areas contained bottom features indicative of submerged cultural resources (Figure 1C.15). Target inspection, which was conducted with surface supply diving techniques and completed in October 2001, indicated that of the ten potential targets, only one represented a shipwreck. Located in Lease Block VR118, (Figure 1C.16) Target 15 was a modern, steel-hulled shrimp trawler unassociated with any reported hangs. Of the remaining nine targets, two represented modern debris such as pipe or platform debris associated with the oil industry, and 7 represented natural bottom features or had negative findings. These results raise many questions, the least of which is reported coordinate accuracy of offshore objects. However, our analysis of these data is incomplete and positing implications at this time would be premature.

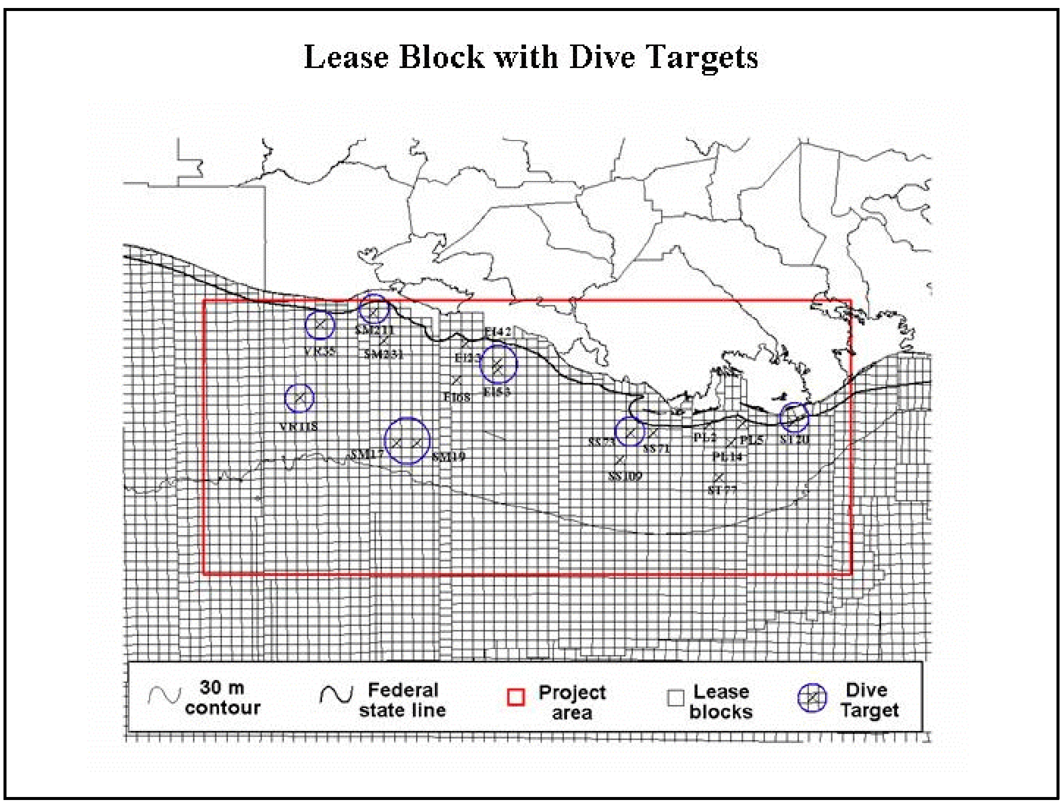

Figure 1C.15. Lease block with dive targets.

Figure 1C.16. Task 2: diving.

(Figure 1C.17) The third task of this project was and is a comparison of marine magnetometer technologies and survey line spacing. The goals of this task are: one, a comparison of different marine magnetometers to determine whether there is a significant difference in their performance in detecting shipwrecks; and two, to evaluate the magnetometers at various line spacings to

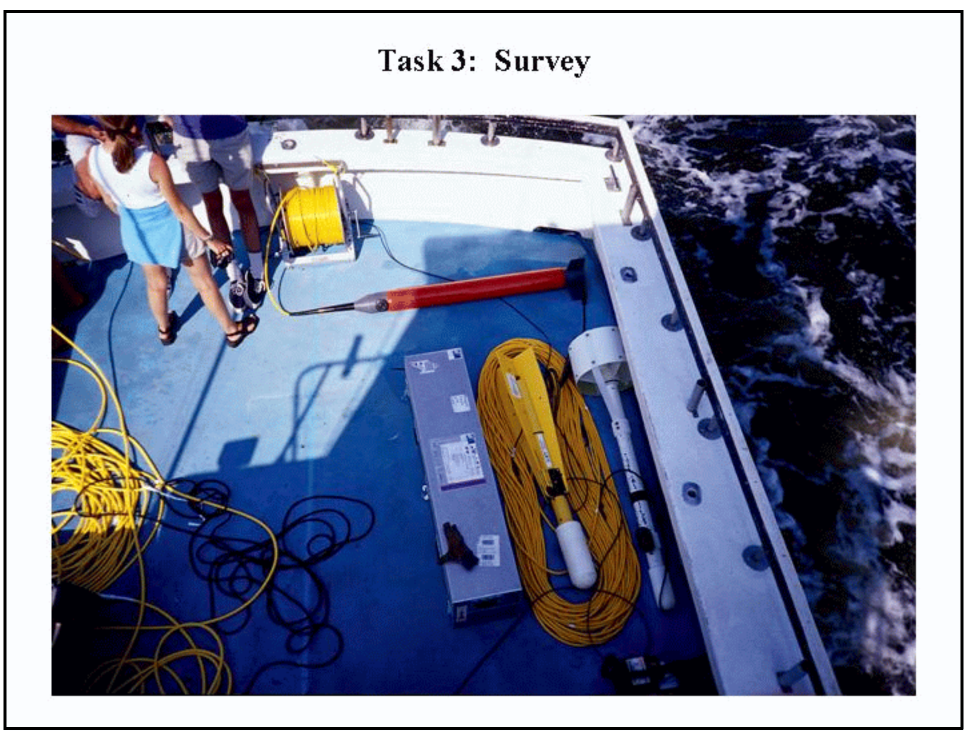

Figure 1C.17. Task 3: survey.

determine the minimally acceptable survey line spacing for detecting historic shipwrecks. Both study aspects are applicable to identifying warranted changes, if any, in the current MMS GOMR survey methodology.

To accomplish these tasks, surveys were conducted over two known shipwrecks, the *Josephine*, shown in Figure 1C.18, a nineteenth-century, iron-hulled sidewheeler located between Ship and Horn Islands south of Biloxi, Mississippi, and the wreck of the *Rhoda*, a nineteenth-century, wooden-hulled bark located in Pensacola Bay. Magnetometers employed and assessed during this investigation stage included the "industry-standard" Geometerics 866, (Figure 1C.19) its

***Josephine* Sidewheeler**

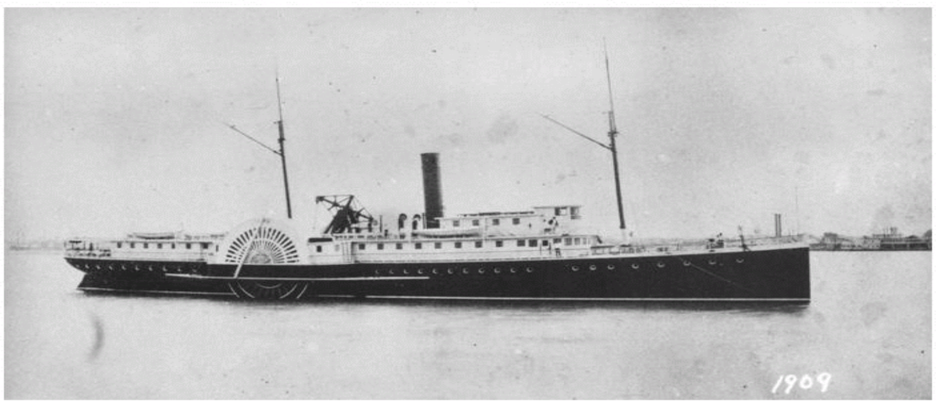

Figure 1C.18. *Josephine* sidewheeler.

866 Magnetometer

Figure 1C.19. 866 magnetometer.

submersible magnetometer base stations were employed to address questions of diurnal variation replacement the new Geometrics 877, (Figure 1C.20), and current state-of-the art magnetometers including the Geometrics cesium 881, (Figure 1C.21) and the Marine Magnetics Sea Spy, an Overhauser-type magnetometer (Figure 1C.22). In addition to the magnetometers, land-based and and its effect on data interpretation relative to the potential need for base stations (Figure 1C. 23).

877 Magnetometer

Figure 1C.20. 877 magnetometer.

881 Magnetometer

Figure 1C.21. 881 magnetometer.

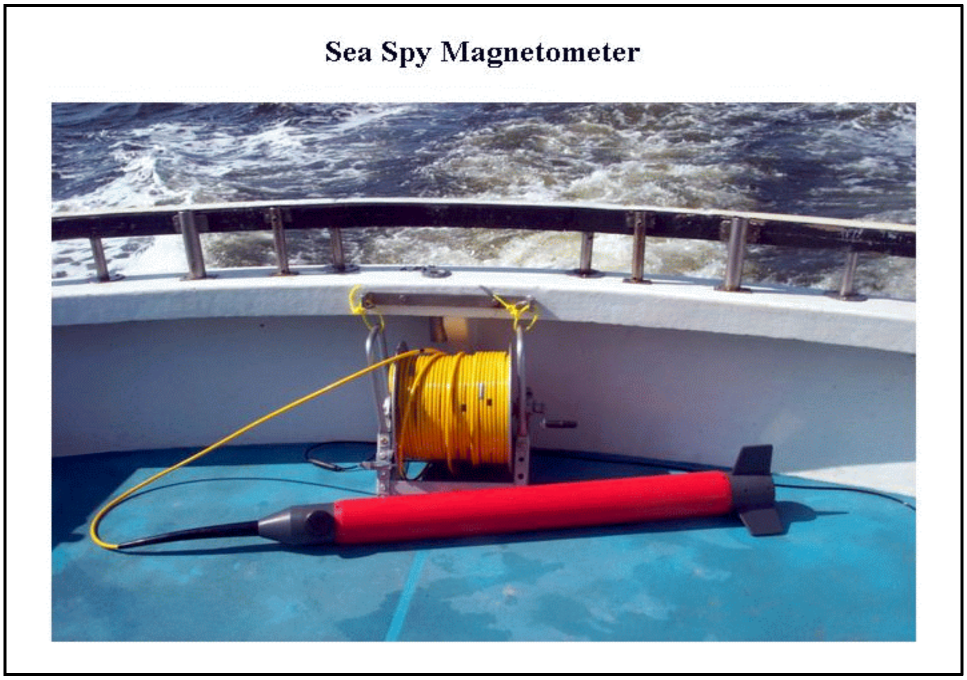

Figure 1C.22. Sea Spy magnetometer.

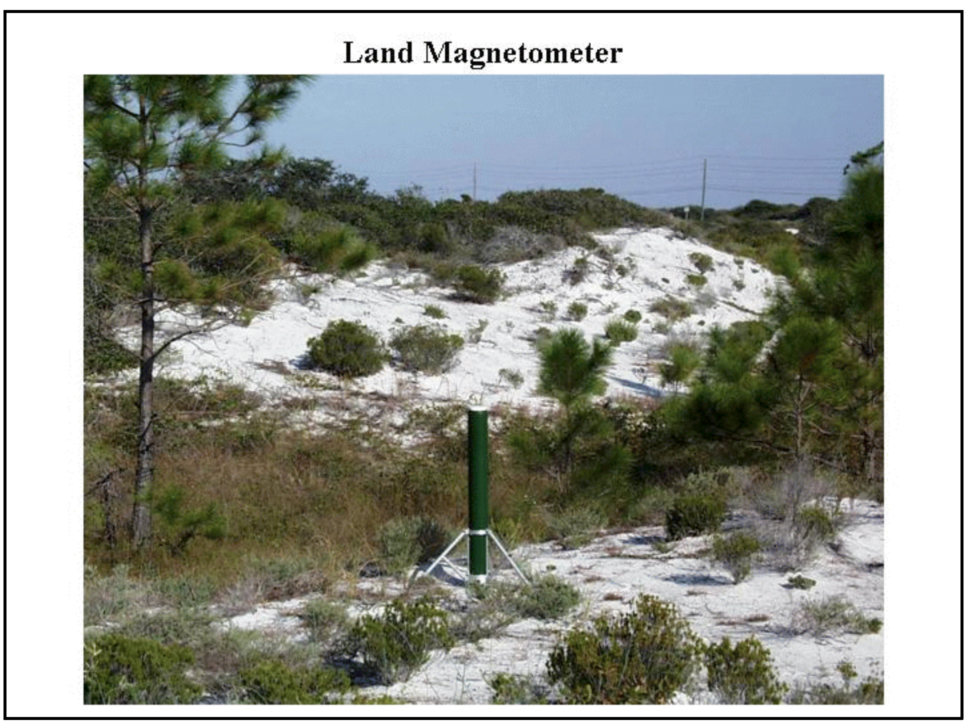

Figure 1C.23. Land magnetometer.

Sentinel Magnetometer

Figure 1C.24. Sentinel magnetometer.

Because land base stations have not been employed by the industry due to constraints of working offshore away from land, a location precluding their use, a Marine Magnetics Sentinel submersible base station was employed to address questions of its functionality as well as comparative results to land base stations (Figure 1C.24).

To address aspects of instrument sensitivity and the maximum or minimum line spacing that allows detection of various wreck types by each instrument, three transect grids were run with each instrument. The larger 600 meter grid was composed of transects spaced at 25 meters out to 150 meters from each wreck and then at intervals of 200 and 300 meters (Figure 1C.25). Two 30-meter grids were run, one at 4 knots and one at 6 knots in an effort to determine if increased speeds affect instrumentation sensitivity (Figure 1C.26).

Although data are currently being edited and assessed, preliminary indications are that differences do exist in magnetometer sensitivities. Figure 1C.27 illustrates the center line of the main grid atop the *Rhoda* for all magnetometers and indicates the difference in sensitivity as reflected in the larger gamma deviations for instruments. Interestingly, the 886 and 881 recorded strengths of 1,100 gamma, while the Sea Spy and 877 recorded strengths of 2,100 and 4,000 gammas respectively. These types of data will also be employed to determine maximum gamma deviation or sensitivity at 25-, 50- and 100-meter transect intervals, with 50 meters being the transect interval now required by the MMS for designated historic shipwreck high probability areas in the GOMR.

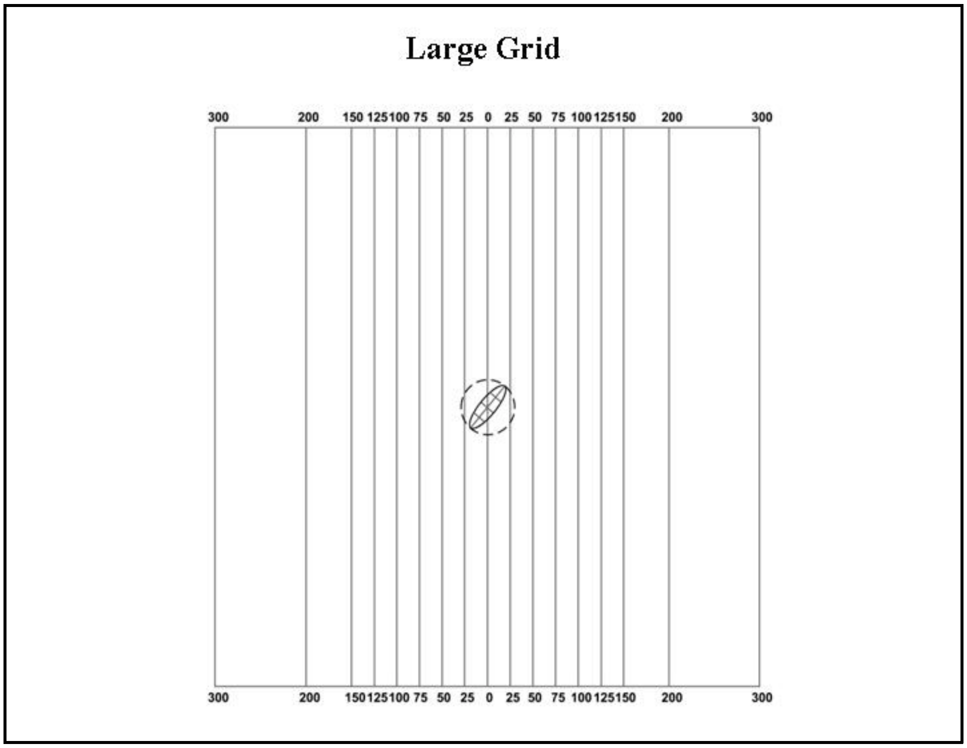

Figure 1C.25. Large grid.

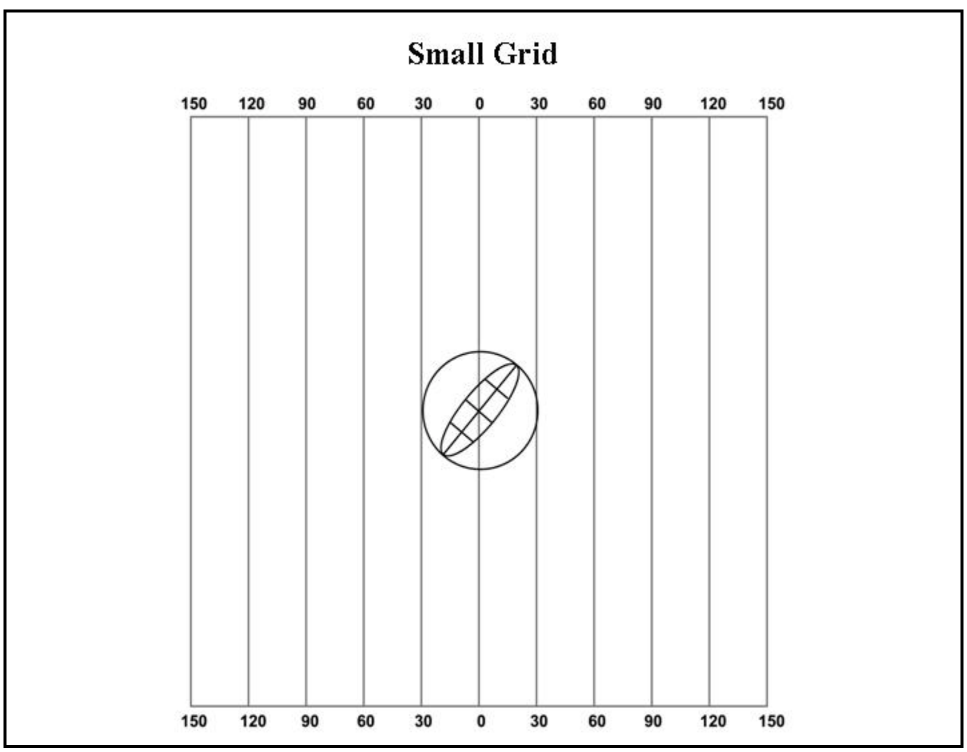

Figure 1C.26. Small grid.

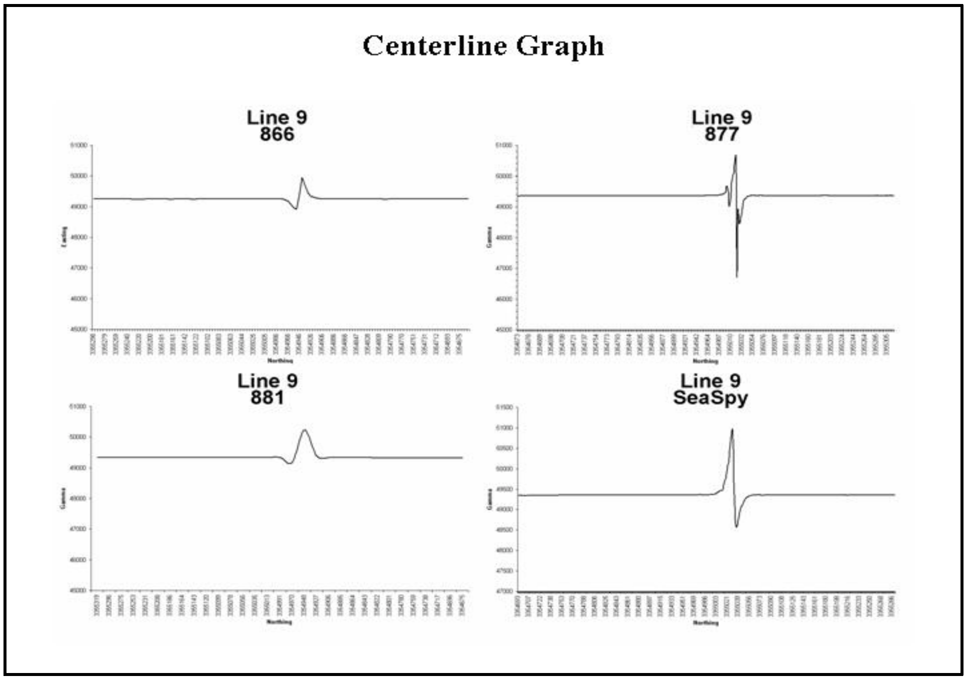

Figure 1C.27. Centerline graph.

Contour maps will also be generated from data for each magnetometer for each survey grid of varying line space (Figure 1C.28). Maps, such as these initial efforts, will be employed to address questions concerning magnetometer sensitivity, survey speed, transect interval, and diurnal variation, as well as issues concerning shipwreck signatures.

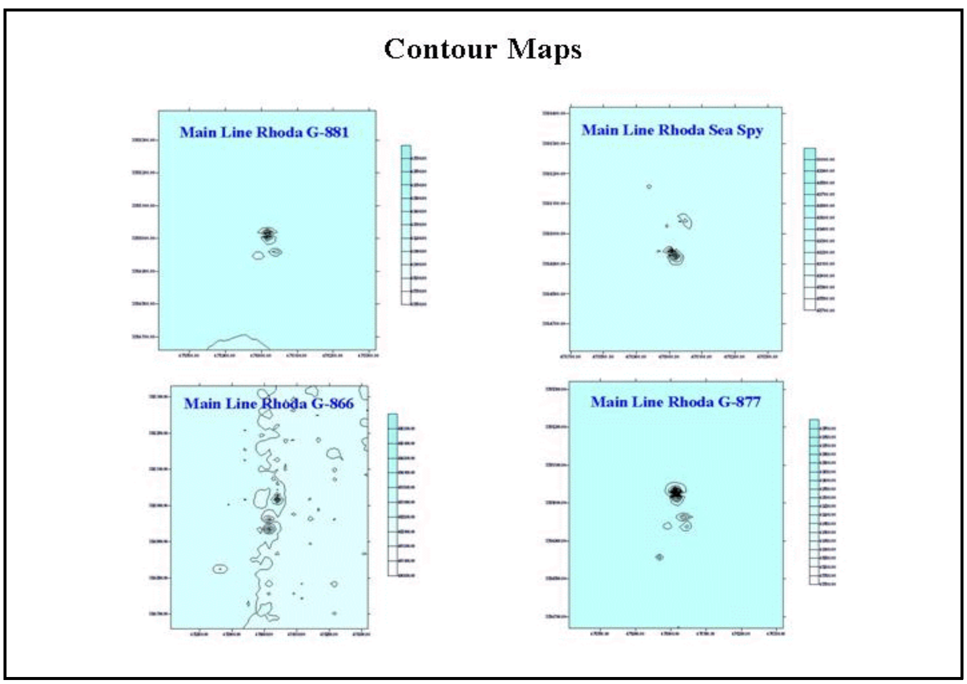

Figure 1C.28. Contour maps.

Currently we are reviewing, comparing, contrasting, and evaluating survey data and once this work is completed, we will make recommendations on survey instrumentation and minimal acceptable line spacing intervals to improve the detection and identification of historic shipwrecks in the Minerals Management Service's GOMR.

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NEW TECHNOLOGY, THE AUV AND THE POTENTIAL IN OILFIELD MARITIME ARCHAEOLOGY

Mr. Daniel J. Warren
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Recent years have seen rapid development in the technology for underwater exploration in the oil, gas, and cable industry. The industry requirement for faster, more detailed surveys and the move toward deepwater explorations has fostered development of various data acquisition systems. Although designed for natural resources and geophysical surveys, these new technologies have also greatly improved the ability of industry archaeologists to detect, document, and protect submerged cultural resources. These technologies will continue to have a significant influence on marine archaeology as they move into mainstream use in this field. Three of the systems that will have the greatest impact are high speed sonar systems, high resolution multibeam systems, and autonomous underwater vehicles.

Initially developed for the military, high speed side scan sonar has moved beyond the limitations of traditional sonar systems. Conventional side scan systems use a single beam per side to generate an image of the seafloor. This results in the decrease in resolution with range and requires speeds of five knots or less to obtain 10% coverage of the seafloor. These drawbacks were overcome in high speed sonar by designing systems that utilize several focused adjacent, parallel beams per side to produce an image of the seafloor. The result of using several beams is that the arrays can be towed at faster speeds and produce higher resolution data than conventional sonars.

The Klein Corporation was the first to introduce a commercial high speed sonar system. The Klein 5500 is a five-beam 455 kHz side scan sonar designed for hydrographic applications. The 5500 system can acquire high resolution imagery of the seafloor and bottom obstructions while operating at tow speeds up to 10 knots.

High speed sonars have two main benefits for both commercial and archaeological applications. The first is the ability to survey at higher speeds without loss of bottom coverage. Operation costs are often dependent on the time needed to conduct fieldwork. Using the new sonar systems, archaeologists can survey at more than twice the speed of conventional sonar allowing larger or more detailed surveys to be carried out. Secondly, the high resolution imagery from these systems can provide archaeologists with finely detailed imagery of underwater sites.

In 1999, while conducting a cable route survey along the Eastern Seaboard of the United States, C & C Technologies Inc. undertook a survey of the Civil War Ironclad, *Monitor,* utilizing the Klein 5500 system. The *Monitor* rests in roughly 200 feet of water off Cape Hatteras, North Carolina. Several passes were made over the site with the Klein system at speeds between six and eight knots. This was the first survey of the *Monitor* shipwreck with this type of high resolution system. The results were beyond expectations. The images clearly show minute details of the wreck including an anchor well, portions of the propeller shaft, damage to the hull, and the gun turret. Copies of these images were given to the National Oceanographic and Atmospheric Administration, which oversees the *Monitor* site, for analysis by their marine archaeologists.

High resolution multibeam systems use hundreds of beams of sound to take extremely accurate bathymetric measurements of the seafloor. Once collected, this data can be processed then combined with visualization software such as Fledermaus to provide a three-dimensional picture of the seafloor. Several high resolution systems already in use or under development have the potential to provide multibeam images nearly as detailed as side scan sonar.

One of the systems currently in use in the oil and gas industry in the Gulf of Mexico (GOM) is the Simrad EM 3000 high resolution multibeam system. The EM 3000 is a 300 kHz multibeam system. It is rated for depths from 0.5 meters to 150 meters below the transducer and has an accuracy of 5 to 10 centimeters throughout the swath width. The EM 3000 has been used to document shipwreck sites such as the S. S. *William Beaumont* off the coast of Texas. Additionally, in 2001 the EM 3000 was used during a pipeline survey in conjunction with side scan sonar to map the locations of several potential sinkholes off the coast of Florida.

The use of high resolution multibeam systems such as the EM 3000 in conjunction with other systems can provide archaeologists with an unique view of underwater sites. Using these systems together, it will be possible for archaeologists much more easily to study distribution and patterning on wreck sites in any depths or conditions of visibility. Also, by having detailed bathymetric maps of the site, it will be easier and less time consuming to develop a feasible site excavation plan.

High speed sonar and high resolution multibeam have had a enormous impact on how surveys are conducted in the oil, gas, and cable industry. But the most significant development has been the recent introduction of the Autonomous Underwater Vehicle or AUV for deepwater exploration. The use of these untethered systems is setting a new standard for underwater surveying in the oil, gas, and cable industry and will in the near future have a significant impact on how deepwater archaeological surveys are conducted.

Traditionally, deepwater geophysical surveys are conducted using a method known as a two-boat shoot. This technique involves having one vessel, usually with a hull mounted multibeam bathymetry system, tow a combined side scan sonar and subbottom system behind the boat while a second boat records the position of the towfish from the signal of and acoustic beacon on the unit. Depending on water depths, this technique can require that several miles of armored cable be let out behind the tow boat to get the array close enough to the seafloor to collect usable data. Utilizing this type of survey, the tow vessel is limited in speed to about two knots due to the amount of cable extended behind the boat and the need to keep the array at depth. Additionally, because of the length of the tow cable, line turns can take anywhere from 4 to 8 hours depending on water depth. Another drawback to this method of deepwater survey is positioning accuracy. Due to the influence of surface conditions on the tow vessel and undersea currents on the towed array along with horizontal USBL inaccuracy, the positioning accuracy of a deep tow system is usually only within thirty meters.

In January 2001 the first commercial AUV rated to a depth of 3,000 meters went into operation in the GOM. This system, the HUGIN 3000 AUV, was developed and built by C & C Technologies, Inc. Lafayette, Louisiana, in conjunction with Kongsberg Simrad of Norway. The HUGIN AUV or High Precision Untethered Geosurvey and Inspection System Autonomous Underwater Vehicle was designed to collect deepwater, high resolution geophysical data for site and route surveys in water depths down to 3,000 meters.

The HUGIN AUV contains a multi-instrument survey payload consisting of a Simrad EM 2000, a 200 kHz Swath Bathymetry system, dual frequency Edgetech Side Scan Sonar systems (120 kHz and 410 kHz), and an Edgetech Chirp Subbottom Profiler. Primary positioning of the AUV is accomplished using an inertial guidance system. This system uses precision gyros and accelerometers to maintain the AUV track of the mission plan. The AUV is also equipped with two acoustic modems, one providing a command link by which the systems of the AUV can be adjusted or the mission changed by commands from the mothership. The other modem is used to provide the mother ship with real time displays of the data being collected.

The AUV has several advantages over the traditional deep tow system. First, since the vehicle is untethered, there is no need for long expensive armored cable or a second boat for positioning. Secondly, because it is not tethered and has an internal positioning system, the AUV is able to survey at constant depth and stay online even in adverse sea conditions and currents. This allows a much higher accuracy for positioning during a survey. The accuracy of the AUV is within three to six meters at 1,400-meter water depth following post processing as compared to thirty meters with a deep tow. Finally, surveying with the AUV is much faster than with a deep tow system. The AUV can travel at up to four knots and takes only five minutes to make a line turn as compared to the deep tow that operates at two knots and takes several hours to make a line turn.

The applications of the AUV for archaeological surveys fall into two categories: area reconnaissance surveys and site specific surveys. The effectiveness of the AUV in these types of survey was shown in early 2001 during a route survey in Mississippi Canyon Area of the GOM for British Petroleum and Shell International. An initial survey had located a shipwreck of the passenger-freighter *Robert E. Lee* but did not locate another shipwreck known to be in the vicinity. An additional area survey was conducted to locate this second wreck site. The AUV surveyed a 1.5 by 2 mile area and was able to locate and collect imagery of the second wrecksite as well as additional data on the *Robert E. Lee*. This tasked was accomplished by the AUV in just under nine hours. The same task would have taken over three days of constant surveying with a deep tow system. An additional survey of the second wreck was undertaken following concerns that its attributes did not match those of the vessel that was suppose to be at this location. This survey carried out in approximately 2 hours consisted of the running of 33 tracklines spaced 10 meters apart. This type of site specific survey would be for all practical purposes impossible with a deep tow system since a single line turn would take up to four hours, and positioning would not be adequate to maintain 10-meter line spacing. Based on the data collected during the site-specific survey, the second area of wreckage was determined not to be that of a freighter *Alcoa Puritan* as was first thought, but the remains of the German U-boat, *U-166*. These findings were later confirmed by an ROV investigation of the site.

The development of new technologies in underwater exploration has led to new systems that have archaeological as well as commercial applications. The move toward the use of autonomous underwater vehicles will allow more deepwater sites to be explored and documented. Additionally, it is likely that eventually as AUV technology progresses and new systems developed, AUVs will become the standard in shallow water surveying as well, taking the place of towed systems all together. As these systems move beyond industry-specific uses and into the mainstream of use, archaeologists will develop new techniques and survey methods to utilize their full potential to locate and document submerged cultural resources.

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UNRAVELING THE MYSTERY: THE DISCOVERY OF THE U-166

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HISTORIC BACKGROUND

In the spring of 1942 the war was going well for Nazi Germany as Hitler launched Operation Drumbeat. Using the might of Germany's *Unterseebootes* the new operation would take the war to the coasts of America as his predecessors had done in World War I. Unlike World War I, however, the U-boats would not be limited to the east coast of the United States, but would extend their destruction to America's soft underbelly, the Gulf of Mexico (GOM) (Miller 2000).

Hitler left the running of Operation Drumbeat to Karl Dönitz, the commander of the Krieggsmarine as the German Navy was known. In May 1942 with the sinking of the *Norlindo* by *U-507*, a wave of destruction began in the GOM that in just under 12 months would see 17 U-boats send 56 merchant vessels to the bottom and severely damage 14 others. Two of the vessels that fell victim to this onslaught were the cargo freighter *Alcoa Puritan* and the passenger freighter *Robert E. Lee* (Wiggins 1995), Figure 1C.29.

Figure 1C.29. SS *Robert E. Lee*, 20 January 1942. 5,184-ton, 375 ft. x 55 ft. Photo courtesy of the Mariners' Museum, Newport News, Virginia.

Korvettenkapitän Harro Schacht, commanding U-507, was the first U-boat commander to enter the GOM. On 6 May 1942, Schacht, sank his fourth ship in the Gulf. At 11:55, he attacked the *Alcoa Puritan* as she was in route from Port-of-Spain, Trinidad to Mobile, Alabama with a load of bauxite. The first torpedo missed and the alarm was sounded. The captain of the *Alcoa* immediately ordered full speed (about 16 knots) and turned his ship to present as small a target as possible to the U-boat. U-507 surfaced and began pursuit at about 18 knots, slowly overtaking the freighter. At a distance of about a mile the crew of U-507 opened fire with their deck gun. Over the next forty minutes, the U-boat expended nearly seventy-five rounds, scoring approximately fifteen hits, and disabling the *Alcoa Puritan*'s steerage. The captain brought the crippled freighter to a stop and gave orders to abandon ship. After all the crew made it off the freighter, U-507 moved in and finished the ship off with a torpedo. The *Alcoa Puritan* sank stern first in approximately eight minutes. The U-boat approached within 100 yards of the survivors and a German officer shouted through a megaphone, "Sorry we can't help you. Hope you get ashore." He then waved as U-507 sailed away. About 3 1/5 hours later the survivors were rescued by the U.S. Coast Guard cutter *Boutwell* (Browning 1996).

A few months later, in July, the passenger freighter *Robert E. Lee* left Trinidad with limited cargo and approximately 270 passengers, many of whom were American construction workers or survivors of other U-boat attacks in the Caribbean. She carried approximately 131 crewmembers and 6 armed guards, who manned a deck gun mounted on the stern of the vessel. She came up through the Caribbean with a convoy then continued into the GOM with a naval escort vessel, Patrol Craft 566. Lieutenant Commander H. C. Claudius was in command of PC-566. She was a newly commissioned vessel and her first mission was to escort the *Robert E. Lee* through the GOM (USS PS-566 1942; and Henderson 1942).

Late in the evening on July 29 they neared Tampa, Florida for a scheduled stop. The passengers asked Captain William C. Heath of the *Robert E. Lee* to allow them to disembark at Tampa to escape the miserable conditions on board the overcrowded freighter. Captain Heath agreed, but when a pilot was unavailable to guide the boat into the Tampa harbor he decided to continue on to their final destination of New Orleans, Louisiana. With the decision to continue to New Orleans the naval escort broke radio silence to notify the Gulf Sea Frontier command (The military command that oversaw wartime shipping activities in the GOM) that the *Robert E. Lee* was proceeding to New Orleans. The escort was ordered to continue with the *Robert E. Lee*. (Talbot-Booth 1942; Wiggins 1995; and Browning 1996).

In July 1942 there were at least ten U-boats operating in the GOM. One of these was the *U-166* commanded by Hans-Günther Kühlmann. The *U-166* had been laying mines off the mouth of the Mississippi for several days. On 27 July 1942 Kühlmann radioed the German Subcommand that he had finished his mine-laying operation. Although no further messages were received from Kühlmann after July 27 it is presumed that the *U-166* took up position to attack shipping coming into or out of the Mississippi River. On 30 July the *U-166* was prowling along the shipping lanes as the *Robert E. Lee* and PC-566 steamed toward New Orleans (War Diary 1942 and Garrison 1989).

The skies were clear and the sea calm on the evening of 30 July as the *Robert E. Lee* neared the Mississippi River. Around 4:30 p.m. and only 45 miles from Southwest Pass the passengers must have been anticipating their arrival in New Orleans when a few of them saw something in the water streaking towards their vessel. They questioned each other about whether it could be a shark or perhaps a dolphin, but it was a torpedo. The German “eel” slammed into the starboard side of the vessel, exploding just aft of the engine room. The ship began sinking quickly and many of the passenger and crew frantically donned life jackets then jumped overboard into the Gulf waters. Amidst the chaos, members of the crew managed to lower six lifeboats and sixteen life rafts that were quickly overloaded with survivors (Henderson 1942).

The crew of the escort vessel, traveling approximately a half-mile ahead of the *Robert E. Lee*, had been radioing New Orleans for a pilot when the attack occurred. Immediately PC-566 went into action. The Patrol Craft raced to the area where they had last spotted a periscope and the crew dropped a spread of five depth charges. After coming about they gained sonar contact on the U-boat and maneuvered to drop another spread of depth charges. Upon coming around for the second attack, Lieutenant Commander Claudius noted the *Robert E. Lee* had already disappeared beneath the water leaving only lifeboats and scattered debris to mark the location. It is estimated that the freighter sank within five to fifteen minutes of being hit. Following the escort’s attack on the U-boat an oil slick was reported and no further signs of the U-boat were observed. Feeling that the U-boat was no longer a threat, the crew of *PC-566* turned to the task of rescuing the survivors of the *Robert E. Lee*. (Henderson 1942; and Wiggins 1995).

Soon search planes appeared overhead to help watch for the U-boat and direct other rescue vessels to the site. Just after 8:30 p.m., two addition vessels, SC-519 and the tugboat *Underwriter*, joined the rescue operation. The *Underwriter* had just arrives at the pilot station to reopen South Pass when the request came to help. Bar pilot Captain Albro Michell recalled the events:

> South Pass was closed during the war and we had gone down to open it back up. We had just arrived at the pilot station when we were asked to go out and help in the rescue of a boat that had been torpedoed… . We took about 50 to 60 passengers off the naval ship onto the *Underwriter*. The seas were dead calm, otherwise we would not have been able to transfer the victims. Someone was watching out for them… .
>
> When we were asked to go out we only knew a ship had been torpedoed. We still had the provisions onboard for the pilot station; we didn’t have time to unload them. The survivors were hungry and ate all the provisions on the way into Venice (Michell 2001).

The survivors were transported to Venice, Louisiana then by bus and ambulance to the New Orleans hospital. As a result of the U-boat attack, 15 passengers and 10 crew were lost, including Winifred Grey of New Orleans, one of the few women merchant marine to be lost in wartime action in the GOM (www.usmm.org).

On 1 August two days after the *Robert E. Lee* was sunk, Coast Guard aviators, Henry White and George Boggs were on patrol in their Grumman J4F seaplane out of Houma, Louisiana. At about 1:30 PM they spotted a German U-boat on the surface. Immediately they radioed their position south of Isles Dernieres, Louisiana and began an attack run on the enemy vessel. The U-boat initiated a crash dive and was quickly slipping beneath the surface. When the plane neared 250 feet, White yelled “NOW!” and Boggs released the charge. He reported seeing the charge detonate near the vessel and a light to medium oil slick appeared on the surface of the water. After returning to base White and Boggs were instructed that the incident was classified and not to speak of it further. At the end of the war they were told that it was the *U-166* they had sunk that day (Wiggins 1995; “Baseball” 1943).

But was it? The entire premise that the *U-166* was sunk that day in August is based entirely on the fact that the *U-166* never returned from its war patrol and was never heard from again. No other evidence supports the claim. The last radio message from the *U-166* was on 27 July 1942 three days before sinking the *Robert E. Lee*.

The area in which the *U-166* is thought to have been sunk, is probably one of the most surveyed regions in the world. Oil and gas development in the area have led to numerous intensive surveys using various means or remote sensing instruments. For decades individuals, companies, and governments have extensively searched the area for the *U-166*. In 1997 a team from Germany came to search for the U-boat, but no trace of the *U-166* was identified (www.uboat.net; and McNamara 2000).

OIL AND GAS SURVEYS

In 1986, Shell Offshore, Inc. was conducting oil and gas exploration in the Mississippi Canyon Area of the GOM. They contracted John Chance and Associates to conduct the survey using a deep-tow side scan sonar. While performing the survey they detected two shipwrecks, which they identified as the *Robert E. Lee* and the *Alcoa Puritan*. The two sunken vessels would remain identified as such for the next sixteen years.

In January 2001, C & C Technologies, Inc. (C & C) conducted a deep-water pipeline survey for British Petroleum (BP) Amoco and Shell International in the vicinity of the reported location of the *Robert E. Lee* and *Alcoa Puritan*. This survey was conducted using C & C’s new HUGIN 3,000 AUV (High Precision Untethered Geosurvey and Inspection System, Autonomous Underwater Vehicle). The HUGIN 3000 is the world’s first commercially operated AUV capable of surveying to 3000 meters water depth. It is untethered; therefore, it can operate even in rough seas at faster speeds with greater mobility and accuracy than conventional towed arrays. Operating in 5,000 feet of water C & C’s AUV is accurate to within 9 feet after post processing. Conventional towed systems are typically only accurate to 100 or more feet at the same water depth. The AUV utilizes a state-of-the-art multibeam bathymetry and imagery system, a dual frequency chirp side scan sonar, chirp sub-bottom profiler, a inertial navigation system coupled with the precision HiPAP (High Precision Acoustic Positioning) acoustic tracking system.

During the January survey, a large shipwreck was detected at the edge of the AUV’s survey corridor in 5000 feet of water. C & C Marine Archaeologists Robert A. Church and Daniel J. Warren contacted the United States Department of Interior, Minerals Management Service (MMS) to verify the identity of the vessel as the *Robert E. Lee*. C & C asked their clients if they could run a few investigation lines around the *Robert E. Lee* and the reported location of the *Alcoa Puritan*. BP and Shell not only responded favorably to the additional investigation they decided to have C & C conduct a 2 mile by 1.5 mile investigation survey in the area to precisely position any wreckage or out lying debris of both shipwrecks. This survey was conducted in March 2001 and addressed the archaeological and engineering concerns of the companies. The investigation survey consisted of 17 survey lines at 492-foot (150 meter) line spacing for a total of 31.7 nautical line mile. Using the AUV the entire investigation survey took less than 9 hours to complete, a fraction of the 72 hours a conventional deep-towed system would have required.

Upon completion of the offshore work the data from the archaeological survey was reviewed by the C & C's marine archaeologists. As they began analyzing the data the archaeologists realized that the debris scatter formerly identified as the *Alcoa Puritan* did not match the characteristics of a 6,759-ton freighter. The target consisted of two large sonar contacts with debris of various size scattered between them. The largest section of debris measured approximately 200 feet long and 20 feet wide. The other large section measured approximately 55 feet long and 20 feet wide. This made a combined length of approximately 255 feet, just over half the length of the *Alcoa Puritan,* which was 397 feet long by 60 feet at beam. Based on this data Church and Warren were doubtful the target was the *Alcoa Puritan*, but realizes it did match closely to the dimensions of a Type IX-C German U-boat (Figure 1C.30), as was the type of U-166.

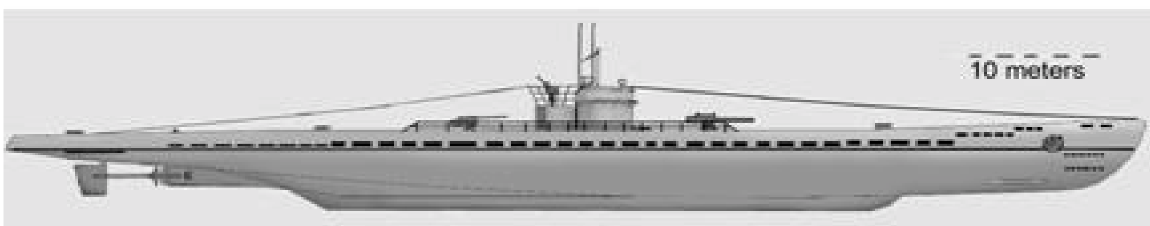

Figure 1C.30. Type IXC German U-boat. Length = 252 feet (76.76 meters), Beam = 22 feet (6.76 meters)

A NEW INTERPRETATION

The data from the AUV provided circumstantial evidence to support the *U-166* hypothesis. But, it did not seem reasonable to locate the *U-166* 140 miles away from where it was reportedly bombed and within less than a mile of the U-boats last victim. One possibility to explain the discrepancy was put forward by the archaeologists. What if the crew of the *PC-566* were far luckier on 30 July than anyone had given them credit and had actually sunk the *U-166* instead of just chasing it off as was presumed? If this was the case then what U-boat was bombed by White and Boggs on 1 August and what happened to that vessel?

Further research revealed there were three U-boats operating in the GOM on 1 August 1942 (*U-166*, *U-509*, and *U-171*). The *U-166* sank in the GOM with no survivors. Only infrequent radio transmissions provide clues to the *U-166*'s activities in the GOM, but if it was sunk by PC-566, then the Coast Guard could not have attacked it two days later. *U-509* did not venture very far into the

Gulf and did not sink any shipping during that patrol. It arrived safely back in Lorient, France on 12 September 1942 with no incident mentioned of a seaplane attacking them on 1 August. The only other boat known to remain in the Gulf at this time was the *U-171* commanded by Günther Pfeffer (War Diary 1942; and www.uboat.net).

The *U-171* arrived at its assigned area of operation between Galveston and New Orleans on 23 July 1942. Pfeffer's objective was to sink shipping coming into and out of the Port of Galveston. However, he found that the waters off Galveston were too shallow and radioed that he was moving toward the New Orleans area. Pfeffer found success off the Louisiana coast, sinking the *R. M. Parker, Jr.* on 13 August 1942. Curiously the attack on the *R. M. Parker, Jr.* took place within three miles of the location that White and Boggs made their attack on a U-boat (Wiggins 1995). On 9 October 1942, while returning from their patrol in the GOM, the *U-171* struck a mine and sank in the Bay of Biscay. Pfeffer along with twenty-nine crewmen survived, but twenty-two crewmen and the Captain's logs went down with the vessel. In reconstructed logs Pfeffer mentioned that between July 27 and 13 August 1942 a "flying boat" had dropped one depth charge on them and they escaped with no damage (NARA, *U-171*). From this research the archaeologist surmised that White and Boggs bombed the *U-171* on 1 August 1942. It also seemed probable that the debris to the east of the *Robert E. Lee* was the remains of the *U-166*, which *PC-566* sank following the attack on the *Robert E. Lee*. According to the Action Report of *PC-566*, Lieutenant Commander Claudius and his Executive Officer, D. Howard felt they had sunk or severely crippled the U-boat. Furthermore, Claudius stated that they "believed that the submarine was watching the sinking of the SS *Robert E. Lee* and had not been aware of our [PC-*566*] presence." It was not until the U-boat heard the ping of the sonar that they began to dive. If *U-166* was not expecting the naval escort, then it is doubtful the U-boat had overheard the radio transition sent by PC-*566* the previous day.

FURTHER INVESTIGATIONS

With the new hypothesis, C & C informed their clients, BP and Shell, that they might have found the long sought after U-boat. C & C, BP, and Shell then held a meeting with the MMS to fully disclosed the information. In light of the possibility of the new discovery, BP and Shell sponsored further site investigations of the *Robert E. Lee* and the suspected *U-166* site using the AUV (Figure 1C.31). The additional investigation provided sonar and bathymetry images and provided further evidence supporting the *U-166* hypothesis. The conning tower and deck guns of a U-boat could clearly be recognized from the 410 kHz sonar images. The bathymetry data showed that the U-boat was lying in what appeared to be a six-foot deep impact creator. Because the possibility that the site represented a significant historical wreck, ground truthing was warranted with a Remotely Operated Vehicle (ROV) for final verification of the remains.

On 31 May and 1 June 2001 a research team from C & C, BP, Shell, and the MMS conducted an ROV survey of the SS *Robert E. Lee* and the suspected site of the *U-166*. The archaeologist from C & C were joined by marine archaeologist Jack Irion and Richard Anuskiewicz of the MMS for the expedition. The research team left onboard the *Gary Chouest*, an anchor-handling vessel on contract to Shell, which was equipped with Oceaneering's Millennium VI ROV. After reaching the site, it took a hour to lower the ROV to the seafloor. The researchers setup about 200 feet south of

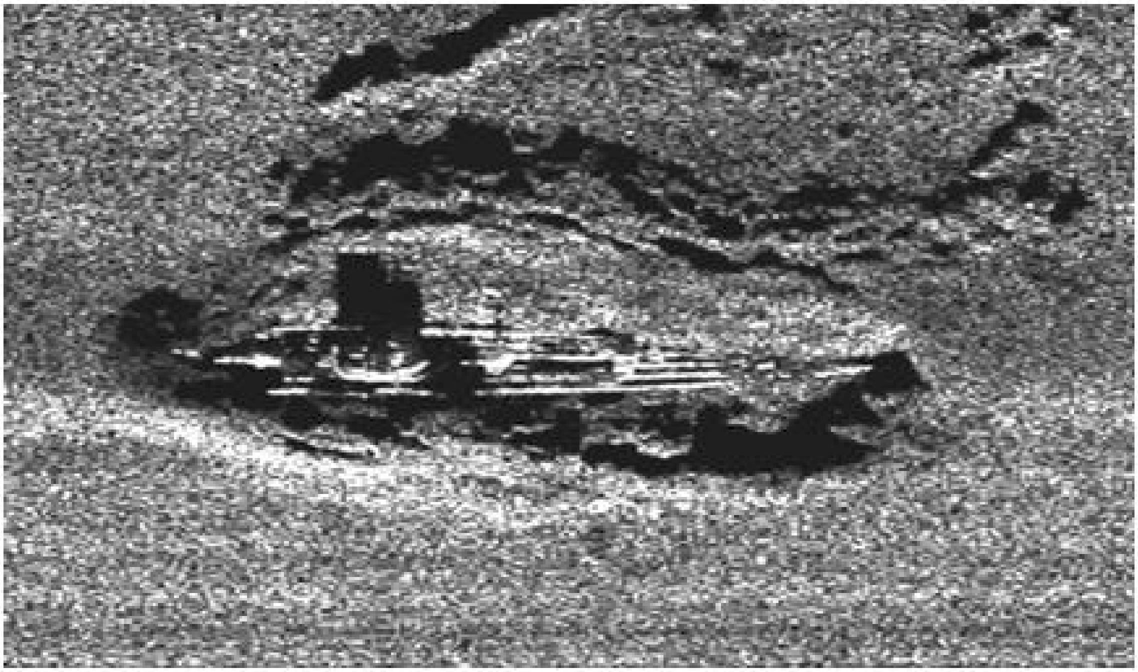

Figure 1C.31. AUV 410kHz side scan sonar image, ROV survey.

the U-boat and slowly moved the ROV across the seafloor toward the wreck site. The first image of the U-boat was the side of the conning tower looming out of the darkness.

The conning tower and stern appear to be in tacked and in good order. This section is deeply imbedded in the seafloor, only with the top of the deck, conning tower and deck guns visible. The conning tower is in excellent condition with the splashguard and railing of the wintergarden showing little or no damage. The 105mm deck gun, 37mm and 20mm antiaircraft guns are in place and clearly visible. The teak decking that once covered the deck frame is no longer present, having likely been eaten away by biological organisms.

After completing a thorough investigation of the stern section and conning tower, the research team relocated the ROV to the separated bow section, which lies 490 feet to the west-northwest. The bow section provided a reveling glimpse of what caused the U-boat to plummet to the seafloor. Just forward of where the forward torpedo-loading hatch would have been, a large indentation is visible in the deck. This damage appears to be the result of a depth charge explosion. The jagged metal where the bow tore away from the rest of the vessel is flared outward as if caused by an internal explosion. The evidence at the bow suggests a depth charge exploded almost right on top of the deck, rupturing the pressure hull. That event in turn caused an internal explosion, possibly from an armed torpedo or from salt water rushing into the battery room, both of which were present in that location of the U-boat. There is a large amount of scatted debris between the two sections of the U-boat, including what appear to possibly be two torpedoes partially protruding from the seafloor.

The ROV was then moved over to the site of the *Robert E. Lee*. As the stern of the vessel came into view, there was no doubt we were looking at the passenger freighter. The ROV maneuvered around the entanglements of the structure, collecting detailed video images of the final resting place of the *Robert E. Lee*. The deck gun on the stern was seen, which the eight man gun crew manned. Two lifeboats were videoed lying off to the port side of the ship. A large scatter of debris surrounds the freighter. During exploration of the debris field an unexpected discovery was made in the late hours of the survey. About 1:00 in the morning we moved the ROV toward a piece of debris lying over 200 feet off the port side of the *Robert E. Lee*. The first thing that came into view as we approached the unknown debris was a bit of metal framing lying on the seafloor. Then as the camera panned around, there stood the telegraph off the bridge of the *Robert E. Lee* (Figure 1C.32). It was an unbelievable find, just standing all alone on the seafloor just as if it were still on the bridge. Made of brass, it was in pristine condition and the words on the face of the telegraph could still be read. The indicator arrow from the engine room was locked in the “STOP” position, indicating that the “All Stop” command was sent and executed before the ship went down. The handle, however, was pulled back into the “FINISHED WITH ENGINES” position, a command that was never executed. This left the researchers to speculate that as the ship was sinking the bridge officer possibly pulled the handle back to that position out habit before leaving the bridge.

The new technology of the AUV, the historical research, and the combined efforts of the expedition team, positively identified the final resting-place of the *Robert E. Lee* and the *U-166*, solving one

Figure 1C.32. Bridge telegraph of the *SS Robert E. Lee* as found on the seafloor, 1 June 2001.

of the great historical mysteries of World War II in the GOM. On 30 July 1942, 25 lives were lost from the *Robert E Lee* and 52 German sailors from the U-boat. As the news of the discovery spread to the surviving family members it helped bring some closure to questions gone unanswered and some vindication for the crew of PC-*566* over credit never given. One of the unique elements of this archaeological site is that it tells the whole story of the U-boat war in the GOM. The hunter, U-166; its last victim, the *Robert E. Lee*; and the lifeboats representing the survivors are all found within a mile from each other on the seafloor. Now the history has been rewritten and story set straight with the discovery of the U-166.

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GEOPHYSICAL REMOTE SENSING AND UNDERWATER CULTURAL RESOURCE MANAGEMENT OF SUBMERGED PREHISTORIC SITES IN APALACHEE BAY: A DEEPWATER EXAMPLE, SITE PREDICTIVE MODELS, AND SITE DISCOVERIES

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ABSTRACT

This paper briefly describes progress made in finding and investigating prehistoric sites in open ocean settings over the continental shelf of Northwestern Florida. It presents an example of "deep" water survey near the proposed "Clovis Shoreline" (40 meter isobath) conducted in 2000 and 2001, as well as submerged prehistoric site archaeology practiced in shallower water in Apalachee Bay since 1986. A significant number of sites and artifacts have been located on Florida's western continental shelf as part of this programmatic research. These sites represent Paleoindian and Archaic occupations of the shelf when it was exposed by lowered sea levels during the last glacial maximum.

INTRODUCTION

This paper briefly describes progress made in finding and investigating prehistoric sites in open ocean settings over the continental shelf of Northwestern Florida. It describes beginning archaeological research in "deep" water near the proposed "Clovis Shoreline" (at the 40 meter isobath), as well as abundant work conducted in shallower water since 1986. In other areas of the Gulf of Mexico (GOM), the sites reported here would be in federal waters, but in this area they are in submerged lands that belong to the state of Florida to a distance of 9 nautical miles. It is my opinion that this work can be a useful analog for resource managers in Alabama, Mississippi, and Louisiana, even though the sediment loads there are more substantial.

Professional cultural resource managers are more and more in need of examples of procedures, protocols, and practical experience with marine submerged prehistoric sites because of increased offshore mining of sand to replenish beaches, and other infrastructure and resource procurement projects. There are prehistoric sites threatened by this dredging. It is a fact that state and federal laws protect these resources like any other cultural resources. There is a robust interest in and practice of finding and managing historic shipwrecks in the cultural resource management community. The failure to consider submerged prehistoric sites is due in part to the historic lack of a formal academic discipline of this kind of study and the lack of experienced researchers and consultants.

Because of modern remote sensing and excavation equipment, increased research funding, and continued forays offshore, faculty and students at Florida State University are having good success at finding and managing marine submerged prehistoric sites and understanding the physiographic and stratigraphic character of the submerged landscape within which they occur. A set of procedures for finding and managing marine submerged prehistoric sites has been developed from research conducted since 1986.

This paper provides background on principles of finding submerged prehistoric sites, details of local sea level rise that are relevant to knowing where to find sites of different ages, and a very short description of the ages of cultures available in the local prehistory. Deepwater research seeking the Clovis Shoreline in federal waters is described next. The paper concludes with a summary of our findings in more near-shore state waters.

Experience has shown that offshore sites are predicted by local models of terrestrial geology and archaeology, combined with a knowledge of local sea level rise and local bottom morphology. This information can be collected for areas with early occupation expressed terrestrially, and in some cases it may be possible to follow specific occupation patches offshore in specific drainages (such as the PaleoAucilla example presented here). Another part of the procedure is to conduct remote sensing, coring, and induction dredge operations to find, characterize, and study the paleo-topography and sedimentary sequences locally.

This methodological sequence has been a fruitful approach in our work with the PaleoAucilla drainage system in the Apalachee Bay (Figure 1C.33). By modeling the kinds of environments, sites, time periods of exposure, and culture groups that might be represented and finding sites on the continental shelf, we contribute information to incorporate into local site file inventories and cultural historical and processual reconstructions.

Figure 1C.33 shows the distribution of late Pleistocene and early Holocene archaeological sites in Florida, and the extent of the Floridian continental shelf and the bathymetric contours that represent paleo-shorelines at various stages of the transgression process. While there may be some subsidence due to accumulated sediment and water weight since submergence (Stright 1995), and some movement due to karstic solution uplift (Opdyke *et al.* 1984), the Florida continental shelf platform is considered “stable.”

Figure 1C.34 shows radiocarbon controlled sea level curves for the GOM, and Caribbean. Three curves come from the western GOM (Curray 1965; Frazier 1974; Nelson and Bray 1970) and one from Barbados (Fairbanks 1989). There is a short 8,000 to 6,000-rcybp sequence suggested by this research program for the northwestern continental shelf (Faught and Donoghue 1997). Some time between 5,000 and 4,000 rcybp sea levels were at today’s levels in the Big Bend.

The continental shelf of the Big Bend of Florida is a drowned karst landscape submerged by a relatively low energy open ocean (CEI (Coastal Environments) 1977; Rupert and Spencer 1988). The seafloor bottom is somewhat like a basin and range landscape. Limestone outcrops of various relief and scale are interspersed by plains of coarse shelly sand and beds of sea grass growing in fine-grained organic sediments. The general trend of the bottom is flat but there is relief over long distances, particularly in the vicinity of paleochannels. Rock out crops can be from a few centimeters to 80 cm in height, sandy plains can cover karst voids of various relief.

Work by Ballard and Uchupi (Ballard and Uchupi 1970) indicates several paleocoastal features (shore-face erosion ledges and drowned barrier islands) at certain depths on the western Floridian continental shelf (that is at 160, 60, 40, 32, and 20 meters; Figure 1C.33 and Figure 1C.34). Full glacial lowering of

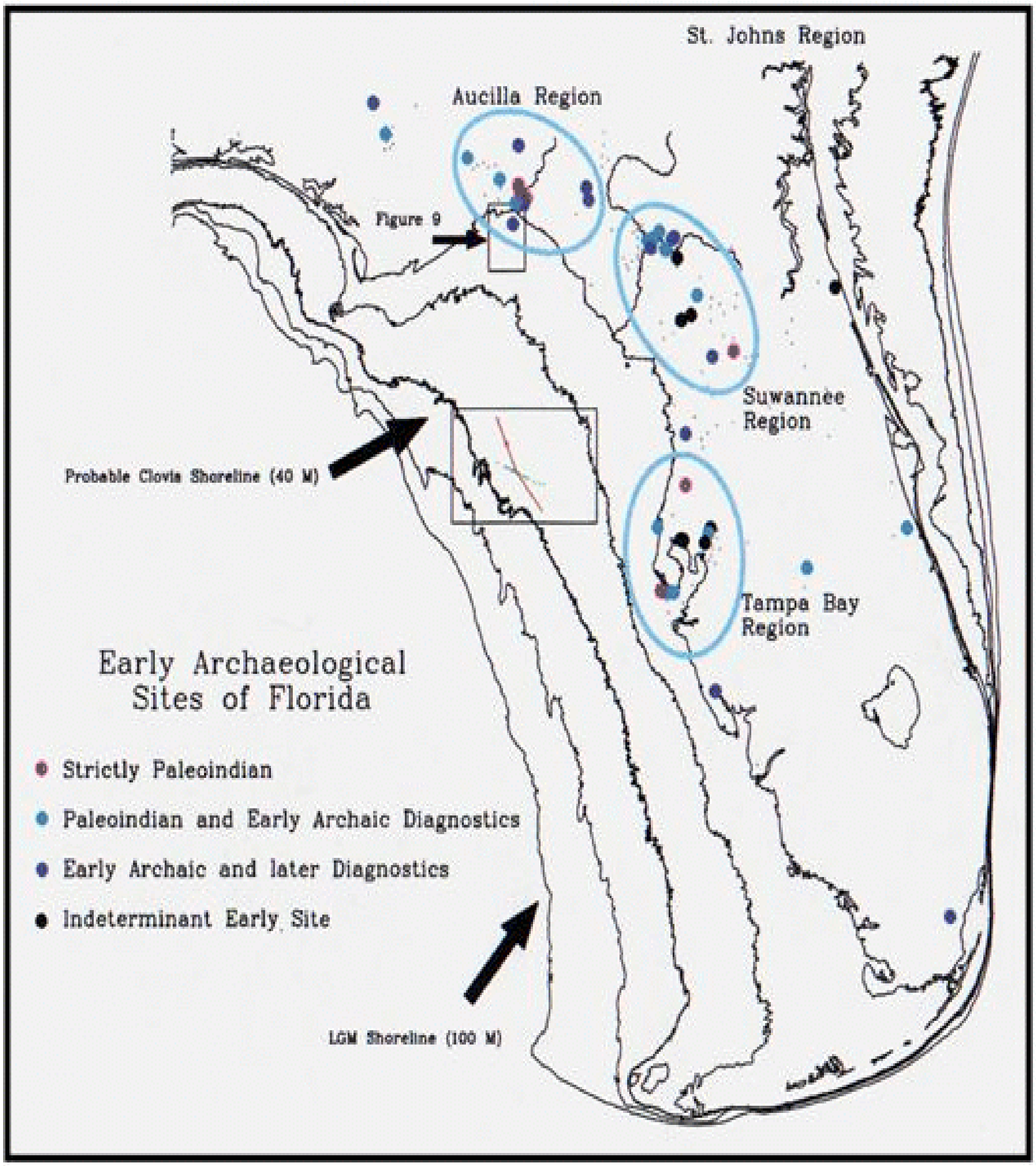

Figure 1C.33. Peninsular Florida, showing the distribution of find spots and excavated sites of Paleoindian and Early Archaic archaeological sites on land. Bathymetric contours at 20 meter intervals. The 40-meter contour is possibly the Clovis Shoreline (Dunbar *et al.* 1992; Faught and Donoghue 1997). Two research areas are shown: the southern area is that of Figure 1C.35, the northern of Figure 1C.36.

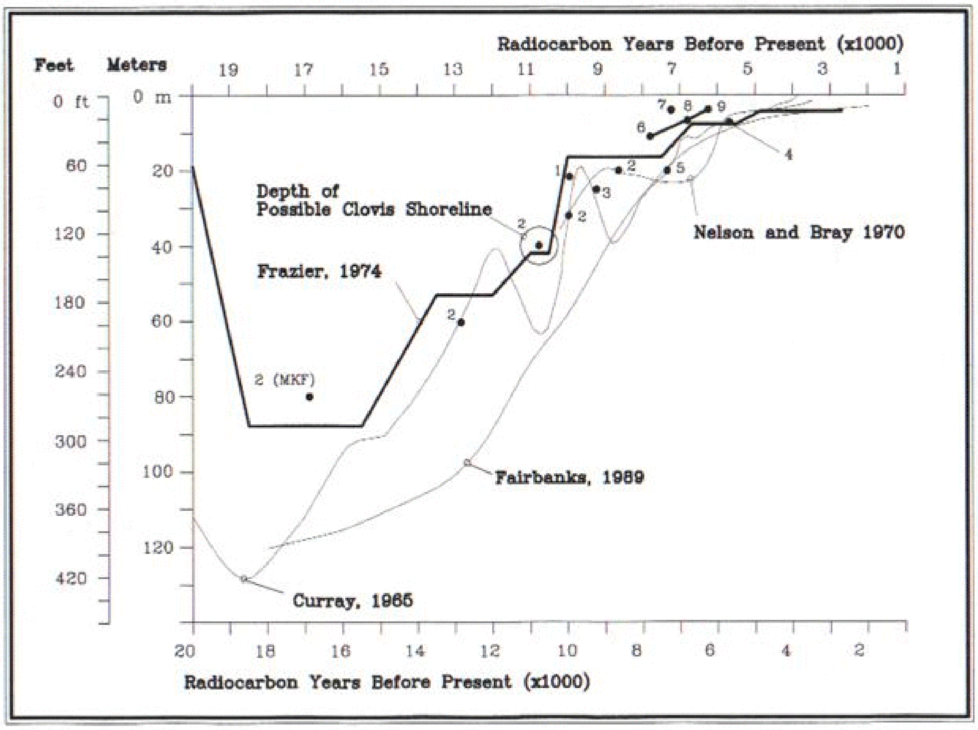

Figure 1C.34. Citations associated with curves are found in the references list. 1 = (Frazier 1974) 2 = (Ballard and Uchupi 1970) 3 – 9 = this research project.

this shelf was probably between 60 and 100-meter depths. The 160-meter isobath is anomalous, and may be a much earlier than the late Pleistocene. The Younger Dryas or Clovis Shoreline, may be at 40 m based on an overlap of western GOM data (Frazier 1974) and the paleocoastal features reported by Ballard and Uchupi at 40 meters (Faught and Donoghue 1997).

A simplified chronology of occupations in northwestern Florida is presented in Table 1C.1. The late Pleistocene-early Holocene cultural sequence in Florida is based on isolated artifacts and stratigraphic occurrences of diagnostic fluted Clovis points (or knives), lanceolate Suwannee points (or knives), and notched Bolen and Kirk projectile points (or knives) in that order. Sites are located on the karst landscape near sinkholes and river channels where there is much chert available. These represent adaptations showing social relationship with Clovis Paleoindians. Middle Archaic occupations are also represented in this portion of Florida, and they are marked by Archaic Stemmed Points. There may be a hiatus of occupation between the two cultural patches. The meaning of this is that sites found nearer to the modern shoreline have potential for occupation by both groups (Paleo / E. Archaic and Middle Archaic). Work farther offshore should restrict the discoveries to only the earlier group (Paleoindian and Early Archaic).

Table 1C.1. Sequence of culture history and sea level rise in northwestern Florida.

Projectile Point Type Name and Possible Depth Limit	
Lanceolate Clovis 11,000 rcybp	**Beginning Younger Dryas** 40 Meter Contour ??
Lanceolate Suwannee Greenbriar 10,500 rcybp estimate	**Younger Dryas** 40 Meter Contour
Side Notched Bolen Big Sandy Taylor 10,000 rcybp	**End of Younger Dryas** 40 Meter Contour
Corner Notched Palmer Bolen Kirk 9,500 rcybp	**Beginning Second Melt-water Pulse** 20 meters ??
Archaic Stemmed Several varieties 7,500 rcybp	**Last Phases of Submergence** 10 to 5 meters

DEEPWATER RESEARCH: SUSTAINABLE SEAS EXPEDITIONS 2000 AND 2001 TO THE FLORIDA MIDDLE GROUNDS

I was invited by Dr. Sylvia Earle of the National Geographic Society to accompany her on the Sustainable Seas Expedition (SSE) of 2000 to conduct work in and around Stu's Ridge at the 80-meter isobath, and the Florida Middle Grounds, between the 40-and 50-meter isobaths seeking paleohuman occupation sites. Stu's Ridge, a well-known grouper habitat, occurs around the 80-meter isobath and exhibits a wave cut notch, formed in a coquina. Wave cut notches are unequivocal evidence for sea level still stand, but we do not know the duration, or the age of the notch. It does have potential to mark the LGM (late glacial maximum) sea level stand.

The Florida Middle Grounds, on the other hand, is composed of high relief, flat topped, carbonate pinnacles with abundant algal growth, mollusks, and coral. The habitat of the Middle Grounds supports abundant marine life. This area is fished commercially and recreationally on a regular basis causing a depletion in marine fauna.

The Middle Grounds has been interpreted as a possible paleoreef feature, probably resulting from vertical reef growth with rising sea levels. An alternative interpretation, that it may be a pinnacle karst feature, is also possible. The tops of the Middle Grounds pinnacles are flat and occur at depths of approximately 30 meters. The eastern margins of the Middle Grounds are at the 40-meter contour, meaning that submerged prehistoric sites are more likely in shallower water, and east of this feature.

In the 2000 SSE cruise most of the research time was spent in the study of marine organisms by biological colleagues, and I spent time getting to know the DeepWorker submarines, studying the navigational maps, and making fathometer observations. One long transect (Figure 1C.35) was made with the fathometer aboard the NOAA Ship *Gordon Gunter*, while underway from Tampa Bay to the Middle Grounds (bearing 291 degrees) at about 10 knots on 12 August, 5:45 a.m. to 9:00 a.m. I observed and recorded positions of channels and rocky outcrops. Fathometers act as weak subbottom profilers, but there is no other record (digital or hard copy) other than bottom depth, latitude and longitude, and the perceptions of the observer.

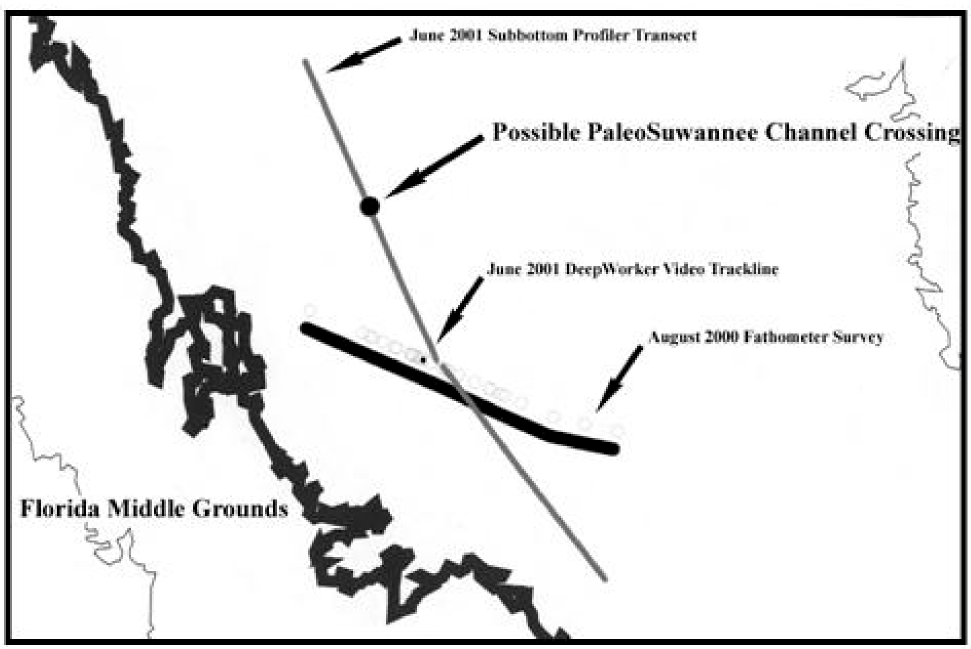

Figure 1C.35. Close-up of Middle Grounds research area and various tracklines outlined in Figure 1C.33. The heavy contour line is the 40-meter isobath. The 2000 fathometer survey and the 2001 subbottom tracklines are shown, as well as the 2001 DeepWorker video transect and the position of the subbottom profiler channel crossing.

Twelve anomalies were recorded as rocky rises, and eleven were channel or sediment filled depressions. Some of these latter features represent either side of a larger channel features. One location was targeted for further investigation. It is a rocky rise with nearby karst depression features analogous to features we are familiar with in our research nearer to the shoreline (summarized below). A topographic map was made from recorded fathometer data collected during nighttime tracklines shown in Figure 1C.36.

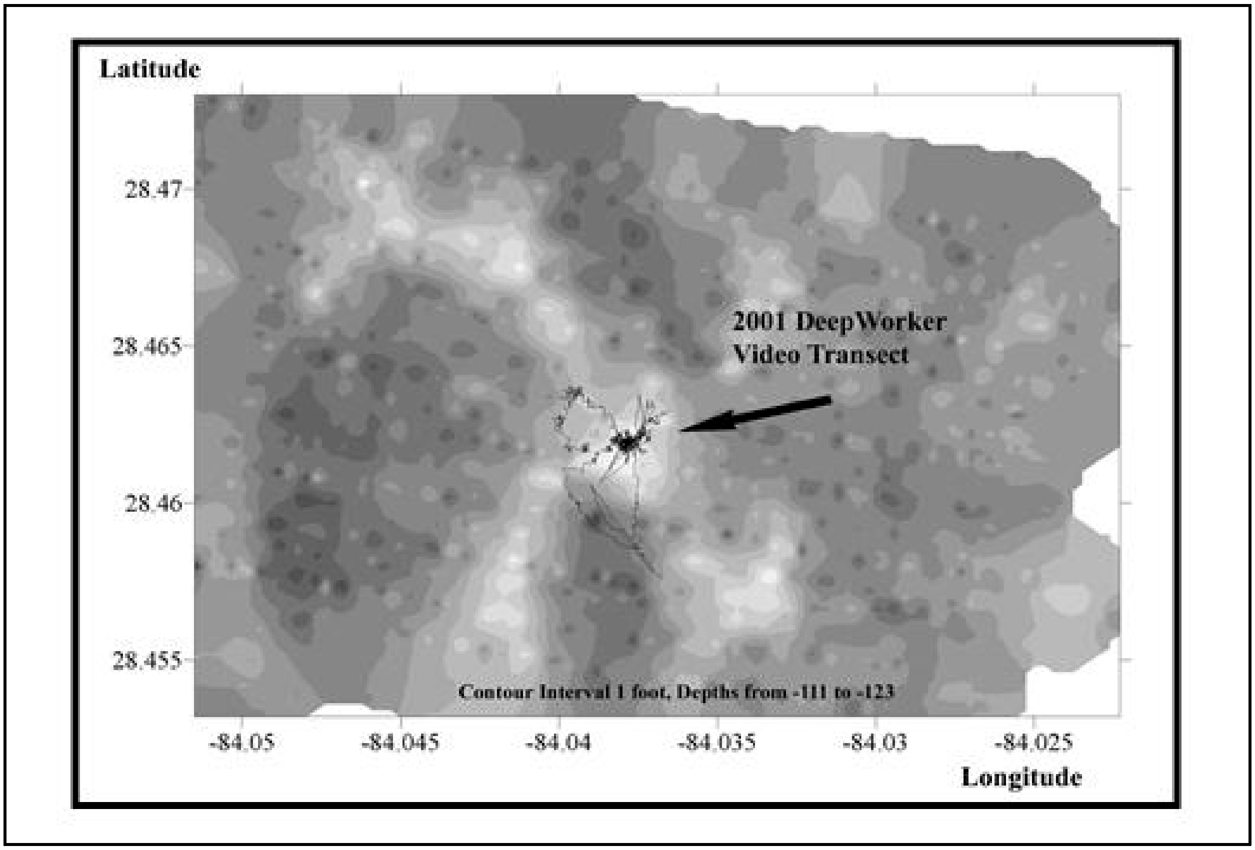

Figure 1C.36. Topographic map of the 2001 target area and submarine tracklines conducted there. Light areas are highs, darker colors lows. Range of topography is between -123 and -111. DeepWorker exploration of this location revealed bedrock exposures of limestone indicative of relict terrestrial conditions, but with significant sea floor life, and fish there now.

We developed an understanding of the needs of an archaeologist while at sea and agreed to try again in 2001. I proposed that we conduct subbottom profiler remote sensing research to identify the mouths of any channels that debouched at 40 meters and to search for artifacts around a potential rock outcrop features identified in 2000 by the study of fathometer returns. In June of 2001, and with the help of the able-bodied crew and scientists aboard the NOAA Ship *Gordon Gunter,* I organized two operations that were focused on the discovery of relict channel features and Paleoindian occupation sites (Figures 1C.33 and 1C.35).

One operation consisted of two nighttime sessions of subbottom profiler remote sensing to discover the position of what was thought to be multiple relict river channel mouths east of the Florida Middle

Grounds. A transect of 41 nautical miles (about 76 kilometers) was completed. Florida State's Program in Underwater Archaeology has a dual frequency BENTHOS Chirp subbottom profiler (2-7 kHz and 10-20 kHz) that was towed at speeds of between three and four knots in two sessions. The Chirp system digitizes the analog sound data to a computer hard drive for later processing. BENTHOS has developed a Windows based software for real time data processing, image display, and manipulation. Signal classification algorithms are included. The track line data is embedded with NMEA-183 formatted data as supplied by a GPS receiver with an accuracy of between 4 and 6 meters.

The subbottom profiler transects were designed to encounter the mouths of rivers that might have come out into what might have been a bay-like feature inside of the Florida Middle Grounds. At the time, I thought there might be several of these crossings in the subbottom profiler pathway. However, only one channel feature was crossed in almost 40 nautical miles of remote sensing (Figure 1C.35). This feature was at the approximate latitude of the Suwannee River along today's coast. Surely, more remote sensing will be needed to confirm this finding or to show it to be the result of sampling bias.

A second research operation was conducted around the topographically reconstructed target from 2000 (described above) with a video transect by a DeepWorker submarine piloted by George P. Schmal of NOAA's Flower Gardens. There are two or three hours of video recording the trackline observations conducted over rocky areas and sandy sea floor bottom. There was no manipulator arm available for this transect, so no samples could be taken of the potential objects. One note of interest is that the biologist piloting the submarine was involved in aiming the camera at larger scale scenes, and scenes that focused on fish and fish behavior. In several frames of the video there are objects that very easily could be artifacts, as we are used to seeing in more shallow water, but until we can get some divers down to the target to look and collect, we will not know for sure. The DeepWorker proved its potentials, moreover, with certain upgrades and a pilot with archaeological experience it could be a great remote sensing tool (this is in no way a critic of the pilot of the sub, rather an interesting note about research attention and focus).

RESEARCH IN SHALLOWER WATER: DEVELOPING THE METHODS NEEDED FOR DEEPER WATER DATA RECOVERY

Since 1986, nine multi-week forays to open ocean localities on the Floridian continental shelf have been organized. Four were organized for doctoral dissertation field research in 1988, 1989, 1991, and 1992 (Dunbar *et al.* 1992; Faught 1988, 1992, 1996; Faught and Donoghue 1997). Another four field sessions have been organized since 1998 as a programmatic approach to submerged prehistoric sites archaeology. These latter four projects have been included in FSU's Field School in Underwater Archaeology. The current incarnation of the research is known as the *PaleoAucilla Prehistory Project* (www.adp.fsu.edu/paleoaucilla).

The intellectual intent of the *PaleoAucilla Prehistory Project* has been to work out from the modern coastline Aucilla River (*known*), to the offshore-*unknown* environment in search of relict portions of that river and sites within its channels and along its margins. The intellectual logic has been to investigate progressively deeper and farther out locations as boats, gear, funding, and staff permit. Most research time has been spent within about 17 km (9 nautical miles) of the modern coastline at depths varying from

12 to 20 feet. We are searching in areas containing channel features, rock outcrops, sea grass beds, and sandy, desert-like plains.

Underwater research has resulted in the retrieval of more than 4,000 chipped stone artifacts from 33 localities (sites) offshore since 1986, samples shown in Figure 1C.37. Of the chipped stone specimens, 1,158 have been found on survey, 1,632 have been retrieved from J&J Hunt, the remainder were collected from two other sites exhibiting hundreds of artifacts each (i.e. Econfina Channel and the Fitch Site in Figure 1C.38). The types and amounts of artifacts that are encountered range from a few isolated chunks of worked chert-quarry debris, to significant numbers of stone tools, biface thinning flakes, and other tool-making and edge-maintenance debris. These latter sites exhibit diagnostic projectile points as well. Based on the presence of diagnostic projectile points and certain unifacial tool types, three locations are late Pleistocene Paleoindian and early Holocene Archaic occupations. Four sites have produced evidence of the middle Holocene Archaic of Florida. Two of the locations indicate both groups: one of these is the J&J Hunt site reported in more detail here, the other is a site found in 2001 called “Ontolo” (Figure 1C.38).

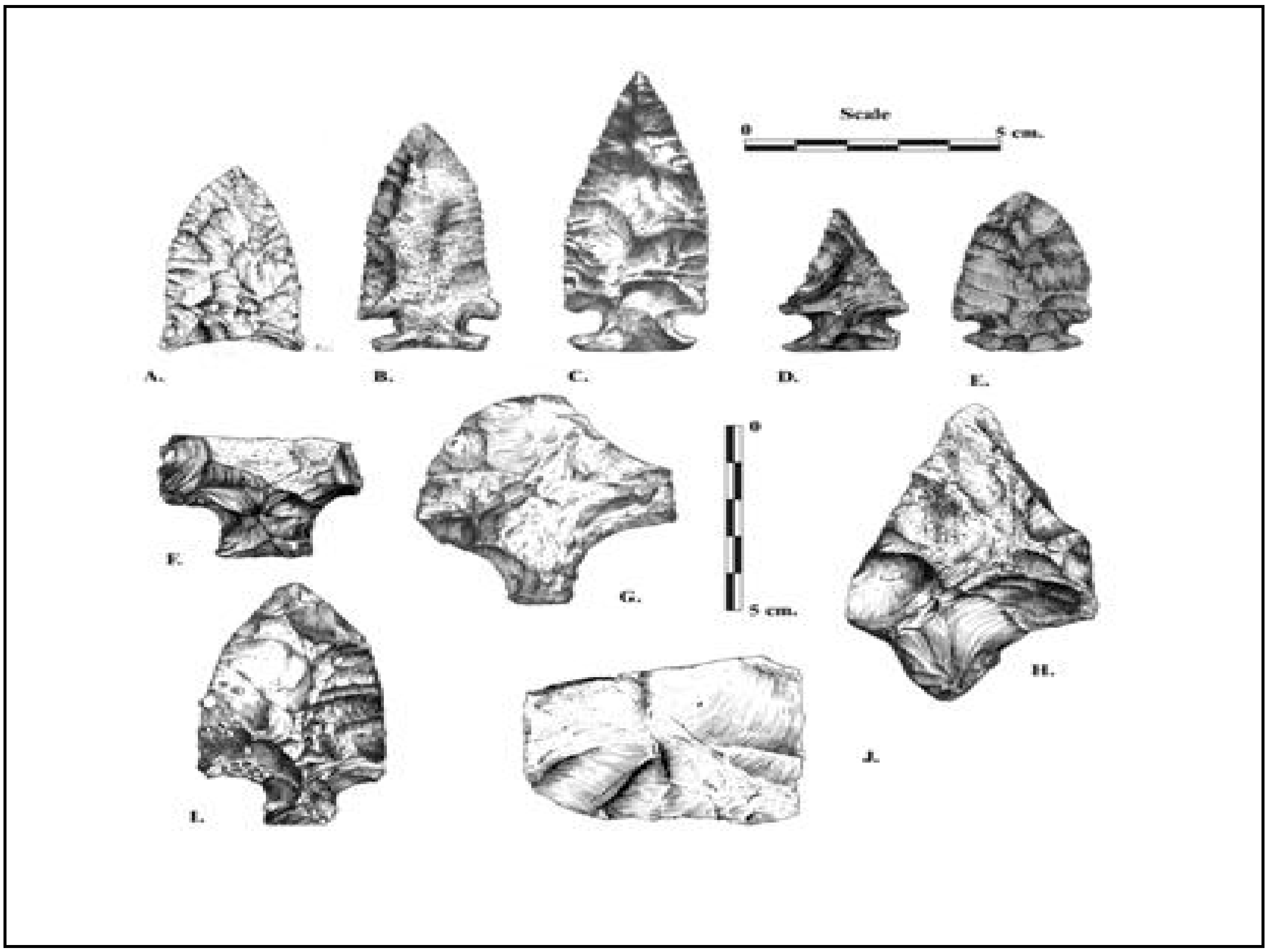

Figure 1C.37. A selection of projectile points found by offshore research. Paleoindian (A,J), Early Archaic(B-E), Middle Archaic(F-I) examples are shown (Drawings by Brian Worthington).

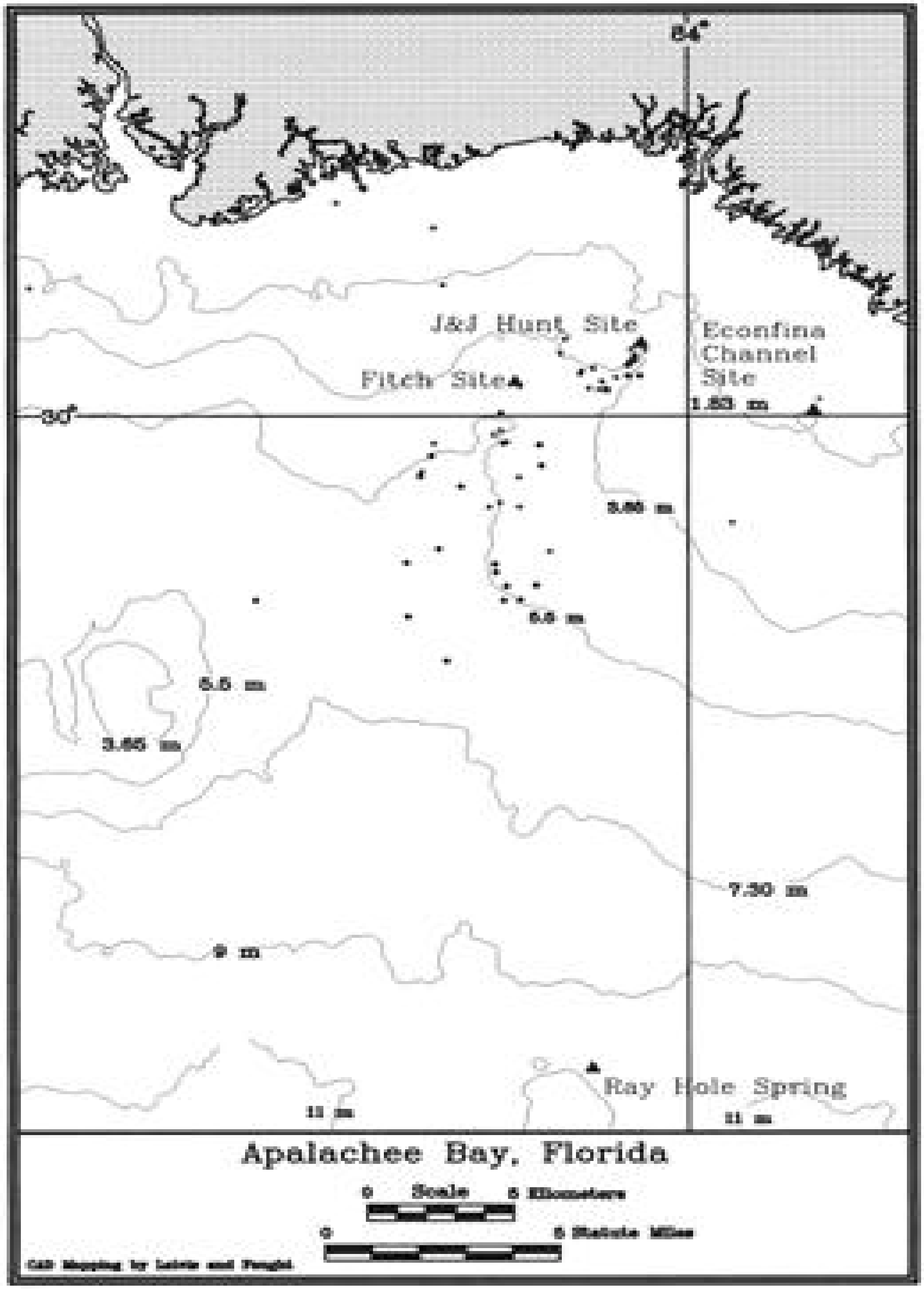

Figure 1C.38. Research area of the Paleo Aucilla Prehistory Project showing the locations of sites mentioned in the text, and sites located by survey operations.

Conducting open ocean operations is a logistical complexity controlled by the size and capabilities of the vessel, or platform to be used at sea. The difficulties with regard to boats (or other working platforms) revolve around adequacy of size, affordability, and availability. Boat sizes of 18 to 23 ft were used during the Ph.D dissertation research to work as far out as 3 nautical miles, but their capabilities in this environment were marginal. Crew sizes were restricted to three to five in each boat—including their dive gear and dredge equipment. There are only emergency overnight capabilities on vessels of these sizes, and no working in seas over about 2 feet.

Larger, more appropriately sized vessels, with galleys, heads, and comfortable sleeping quarters have been leased since 1998 because funds have permitted. We have chartered 50 ft (crew of five), 65 ft (crew of ten), and 72 ft (crew of ten) vessels from Florida State University, Panama City Marine Institute, and Florida Institute of Oceanography. We load the vessels at FSU's Marine Laboratory at Turkey Point, St. Teresa, Florida, and then run four to five hours to the survey areas reported here. The benefits of larger craft cannot be over-stated. Justifications for their procurement include the ability to stay at sea for as many as five days with adequate crew and equipment to run two or three operations simultaneously (remote sensing, diver survey, mapping, coring, or excavations). Crews are rested and better able to sustain safe and effective research activities on these larger vessels.

Just as a stratified random approach is desirable for terrestrial resource management inventory projects, increasing "site encountering success" rates are important factors in locating sites offshore. An initial study area was defined in 1986 that encompasses almost 1,500 square kilometers (585 square statute miles, shown in Figures 1C.33 and 1C.38).

One method of understanding the sea floor bottom with limited resources has been bathymetric enhancement conducted by digitizing the locations of known depth from the NOAA navigation map, recordation in spreadsheet format, gridding in Surfer, and study of depression trends, the likely paths of paleo channel features (Faught 1996). Figure 1C.39 is one such reconstruction of the topography of the seascape around J&J Hunt based on the depths recorded on the NOAA Navigational Map (Apalachee Bay), combined with subbottom profile fathometric data from 1991. The topography of the research area bottom has to be enhanced by a factor of 500 in Figure 1C.39 in order to bring out subtle differentiation.

Subbottom profiler remote sensing is another, better, but more expensive tool for accurately locating the paleo- drainage system offshore and understanding the character of the stratigraphic beds. All told, we have run 216 linear kilometers of subbottom profiler tracklines (111 in 1991 and 105 in 2001). This record crosses channels and other karstic depressions in several places. The equipment used in the 1991 field session included a GEOPULSE 3.5 kHz "Boomer" sounding device with an 2.4 meter hydrophone array, processed by a GEOPULSE 5210A receiver, and recorded on thermal paper. As described above, FSU's Program in Underwater Archaeology now has a dual frequency BENTHOS Chirp subbottom profiler.

Side scan sonar has proven to be another effective instrument for survey of large areas of the seafloor bottom for identifying features which might justify diving or other testing. At the time of this writing side scan sonar operations have accrued 250 kilometers of imagery (with swaths varying from 150 to 200 meters). The use of the side scan sonar for investigating the character of the seafloor bottom cannot be

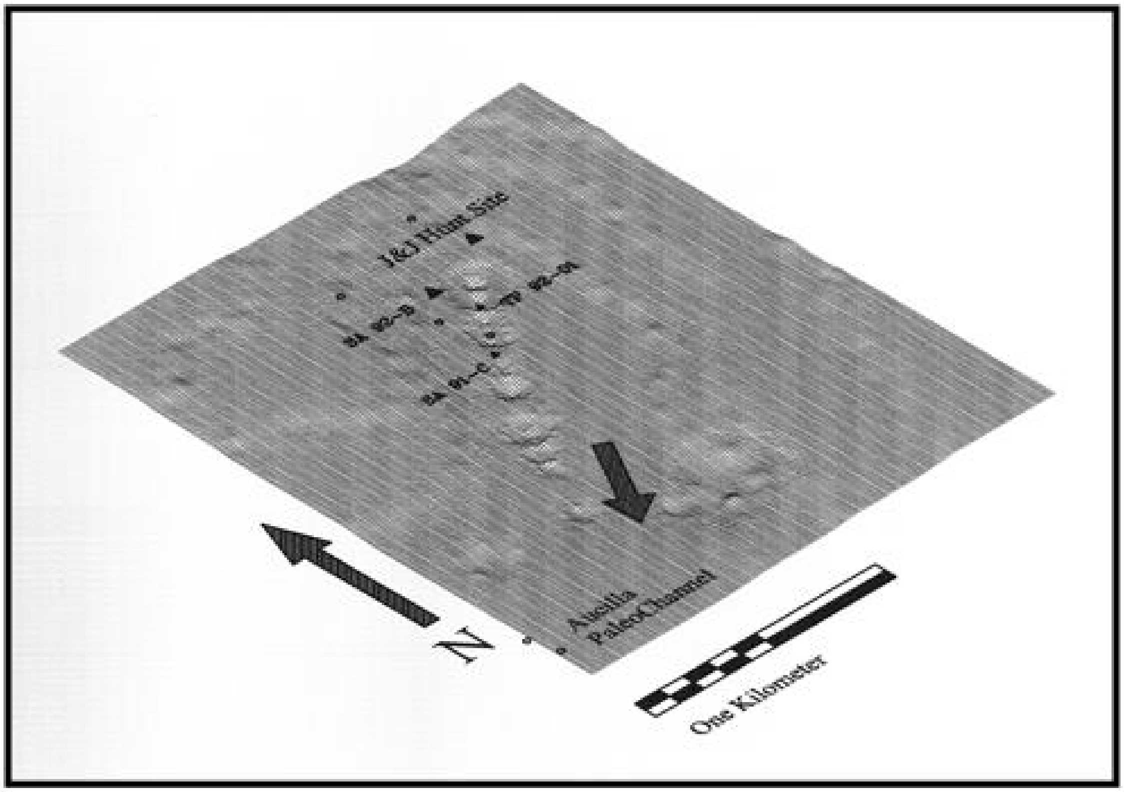

Figure 1C.39. Bathymetric reconstruction of a segment of the PaleoAucilla, showing the location of the J&J Hunt Site and other artifact locations discovered offshore.

understated. Especially when used in conjunction with the use of a third party mosaicking program. The side-scan sonar unit being used by FSU is a Marine Sonic Technology Sea Scan PC “Splash-proof” digital image sonar survey system with a 600 kHz tow fish, a two-gigabyte hard drive, and a Pentium splash-proof CPU. The track line GPS data is embedded in the digital record and is supplied by any GPS system with data output (NMEA-183 type) with an accuracy of between 4 and 6 meters. The swath of the side scan coverage can be set from 100 to 200 meters with the speed of the vessel running between three and four knots.

Before 1998 site locations and remote sensing tracklines were recorded with Loran-C navigational signals, manually plotted on the NOAA Apalachee Bay navigation map, and then digitized onto the CAD map using a State Plane (Florida North Zone) coordinate base (Figure 1C.38). Since 1998 our locations have been recorded in latitude and longitude using DGPS technology, plotted in both GIS and CAD formats by translating the global coordinates into either state plane and UTM coordinates. The differential signals that reach the Big Bend are weak, and therefore most of our GPS data has been without differential control since selective availability was turned off in May of 2000.

Since 1986 this research project has dived at 52 locations and encountered artifacts at 35, a discovery rate of about 67% overall (Faught 1996; Pendleton and Tobon 2002) (Figure 1C.38). In 2001 our rate was six encounters for seven targets dived for a success rate of 85%. Of these artifact encounters, 15 are registered with the Florida State Master Site File because those were encounters of ten or more artifacts (a protocol of the research program). The numbers of artifacts recovered has already been described above.

Initially, all sites are sampled randomly. Controlled hand fanned sampling is employed if artifacts are produced and if time and conditions allow. More intensive excavations, coring, and mapping have been conducted at J&J Hunt, and two other locations (Econfina Channel (Faught 1988), The Dorothy C. Fitch Site (Faught 1996)).

CONCLUSIONS

This paper has briefly described progress made in finding and investigating prehistoric sites in open ocean conditions over the continental shelf of Northwestern Florida. It described initial research in "deep" water near the proposed "Clovis Shoreline" (40 meter), and gave a short overview of abundant research conducted in shallower conditions. I believe that this work can be a useful analog for resource managers in Alabama, Mississippi, and Louisiana, even though the sediment loads there are more substantial. In other areas of the Gulf, many of these sites would be in federal waters, but in this example they are in state of Florida waters to a distance of nine nautical miles. More submerged cultural resource management projects need to consider these kinds of resources, more prehistoric archaeologists need to be able to manage them because of the specialized nature of site prediction, recognition, and analysis, and obviously more sites need to be discovered.

Sustained research in the Florida Big Bend has resulted in practice with several conceptual and methodological techniques found useful in the investigation of marine submerged prehistoric sites. In general, offshore site prediction is best conducted by developing local predictive models; models based on the local terrestrial record of prehistoric sites, local sea level rise history, and local bottom type and past drainage systems. One site prediction model in Florida postulates that artifacts and Pleistocene fauna can be found in river sinkhole features as at the Page Ladson Site, in the Aucilla River. Another site prediction model suggests that sites can be found by taking perpendicular (lateral) transects from the channel margins.

The amount of work that can be accomplished offshore is dependent on sufficient funding, procurement of appropriate boat (or boats), adequate levels of technical support, and the vagaries of inclement weather and crew availability. We have found that use of remote sensing (subbottom profiler and side scan sonar devices) and coring operations are helpful to find paleotopographic features, sediment packages and sites. Induction dredge testing operations have also been effective to investigate sites. One of the more successful approaches is simply having divers in the water seeking artifacts to define sites by hand fanning.

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SESSION 2A

STUDIES ON FATE & EFFECTS OF SYNTHETIC BASED DRILLING MUDS ON THE SEAFLOOR

Chair: Dr. Mary Boatman, Minerals Management Service
Co-Chair: Ms. Sarah Tsoflias, Minerals Management Service

Date: January 8, 2002

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Dr. D. J. Roberts and Dr. D. Herman, Department of Civil and Environmental Engineering, University of Houston

SEAFLOOR MONITORING PROGRAM: STATUS REPORT, 8 JANUARY 2002

Dr. James P. Ray
Shell Global Solutions (US) Inc.

Dr. Mary Boatman
Minerals Management Service

The Gulf of Mexico Comprehensive SBM Monitoring Program represents a joint effort between the federal government and industry to evaluate the effects of the discharge of cuttings containing synthetic based drilling fluid on the seabed. Over the past few years, the industry's synthetic based mud (SBM) activities have been a combined effort of the National Ocean Industries Association (NOIA), American Petroleum Institute (API), Petroleum Equipment Suppliers Association (PESA), and Offshore Operators Committee (OOC). In 1998, numerous technical issues requiring research efforts were identified; to raise the funds, a separate, external subscription was planned.To support the subscription program, API was retained to provide contracting and administrative services.

The Minerals Mangement Service (MMS) and the Department of Energy (DOE) joined with 30 operators, 3 mud companies, and 3 chemical companies, to share in the cost of the Seafloor Monitoring Program. This group of "subscribers" is known as the SBM Research Group (SBMRP). The group has an Oversight committee of eight people (the same as an executive committee) which represents the subscribers. Within the SBMRP are six work groups: the Seafloor Monitoring Program; Toxicity Workgroup; Biodegradation; Modeling; Technology Assessment; and Analytical. Also, there is a separate, but parallel organization known as the SBM Committee comprised of NOIA/API/PESA/OOC. This group represents all of the interested parties, regardless of whether or not they are subscribers to the research program. This group is responsible for handling the policy-related issues, such as effluent guidelines, permits, etc. The program has raised $3.7 million for overall SBM research.

This paper describes the results thus far from the SBM Seafloor Monitoring Program being conducted in the Gulf of Mexico (GOM).

BACKGROUND

Drilling fluids play an essential role in providing for the safety and effectiveness of the drilling process. They provide the means for maintaining pressure on the formations being drilled, removing cuttings from the borehole, protecting and supporting the borehole wall, protecting permeable zones from formation damage, and cooling and lubricating the drill bit and drill string.

Drillers currently use two basic types of drilling fluids: water-based fluids and non-aqueous based fluids. Water-based drilling fluids or muds (WBM) have water or a water-miscible fluid as the continuous phase. Non-aqueous based drilling fluids have an organic, water-immiscible fluid as the continuous phase. Non-aqueous based fluids are subdivided into oil-based fluids, enhanced mineral oil-based fluids, and synthetic-based fluids or muds (SBM) according to the nature of the organic fluid phase (EPA 1999). Non-aqueous based fluids are used when drilling conditions require more stabilization of the borehole, lubricity, and resistance to thermal degradation than can be provided by WBM. The conditions encountered during drilling of the initial portions of a well usually are appropriate for the use of WBM. As conditions requiring a non-aqueous fluid are encountered during drilling of later portions of wells, the WBM is typically discharged and a non-aqueous fluid is used to complete the drilling process.

Non-aqueous based fluids are frequently used in development drilling operations because the well paths are deviated, rather than vertical, in order to reach distant parts of the reservoir from a fixed drilling location. Deviated wells typically have more stringent requirements for drilling fluid lubricity and well bore stability than do vertical wells. Synthetic based drilling fluids, based on organic fluids such as esters, olefins, acetals, and ethers were developed to provide drilling performance equivalent to that of oil-based muds and improvements in environmental performance compared to that of oil-based muds. Olefins and esters predominate in the U.S. offshore drilling.

The U.S. offshore oil and gas drilling industry has developed and made increasing use of SBM over the past decade. The bulk discharge of these fluids is prohibited. However, the discharge of cuttings drilled with SBM has been allowed in the western GOM subject to the same restrictions as the discharge of cuttings drilled with water-based mud. EPA recognized that use of SBM in place of water-based muds may reduce the amount of solids and other drilling fluid components discharged to the marine environment. EPA also recognized that the properly controlled discharge of SBM cuttings could provide non-water quality benefits compared with the use of oil-based muds followed by disposal of the cuttings in shore-based landfills or by injection under the seabed.

EPA (1996) indicated that additional methods development and additional environmental performance information would be needed to develop effluent limitations for SBM cuttings discharges. EPA expressed concern about both the short-term and the long-term seafloor effects of SBM cuttings discharges. The overall objective of this research program is to obtain information about these effects.

OBJECTIVES

The objective of this program is to assess the fate and effects of discharged cuttings drilled with SBM at continental shelf (40-300 m) and deepwater (>300 m) GOM sites. The purposes of this assessment are to: 1) provide the Environmental Protection Agency (EPA) with scientific data upon which to base effluent limitations for the discharge of SBM cuttings; 2) provide industry with scientifically valid data for the environmental assessment of the discharge of SBM cuttings; and 3) provide MMS and DOE with environmental data useful in leasing assessments and offshore management.

Specific sub-objectives include:

- Determination of the thickness and areal extent of SBM cuttings accumulations on the seafloor and the magnitude and temporal behavior of SBM base fluid concentrations in sediments near discharge sties representative of GOM conditions at both continental shelf (40-300 m depth) and deepwater (> 300 m depth) discharge sites.

- Determination of the temporal behavior of SBM base fluid concentrations in sediments near discharge sites representative of GOM conditions at both continental shelf (40-300 m depth) and deepwater (>300 m depth) discharge sites.

- Documentation of physical-chemical conditions in sediments in areas where SBM base fluids are present and comparison of these conditions with conditions in reference sediments distant from SBM discharges. Sediment conditions include SBM base fluid concentrations, effects on sediment oxygen levels due to SBM accumulation, shifts in the depth of the redox potential discontinuity (RPD) layer, and changes in sediment mineralogy due to the addition of drill cuttings solids.

- Determination of whether a zone of biological effect has developed related to the discharge of SBM cuttings. Chemical toxicity, hypoxia, and physical habitat disruption may all contribute to biological effects. Biological changes due to physical effects should be distinguished from those due to the presence of SBM base fluids on cuttings through evaluation of both physical and chemical characteristics of sediments.

STATUS OF CRUISES 1, 2, AND 3

Cruise 1: Scouting Survey of Cuttings Accumulations

An initial scouting survey was conducted 3-8 June 2000 which surveyed ten shelf platforms. The sites were examined for physical and visual determinations of cuttings piles. No large, thick cuttings piles were observed; however, there was limited accumulation, mostly adjacent to structures. The cruise provided data for selection of final five platforms for the screening cruise.

Cruise 2: Screening Cruise

The screening cruise was conducted 26 July – 7 August 2000 and sampled five shelf platforms and 3 locations in the > 300 m depth range. The results of the screening cruise will be used as base data for fine-tuning the sampling design and for selecting the final three shelf platforms for biological and sediment toxicity sampling. Analysis included a physical survey of the site using sonar, video, and swath bathymetry. Sediments were sampled and analyzed using x-ray diffraction, visual inspection, and grain size determination. A sediment profile imaging system was used to take pictures of the upper layers of sediment *in situ*. Oxygen profiles were measured on cores brought to the surface. Hydrographic profiles of the water column were taken for salinity and temperature. Sediments were also analyzed for trace metals (arsenic, cadmium, chromium, copper, mercury, nickel, lead, vanadium, and zinc). Macrofaunal samples were also collected.

The preliminary results showed no large cuttings piles but some visual evidence of cuttings and SBM contamination near some platforms. Bacterial mats were observed in some locations. All analyses are completed.

Cruise 3: Sampling Cruise 1

Sampling cruise 1 was conducted in early May 2001 and visited eight sites: five shelf locations in the 40 – 300 m depth ranges and three locations in the > 300 m depth range. During Sampling Cruise 1, samples were collected for physical and chemical measurements of sediment conditions at all shelf and deepwater sites, for definitive biological and sediment-toxicity analyses at three shelf sites, and for physical survey and video observations of sediment conditions at deepwater sites. Analysis of sediments included redox profiles, grain size, visual inspection, and trace metals (barium, iron, aluminum and manganese). Sediment profile imaging was used to examine the upper portion of the sediments *in situ*. Samples were also collected for analysis of synthetic base fluid, total organic carbon, and total petroleum hydrocarbons. Paleontology samples were collected to assist in the identification of cuttings. At three of the shelf locations, samples were also collected for infauna and sediment toxicity.

A data review meeting is planned for March 2002 and may include modification of the final sampling plan and discussion of the data from this cruise.

REVIEW OF REMAINING PROGRAM SCHEDULE

The second definitive cruise is scheduled for April/May 2002 and will repeat the sampling and analysis plan of the first cruise. A final report is expected the first quarter of 2003.

Dr. James Ray is the manager of the Environmental Ecology and Response section at Shell Global Solutions (US) Inc. (formerly Equilon Technology). He serves as Research Coordinator for the Industry Synthetic Based Drilling Muds Research Program and Chairman of the Offshore Operators Committee, Environmental Sciences Subcommittee. Dr. Ray received his Ph.D. in Biological Oceanography from Texas A&M University and has worked on Gulf of Mexico environmental issues for almost 30 years.

EFFECTS OF OIL AND GAS EXPLORATION AND DEVELOPMENT AT SELECTED CONTINENTAL SLOPE SITES IN THE GULF OF MEXICO

Dr. Alan D. Hart
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Continental Shelf Associates, Inc. and its subcontractors/consultants are conducting a multiyear study to assess the impacts of oil and gas exploration and development at four selected sites on the continental slope in the Gulf of Mexico (GOM). Two exploration sites are being sampled before and after drilling, and three post-development sites are being studied once, after drilling is completed. (Figure 2A.1). The two exploration sites, Garden Banks Area Block 516 and Viosca Knoll Area Block 916, are located in water depths of about 1,000 m, and the two post-development sites, Mississippi Canyon Block Area 292 and Garden Banks Area Block 602, are located in water depths of about 1,100 m. Both water-based and synthetic-based muds were used in the drilling of the exploration and post-development wells.

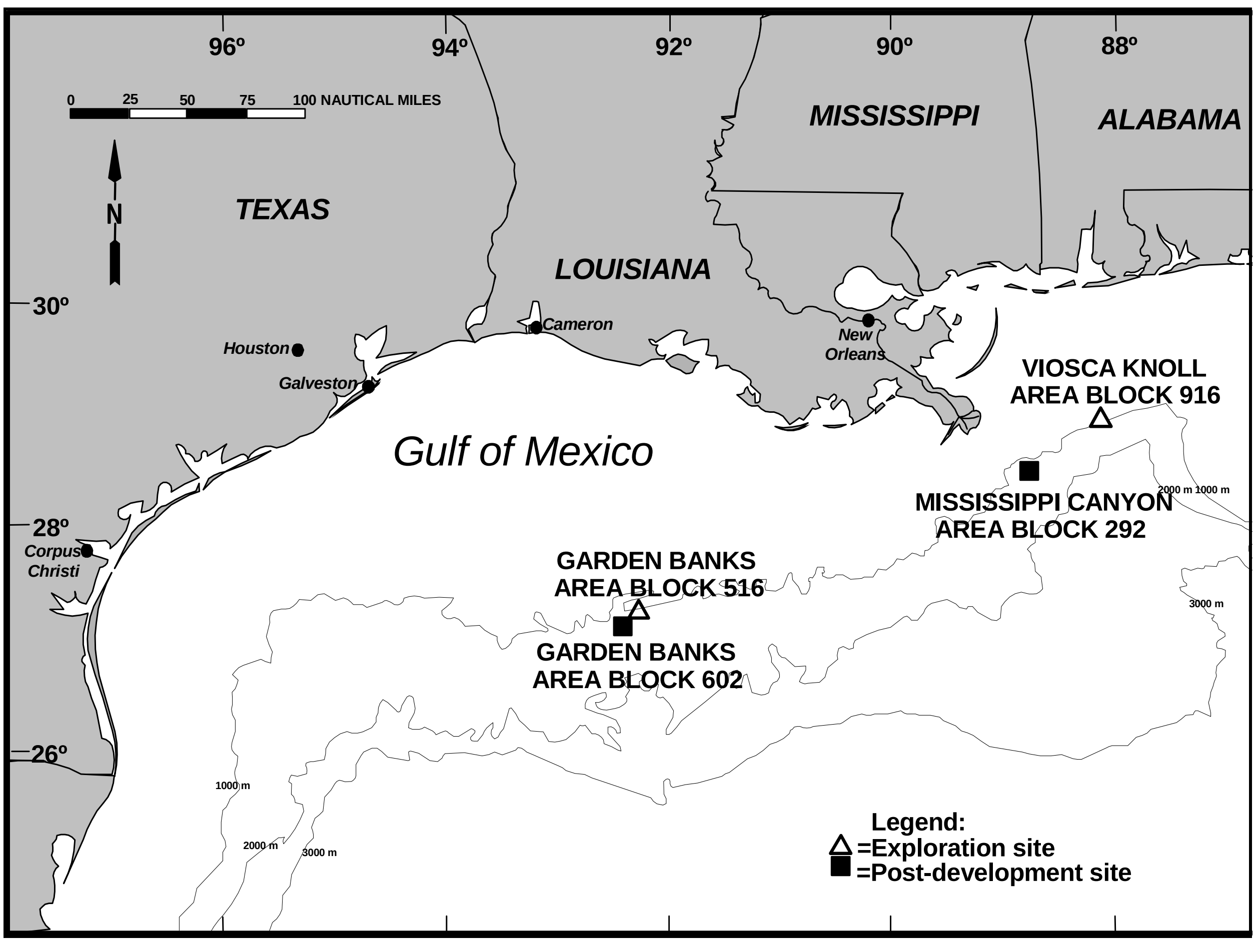

Figure 2A.1. Locations of study sites.

The program consists of two components: physical characterization and chemical/biological characterization. The objective of the physical characterization is to determine the physical impacts of the operations including

1) areal extent and accumulation of muds and cuttings;
2) physical modification/disturbance of the seabed due to anchors and their mooring systems; and
3) accumulation of debris due to operations.

During the first cruise in Fall 2000, one exploration site, Viosca Knoll Area Block 916, was surveyed prior to drilling. At this site, data were collected with a deep-towed side-scan sonar and subbottom profiling system to prepare acoustic reflectivity maps. During the second cruise in Summer 2001, similar data were collected at the two post-development sites and at the Garden Banks Block 516 exploration site (post-drilling) with an autonomous underwater vehicle. Post-drilling data were not collected at Viosca Knoll Area Block 916 because the planned well was removed from the drilling schedule between the first and second cruise.

The objectives of the chemical/biological characterization are

1) to determine the extent of physical/chemical modification of sediments in the immediate area of the wellsites, compared to sediment conditions at reference sites (and before drilling in the case of exploration sites) and
2) to conduct limited biological collections to determine biological effects related to chemical and physical impacts. During the first cruise, pre-drilling sampling was conducted at the two exploration sites.

During the second cruise, post-drilling sampling was conducted at the Garden Banks Block 516 exploration site and at the two post-development sites. Box core samples will be collected at 12 locations within 500 m of each exploration/development site, and two box cores will be collected at each of six reference sites located at least 10 km from each exploration/development site (Figures 2A.2 and 2A.3). Sediment grain size, mineralogy, texture, radionuclides, metals, total organic carbon, and hydrocarbons will be analyzed. Samples for pore water, redox chemistry, and sediment toxicity (10-day acute test) also will be collected. Sediment profiling imagery transects will be performed near each site and at two of the corresponding reference sites. The biological community was sampled using a box core, still photographs, and bottom traps (Figures 2A.2 and 2A.3). Several biological parameters are being measured: 1) microbiotal activity, biomass, and community structure; 2) meiofauna taxonomy including harpacticoid taxonomy/genetic diversity/reproductive status and nematode feeding groups; and 3) megafaunal taxonomy and metal/hydrocarbon concentrations in tissues of selected animals.

Post-drilling data were not collected at Viosca Knoll Area Block 916 because the planned well was removed from the drilling schedule between the first and second cruise. This well was subsequently spudded in November 2001, and because drilling has now occurred at this exploration site, a third cruise in Summer 2002 is being considered to gather post-drilling data at this site.

Interpretation and synthesis of the data will include the testing of hypotheses concerning differences in chemical and biological parameters between areas in the vicinity of exploration, development,

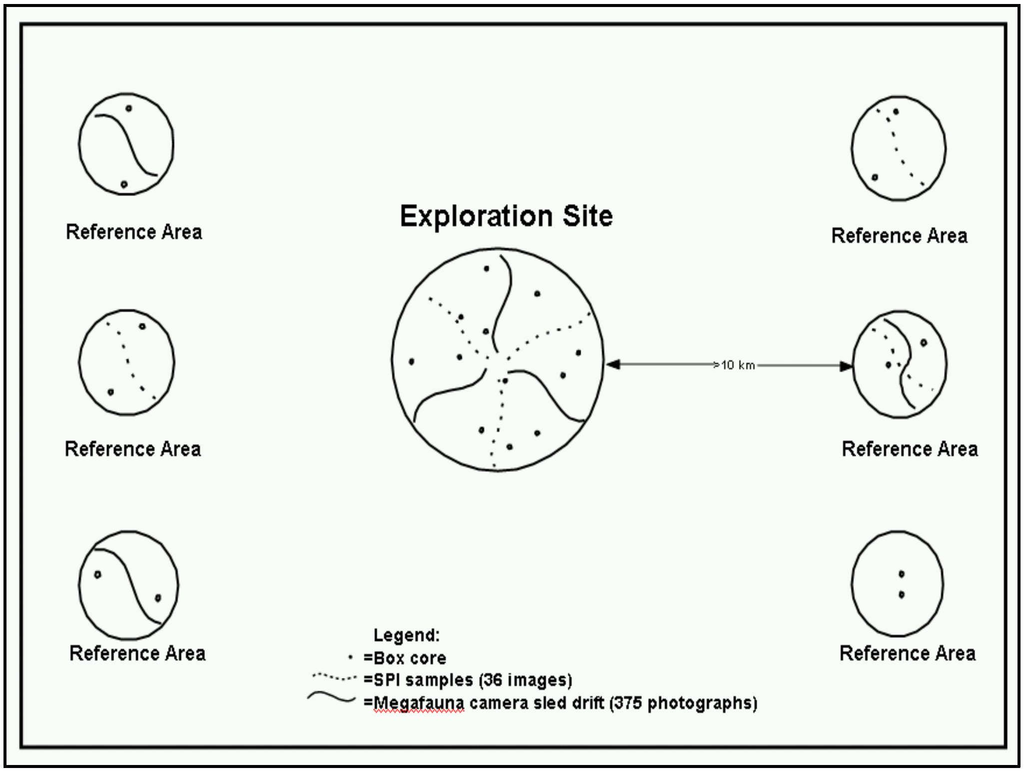

Figure 2A.2. Idealized field sampling design for exploration sites.

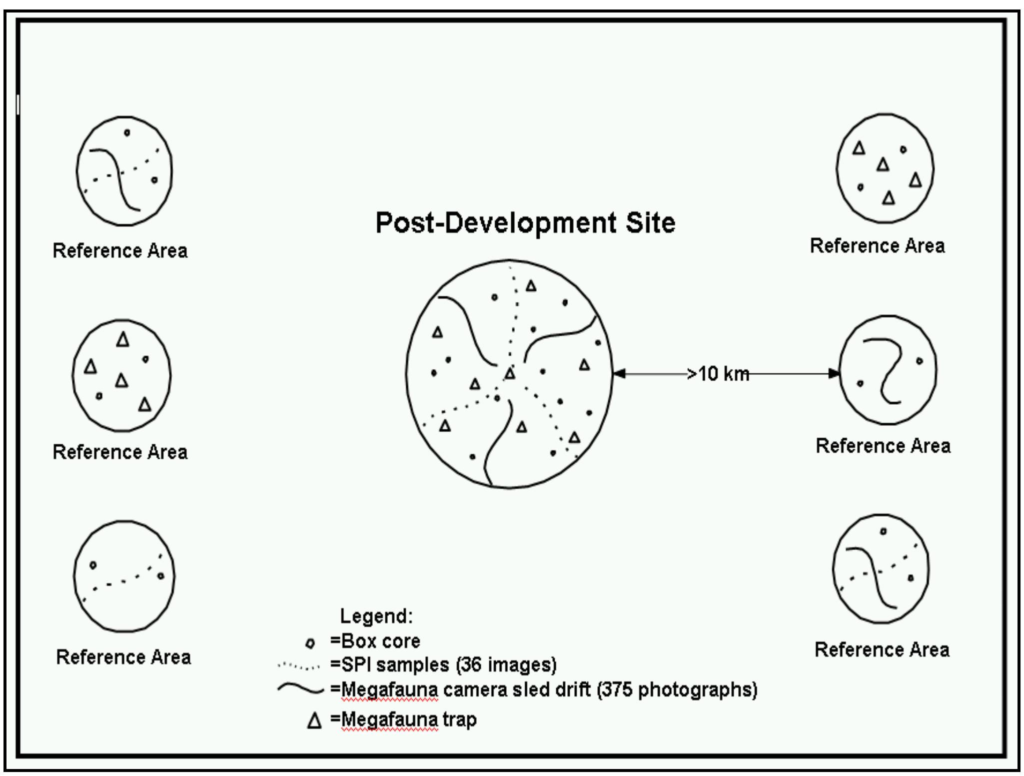

Figure 2A.3. Idealized field sampling design for post-development sites.

and spill sites and reference areas. The tests of hypotheses will provide insight into the effects on the continental slope biota. Relationships between physical/chemical variables and biological variables will also be examined. The data will be used to provide first-order estimates of the extent of impact. A screening level ecological risk assessment for the activities will also be performed.

Dr. Alan Hart is the Science Director of Continental Shelf Associates, Inc. located in Jupiter, Florida. He has 20 years of experience in marine environmental science, including major research programs for federal, state, and industrial clients. He has been involved in characterization and monitoring studies covering a wide range of human activities in the marine environment, including oil and gas operations, dredged material disposal, beach restoration, and sewage outfalls. Dr. Hart received his B.S. in zoology from Texas Tech University in 1973 and his Ph.D. in biological oceanography from Texas A&M University in 1981.

JOINT INDUSTRY PROJECT, GULF OF MEXICO COMPREHENSIVE SYNTHETIC BASED MUDS MONITORING PROGRAM: AN OVERVIEW

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Continental Shelf Associates, Inc. and its subcontractors and consultants are conducting the Gulf of Mexico Comprehensive Synthetic Based Muds Monitoring Program. This program is being funded by a consortium known as the SBM Research Group, which is composed of offshore operators, mud companies, chemical companies, the Minerals Management Service (MMS), and the Department of Energy.

The overall objective of the program is to assess the fate and effects (physical, chemical, and biological) of discharged cuttings drilled with synthetic based mud (SBM) ("SBM cuttings") at continental shelf (40 to 300 m) and deepwater (>300 m) Gulf of Mexico (GOM) sites. This assessment will be used to provide

- the U.S. Environmental Protection Agency (USEPA) with scientific data upon which to base effluent limitations for the discharge of SBM cuttings; and
- the oil and gas industry with scientifically valid data for the environmental assessment of the discharge of SBM cuttings.

There are four specific sub-objectives for the study:

- determine the thickness and areal extent of SBM cuttings accumulations on the seafloor and the magnitude and temporal behavior of SBM base fluid concentrations in sediments near discharge sites representative of GOM conditions at both continental shelf (40- to 300-m depth) and deepwater (>300-m depth) discharge sites;
- determine the temporal behavior of SBM base fluid concentrations in sediments near discharge sites representative of GOM conditions at both continental shelf (40- to 300-m depth) and deepwater (>300-m depth) discharge sites;
- document the physical-chemical conditions in sediments in areas where SBM base fluids are present and compare these conditions with conditions in reference sediments distant from SBM discharges; and
- determine whether a zone of biological effect has developed related to the discharge of SBM cuttings, and if detectable, determine its dimensions.

There are four cruises for the program: Scouting Cruise, Screening Cruise, Sampling Cruise 1 and Sampling Cruise 2. During the Scouting and Screening cruises, preliminary sampling was conducted at study sites to gather data that were used to guide sampling, to designate sampling strata, and to test field and laboratory methodologies. After this preliminary sampling was conducted and the data had been reviewed, the sampling design at each study site was determined, and two sampling cruises were designed to gather data to test statistical hypotheses addressing the objectives of the program.

The Scouting Cruise was conducted in June 2000 as a preliminary survey of a wide range of sites on the continental shelf to 1) assess the extent of cuttings accumulations; 2) assess the suitability of each study site for further sampling during the program; and 3) guide further sampling operations. Based on information gathered about each platform, a remotely operated vehicle (ROV) survey was conducted at 10 selected study sites around the area where cuttings were discharged (Figure 2A.4). The purpose of this ROV survey is to determine if cuttings piles were present and to attempt to assess the distribution of cuttings. Other factors that could affect future sampling at the platform, such as pipeline placement, also were noted. To identify and survey the potential cuttings piles, the ROV was equipped to collect sector-scanning sonar, video, and altimeter data. The sector-scanning sonar was be used to detect and determine the areal extent of the cuttings pile based on acoustical signature. The ROV altimeter was used to determine the cuttings pile vertical relief. The video data was used to document visually detectable differences in substrate texture and vertical relief. The results of this cruise were used to select five of ten continental shelf study sites where the subsequent Screening Cruise was to be conducted.

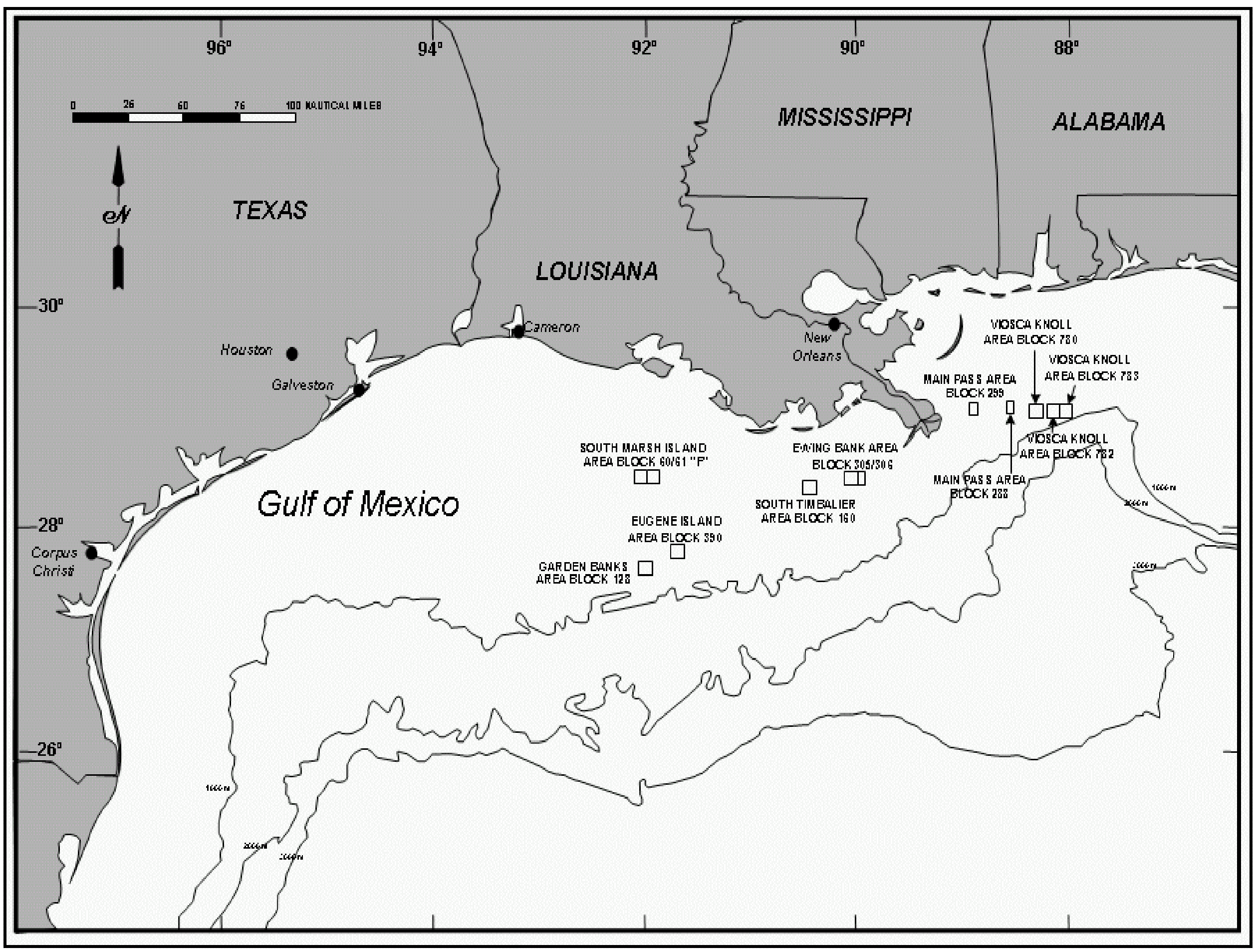

Figure 2A.4. Locations of sites visited during the Scouting Cruise.

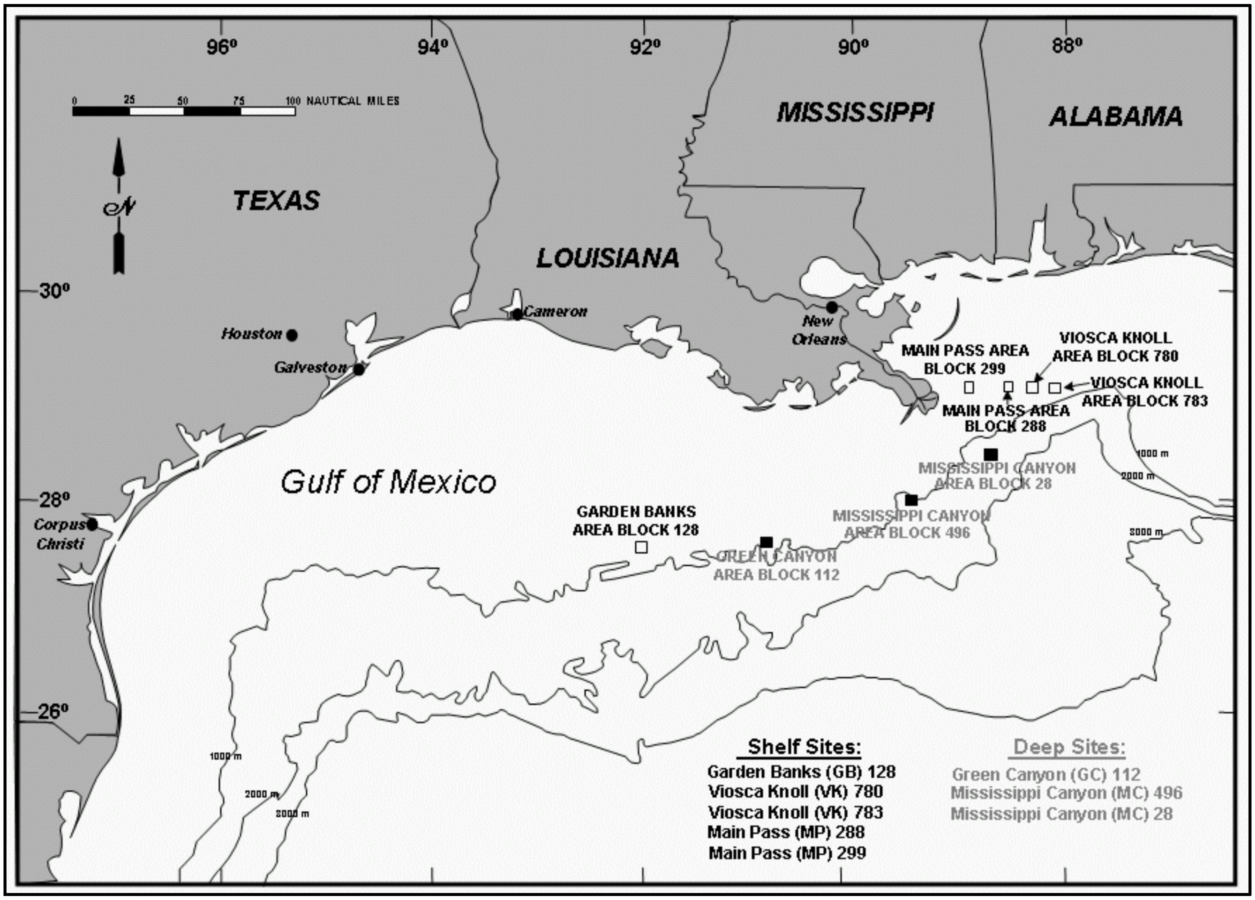

Figure 2A.5. Sites sampled during the Screening Cruise.

During the Screening Cruise (July/August 2000), three deepwater sites and five continental shelf sites were surveyed (Figure 2A.5). The purpose of this cruise was to 1) provide a detailed mapping of the cuttings pile at each platform; 2) assess sediment SBM concentrations and sediment physical-chemical conditions at all eight sites; 3) test and refine the proposed field and laboratory methods; and 4) make preliminary biological and sediment-toxicity assessments at the five continental shelf sites. To provide a detailed mapping of the cuttings pile(s) at each platform during the Screening Cruise, an ROV was equipped with instrumentation to provide high resolution swath bathymetry and simultaneously collected side-scan sonar data. The ROV also was equipped with a videocamera for visual observations. At three sediment sampling stations at each platform, a sediment profile imaging (SPI) system also was deployed. The SPI system provides information concerning redox potential discontinuity (RPD) depth, sediment texture, cuttings, and macroinfauna. A hydrographic profile (temperature and salinity) was conducted at each study site. At each of the eight sites, six samples were collected for physical and chemical measurements of sediment conditions. Three of these samples were collected at random locations near the platform or template, and three were collected at random reference locations. Samples were collected for redox profiling measurements; grain size and mineralogy; SBMs and total petroleum hydrocarbons (TPHs); metals (aluminum, arsenic, barium, cadmium, chromium, copper, mercury, iron, nickel, lead, vanadium, and zinc); total organic carbon (TOC); and carbonate. Six infaunal samples and six sediment toxicity samples were collected at the five continental shelf sites for preliminary biological and sediment-toxicity analyses. In addition, two cores that were collected at each of the eight sites were vertically sectioned in 1- to 2-cm (or other appropriate) increments, and these sections were analyzed separately for grain size, metals, and SBM to investigate vertical layering and thickness of the cuttings pile. An additional sediment sample was collected at a discretionary location at each study site. The sample was located in suspected cuttings accumulations identified during the mapping effort described previously to confirm the presence of cuttings as identified by acoustical and visual (videocamera) observations. At one deepwater site, the Pompano II subsea drilling template in MC 28, additional discretionary samples were collected at locations previously sampled.

Based on the data acquired during the Screening Cruise, a number of decisions concerning sampling during the two sampling cruises were made. The boundaries of three strata were designated: near-field (<100 m), transition (100-250 m), and reference zones (>3,000 m). Platform sites were designated as primary or secondary, which affected what sampling occurred at each study site. The three deepwater study sites and three of the five continental shelf study sites were primary sites, and the remaining two continental shelf sites were secondary sites. Just prior to the beginning of Sampling Cruse 1, it was determined that operations would be occurring at two of the previously selected sites and that these activities made it infeasible to continue to use these two sites for the remainder of the study. Two alternative sites were selected, and Sampling Cruise 1 was conducted in May 2001 at the eight study sites (Figure 2A.6).

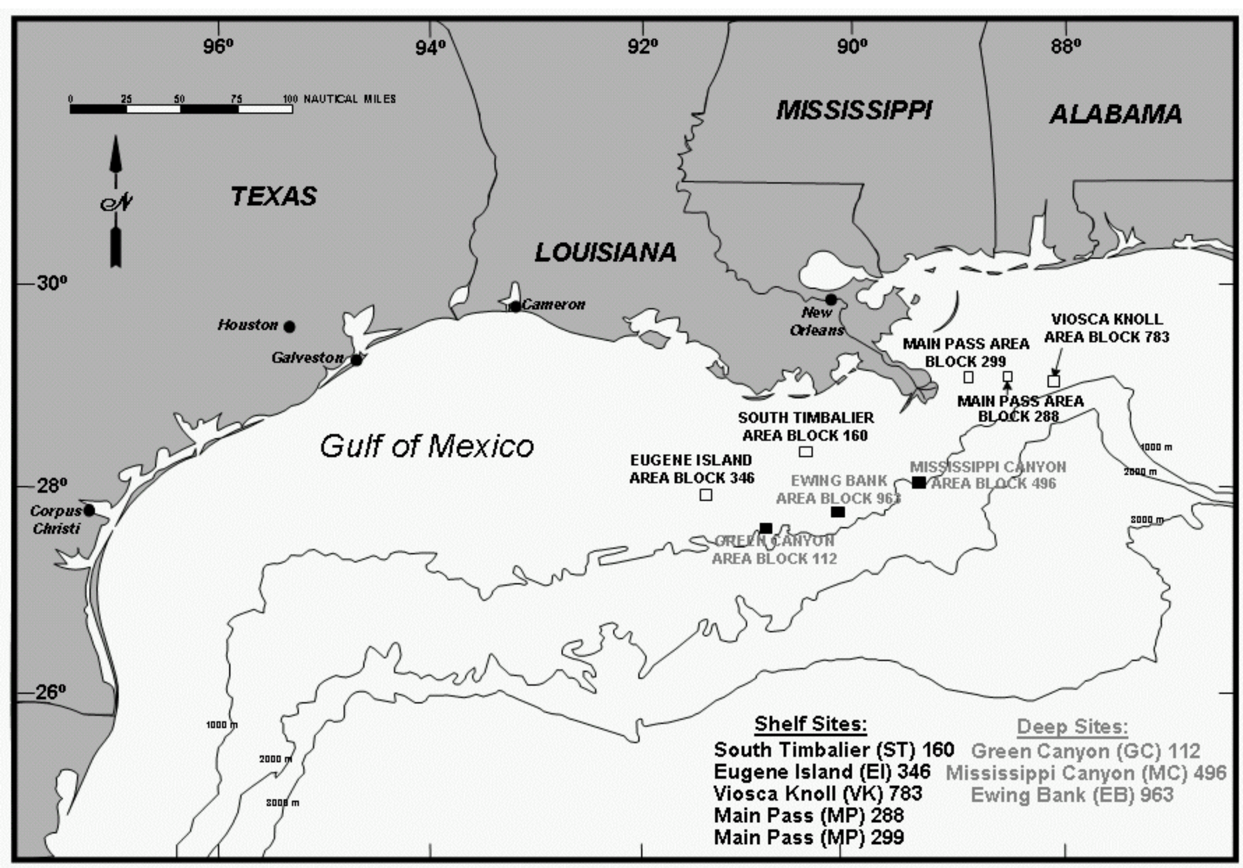

Figure 2A.6. Study sites for Sampling Cruises 1 and 2.

During Sampling Cruise 1, a hydrographic profile (temperature and salinity) was performed at each platform site. At the primary platform sites during each Sampling Cruise, sediment samples were collected at 18 locations—six locations in each of the three sampling strata. These samples were analyzed for hydrocarbons (SBM and TPHs), metals, grain size, paleontology, TOC, and the presence of cuttings (visual analysis by trained mud loggers). Samples of pore water also were collected and analyzed for metals at two sediment sampling locations at each primary platform site. At the primary continental shelf sites, samples for analysis of macroinfauna and sediment toxicity were collected. An additional core was collected at each primary site during Sampling Cruise 1 to be analyzed for selected radionuclides to determine sediment accumulation rates; sediment mixing rates from biological and physical processes; and identification of the presence and thickness of layers of SBM cuttings. SPI images were collected at 12 locations at each primary platform. Sampling at the two secondary continental shelf platform sites was similar to that at the primary sites, but the suite of analyses was not as extensive. Sediment samples were collected at 18 locations—six locations in each sampling stratum, and these samples were analyzed for hydrocarbons (SBM and TPHs), grain size, mineralogy, TOC, and the presence of cuttings. SPI images were collected at 12 locations at each secondary platform.

It is anticpated that Sampling Cruise 2 will be conducted in May 2002. Sampling during this cruise will be the same as Sampling Cruise 1 except sediment samples will not be collected for analysis of radionuclides.

Data collected during the two sampling cruises will be analyzed to address the objectives of the program. Statistical hypotheses will be tested using linear models. Community structure of the infauna will be examined. The sediment quality triad approach will be applied, and a screening level ecological risk assessment will be conducted to gain an understanding of the environmental effects of discharged SBM cuttings.

Dr. Alan Hart is the Science Director of Continental Shelf Associates, Inc. located in Jupiter, Florida. He has 20 years of experience in marine environmental science, including major research programs for federal, state, and industrial clients. He has been involved in characterization and monitoring studies covering a wide range of human activities in the marine environment, including oil and gas operations, dredged material disposal, beach restoration, and sewage outfalls. Dr. Hart received his B.S. in zoology from Texas Tech University in 1973 and his Ph.D. in biological oceanography from Texas A&M University in 1981.

SITE SELECTION: FROM DATABASE TO GIS

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INTRODUCTION

The API SBM Seabed Survey project required the selection of several sites within the Gulf of Mexico where SBM-coated cuttings have been discharged. This discussion will describe the process used to select survey sites for the project.

SITE SELECTION OBJECTIVES

The objective of site selection was to choose study sites for the four project cruises. The project design specified survey of five shallow-water sites—defined as water depths <300 m—and three deep-water sites—defined as water depths >300 m. To handle unforeseen problems, five alternate shallow and three alternate deep sites were also selected.

For the first cruise, all ten primary and alternate shallow sites were visited and investigated. No deep-water sites were visited on the first cruise. For the last three cruises, the top five shallow sites and top three deep sites were initially selected.

The goal was to revisit the same shallow and deep sites during all cruises. Sample collection problems at one site and the addition of new wells at three sites, however, required substituting alternates for one deep site and three shallow sites.

DATA COLLECTION

Mud company records were used to build the initial database of GOM wells where SBM drilling and cuttings discharges had occurred. The data collected included the operator, the block, spud/completion dates, water depth, type of drilling fluid, and estimates of discharge quantities. The operator of each well in the data set was contacted to obtain permission to sample their site if it was selected. The original database included ~360 wells and side tracks in 165 different blocks.

DATABASE GENERATION

The initial database was reduced to 71 wells after considering several restrictions. To minimize boat travel time, western sites were excluded. Sites within a 25-mile radius of the mouth of the Mississippi were excluded. Because of box core tether limits, sites in greater than 700 m of water were excluded. Sites older than approximately three years were excluded. Also, sites without adequate descriptive data were excluded.

GIS MAPPING

The 71 wells were mapped using GIS software. The maps allowed visualization of well locations and important selection criteria. Spud dates and drilling fluid type were identified using different symbols marking the well location. Discharge volumes were identified using different colors for the symbols. These maps were used to aid site selection during project team meetings.

DATA VALIDATION

The 71 wells were further reduced to 25 sites primarily based on the type of drilling fluid used and the amount of SBM cuttings discharged. For these short-list sites, the operators were contacted to verify the existing data on each well, to describe future drilling plans, and to supply additional logistical and safety data.

SITE SELECTION MEETINGS

Final site selection was based on consensus during several meetings held during 2000. Using a set of selection criteria, the ten sites visited during the first project cruise were selected by the site selection subgroup.

Site selection for the other three cruises was made by the entire project team during a meeting following cruise 1. In this meeting, the final ten shallow and six deep primary and alternate sites were chosen.

Both the full program workgroup and the site selection subgroup included MMS personnel.

SITE SELECTION CRITERIA

A meeting of the site selection subgroup was held to rank the 25 short-listed sites after feedback was received from the operators. Several selection criteria were considered to make the ranking including type of SBM, discharge volume, and age of the well or wells.

Internal olefin-based (IO) SBM was the most common type in use in the GOM at the time of site selection. Because of this, the project decided that the majority of the chosen sites should have used IO SBM. Also, because of the specific limits for ester-based SBMs in the recently promulgated EPA SBM Effluent Guidelines, the group attempted to include sites where only ester-based SBM was used; however, none of the 71 sites used only ester-based fluids. Some of the selected sites included the discharge of ester-base SBM cuttings in addition to other SBM types.

Sites with higher volumes of SBM cuttings discharges were preferred. The project team preferred recently drilled sites to study the speed of seabed recovery. Sites with platforms were preferred because they simplified sample collection by providing a reference position.

Sites where drilling was planned during the study were excluded because of the project goal of studying seabed recovery. Fresh SBM cuttings on the seabed would eliminate the ability to study the amount of recovery that occurred between cruises.

Sites distant from other drilling operations were preferred to reduce the influence of other discharges.

Attempts were made to identify and exclude sites where accidental releases occurred.

The project team preferred sites outside the <40 m anoxic zone that occurs in late summer in certain parts of the GOM. There was concern that anoxia would influence the benthic fauna and possibly affect recovery rates. One alternate site that was later substituted as a primary was on the edge of the anoxic zone. Research determined that this site did not become anoxic every year. Also, sampling cruises would occur in May when anoxia was not occurring.

Most of the selected sites did not meet all these criteria. There simply weren’t enough sites in the GOM that perfectly matched the criteria.

CONTINGENCY PLAN FOR UNFORESEEN PROBLEMS

Prior to the first cruise, a contingency plan was developed to handle unforeseen problems with survey sites. The plan called for ranking and selecting alternate sites to be used as substitutes if necessary. When problems arise, conference calls are held to discuss options and make decisions. The entire project team is invited to attend conference calls.

If urgent decisions are needed, the Program Manager has authority to make substitutions.

It was discovered between the second and third cruises that three of the primary study sites were scheduled to have additional drilling. Since one of the project goals is to study seabed recovery over time, alternates were substitutes for these sites—one was in deep water and two in shallow.

Also, box-core sampling of one of the shallow sites during the second cruise was unsuccessful because the corer could not penetrate the hard bottom near the wellhead. For this reason, an alternate site was substituted for this cruise. The ship was equipped with a special corer designed for harder bottom on future cruises.

IMPORTANT CONSIDERATIONS/FINDINGS OF SITE SELECTION PROCESS

It is important when performing these types of selection activities to start work enough in advance to allow preliminary investigative activities to be thorough.

When working with a group that includes operators, mud companies, and regulators, group consensus on decisions should be obtained whenever possible.

Be prepared for the unexpected, and set up contingency plans to handle problems.

Although the original database included 363 wells that were drilled with SBM, the acceptance criteria believed necessary to insure a quality study resulted in this list being narrowed to only a few leading candidates. The chosen sites were those that most closely met the selection criteria, however, certain criteria were relaxed for many of these sites. There just weren't enough sites in the database to provide 16 ideal survey locations.

Dr. Tim Nedwed currently works for ExxonMobil Upstream Research Company studying the fate and effects of offshore discharges. He received a B.S. in chemical engineering from the University of Kansas and an M.S. and Ph.D. in environmental engineering from the University of Houston.

Stephen Rabke, Senior Environmental Scientist, has a B.S. degree and fourteen years of experience in the field of aquatic toxicology. Mr. Rabke is responsible for managing M-I L.L.C.'s environmental testing laboratory. His functions include providing toxicological and research support for product development, development of new test method, and participating in industry workgroups.

Tara Montgomery is a geographer in the Leasing and Environment section of the Minerals Management Service within the Gulf of Mexico OCS Region. After receiving her M.S. in geography in 1994, she began her career in the federal service in the Bureau of Land Management in Burley, Idaho, as a GIS Coordinator and later transferred to the Winnemucca, Nevada, district where she also served as GIS Coordinator for two years prior to moving to New Orleans.

SYNTHETIC-BASED MUDS: WHAT'S THE BIG DEAL?

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The past decade has seen the introduction of new drilling fluids that use synthetic material as the base fluid. The main impetus for their development is to replace the mineral oil and and less environmentally friendly diesel-based fluids that had been used for several decades. The need for an organic base rather than a water base arises during difficult drilling situations due to formation composition or technical problems such as stuck pipe.

The use of a new base fluid raises questions about the effects on the environment and appropriate discharge criteria.

WHAT ARE SYNTHETIC-BASED MUDS (SBMs)?

Synthetic-based muds consist of a base fluid (continuous phase) that is a water insoluble synthetic organic material. The Environmental Protection Agency defines the fluid as"…produced by reaction of purified chemical stock (not fractionation, distillation, cracking, or hydroprocessing)… ." The base fluid is required to have less than 0.001 weight percent polynuclear aromatic hydrocarbons. The base fluid can be one of several synthetic materials, primarily paraffins, olefins, and esters. The polymerization of olefins is most common and is used to make poly alpha olefins (PAO), linear alpha olefins, or internal olefins. The Fischer-Tropsch synthesis is used to make linear paraffins (n-paraffin).

WHAT IS THE HISTORY OF THEIR USE?

Synthetic-based fluids were first used in the Norwegian sector in 1990. In 1995, 49 wells were drilled off the coast using synthetics. The first use was in the United Kingdom sector in 1991 and by end of year, more than 169 wells were drilled in North Sea. Synthetics were first used in the Gulf of Mexico in 1992.

WHAT ARE THE ENVIRONMENTAL ISSUES?

The use of synthetic-based drilling fluids raises several environmental concerns. The cuttings do not disperse like those from wells drilled with water-based fluids, and there is concern that a large pile of cuttings will form near the drill site. The pile would result in the burial of organisms that live in the surrounding environment. Since the drilling fluids are organic, the degradation of the fluids on the seafloor could result in localized anoxia of the surface sediments. Another issue is how long the fluids will stay in the environment or whether they are easily biodegradable. Also, there is concern that the fluids or their degradation products are toxic to marine organisms.

Once these fluids are discharged on the seafloor, there are questions about the recovery time necessary for the seafloor to return to an undisturbed state.

The North Sea experience is different from that of the Gulf of Mexico. Large, multiple-well discharges and shunting in deeper water are characteristic of the drilling practices. Synthetic base fluids used in the early 1990s also exhibited high retention levels on the discharged cuttings. As a result of the drilling practices, thick cuttings piles often formed, resulting in localized anoxia and slow to no recovery on the pile. Sheens were often produced from the discharge. A zone of benthic impacts was clearly observed around structures. The environmental effects were similar to those with earlier fluids.

WHO CARES?

The use of synthetic base fluids is important to oil companies because they reduce drilling time and therefore the costs of renting a drilling rig. The vendors, including mud companies and chemical companies, are interested because of the new products for the market. Regulators and the environmental community are concerned about the short- and long- term environmental effects of discharges or disposal on land.

WHY DO THEY CARE?

The use of synthetic-based drilling fluids has advantages if the cuttings can be discharged, since this reduces costs as well as environmental effects from disposal on land. Oil-based drill fluid derived cuttings cannot be discharged and must be disposed of in landfills onshore, resulting in many environmental problems. The drill times using synthetic fluids are reduced up to 60% when compared to water-based fluids under the same conditions. Drilling with synthetic fluids also results in the generation of less cuttings and therefore reduced mud discharges. In deepwater, the use of synthetic fluids helps inhibit gas hydrate formation and is a good cuttings carrier. Faster drilling and disposal at sea also results in reduced air emissions and fuel use.

WHERE ARE WE GOING?

The industry is working to develop better performing fluids with lower toxicity and better degradability. Better solids control equipment is now required, which means that less fluid is discharged with the cuttings. The result of all these efforts is less environmental impact.

Dr. James Ray is the manager of the Environmental Ecology and Response section at Shell Global Solutions (US) Inc. (formerly Equilon Technology). He serves as Research Coordinator for the Industry Synthetic Based Drilling Muds Research Program and Chairman of the Offshore Operators Committee, Environmental Sciences Subcommittee. Dr. Ray received his Ph.D. in Biological Oceanography from Texas A&M University and has worked on Gulf of Mexico environmental issues for almost 30 years.

EVALUATING THE SEDIMENT TOXICITY OF SYNTHETIC BASED DRILLING MUDS IN THE LABORATORY AND IN THE FIELD

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Bioassays have been used to evaluate the toxicity of sediments to benthic organisms since the 1970s. They were originally used to evaluate the toxicity of dredge spoils to assess suitability for discharge. Since then, sediment bioassays have been an important tool to evaluate the toxicity of sediments in rivers, streams, and coastal environments.

While bioassays have been used to assess the toxicity of water based drillings muds and produced water in the offshore environment, sediment bioassays are relatively new to offshore oil and gas industry. Concerns about sea floor impacts from drill cutting containing synthetic based drilling muds sparked interest in using a bioassay to assess the potential toxicity of SBMs in sediments.

The offshore oil and gas industry, through the American Petroleum Institute and the National Ocean Industries Association, in cooperation with the EPA, evaluated several sediment bioassays to assess the toxicity of SBMS. These bioassays included 10-day tests with the sediment dwelling amphipods, *Rhepoxinius abronius* and *Leptocheirus plumulosus,* and variations of the mysid shrimp drilling mud bioassays and Microtox test where sediment was the exposure medium. The most promising bioassays was the 10-day bioassays with *Leptocheirus plumulosus*. The organism proved sensitive to SBMs, and could be cultured in the laboratory. Moreover, test methods using the organism already existed.

Leptocherius bioassays are being used to evaluate different aspects of SBM toxicity. First, they are being used to evaluate the toxicity of the base fluids used to make the drilling muds. Second, the bioassays are used to evaluate and control the toxicity of drilling muds used in the offshore. Finally, they are being used in sea floor assessments to assess toxicity and, perhaps indirectly, benthic impacts of drill cuttings associated with SBMs. The remainder of this paper deals with the toxicity testing of base fluids, field muds and offshore sediments.

BASE FLUIDS

Table 2A.1 presents data on the toxicity of diesel oil and different synthetic base fluids to *Leptocheirus.* The base fluids rank in toxicity from the most toxic to the least toxic: diesel>linear alpha olefin (LAO) >internal olefin (IO)>ester. While the absolute toxicity values appear to vary among different laboratories and may be affected by sediment composition, the toxicity ranking of the different base fluids has remained consistent.

Table 2A.1. Toxicity of base fluids in sediments to the amphipod, *Leptocheirus plumulosus*.

Base Fluid	4 Day LC50, mg/kg	10 day LC50, mg/kg
Diesel Oil	>1,600	1,249
Internal Olefin	31,269	14,895
Linear Alpha Olefin	6,171	1,855
Ester	30,941	20,000

TOXICITY OF WHOLE SYNTHETIC DRILLING MUDS

New SBM discharge permit regulations require synthetic muds used in the field to undergo the four-day sediments bioassay with *Leptocheirus plumulosus*. Drilling muds are largely composed of based fluid, but also contain emulsifiers, weighting agents and other additives to enhance drilling performance. Table 2A.2 presents the results of four bioassays for each of four different drilling muds. The data show that while there is significant variability in the absolute toxicity values, the relative ranking of the different drilling muds remain consistent.

Table 2A.2. Results of four bioassays for each of four different drilling muds.

Drilling Mud	4 day LC_{50} (ml/kg)	L 95% CI	U 95% CI	Avg.	CV%
Diesel	1.38	1.17	1.63		
Diesel	1.04	0.52	2.02		
Diesel	0.92	0.74	1.14		
Diesel	0.88	0.55	1.19	1.055	21.5
LAO	2.89	2.27	3.72		
LAO	2.47	1.83	3.33		
LAO	2.55	1.24	5.04		
LAO	3.5	2.3	5.9	2.9	16.4
C1618IO	7.9	2.3	18.5		
C1618IO	40.4	27.8	58.8		
C1618IO	51				
C1618IO	13.9	5.4	35.9	28.3	73.1
Ester	77.1	62.6	97.9		
Ester	31.3	27.7	25.4		
Ester	85.7	73.8	100.3		
Ester	44	35	55	59.5	43.7

SEDIMENT TOXICITY IN SEA FLOOR ASSESSMENT

Sediment bioassays are most valuable in sea floor assessment when they are collected along with sediment chemistry and biological data (i.e., abundance and diversity of benthic fauna). This is because sediment bioassay results by themselves are often too variable to establish a casual relationship between suspect contaminated sediments and toxicity. This variability can sometimes be related to non-contaminant related factors such as sediment type, sediment organic content and anoxia. In both the API/NOIA survey and the MMS deepwater environmental program, toxicological, chemical and biological data are being collected. This will allow a "sediment triad analysis" to be performed. A sediment quality triad weighs all three lines of data to more definitively determine whether sediment impacts are indeed due to chemical contaminants, such as SBMs.

In both the API/NOIA and MMS environmental studies, ten-day sediment bioassays are being performed with the amphipod, *Leptocheirus plumulosus*. The toxicity data from neither project are complete, so it not possible to derive conclusions at this time. However, preliminary data suggest that toxicity is predominantly in the samples closest to the site of discharge. It is premature to conclude that this toxicity is related to the presence of drilling muds.

CONCLUSIONS

Sediment toxicity bioassays have been used to evaluate the toxicity of synthetic base fluids, drilling muds, and sediments in the vicinity of drilling discharges. The sediment bioassay using *Letocheirus plumulous* has been adopted by the EPA to regulate the discharge of SBMs. Field studies are underway that will use the sediment bioassays to delineate environmental impacts. Bioassay data on sediments collected in the field, along with chemical and biological data, will provide important information on whether SMBs are causing significant environmental impacts to the sea floor.

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Dr. Andy Glickman is a senior staff environmental scientist with ChevronTexaco and serves as an internal consultant on the environmental impacts of drilling and production operations around the world. He is co-chair of the API/NOIA synthetic drilling muds toxicity work group and is involved in drilling discharge assessments in Brazil, Angola and Caspian Seas, as well as the Gulf of Mexico. Andy has worked for ChevronTexaco for 19 years. He received his Ph.D. in environmental toxicology from the Medical College of Wisconsin and, prior to working for ChevronTexaco, was a research toxicologist at the University of California – Berkeley.

DEGRADATION OF SYNTHETIC DRILLING MUD BASE FLUIDS BY GULF OF MEXICO SEDIMENTS

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INTRODUCTION

The Gulf of Mexico (GOM) is a major center for offshore oil resources in the U.S. Recovering oil from deep-sea, offshore platforms is prohibitively expensive. Of the several costs that must be considered, one is the cost of exploration and drilling the wells. The disposal of cuttings coated with drilling mud is a major problem in this operation. Synthetic base fluids (SBF) have been developed for use in deep sea drilling, where the use of aqueous phase muds is problematic. SBF as part of drilling mud act to cool and lubricate the drill bit and to help bring rock cuttings to the surface. We have been working with the American Petroleum Institute (API) and the US EPA to develop a standardized test to screen the biodegradability of SBF to allow them to be licensed for use offshore. If the cuttings coated with synthetic-based drilling muds cannot be disposed of offshore, the cost to bring them back for land disposal would prohibit any major plans to capitalize on the GOM resources.

The API and EPA funding has been directed at the development of a standardized test to determine the biodegradability of synthetic base fluids. It has not been used to develop accurate predictions on the long-term ecological impact of the disposal of these fluids on the deep GOM sediments. The API and EPA sponsored work has used sediment retrieved from near-shore locations, such as Sportsman's Road in Galveston TX, in the development of a standard test, known as the Closed Bottle Biodegradation Test, which is used to evaluate SBF biodegradability. These sediments were spiked with the test fluids or standards and incubated at atmospheric pressure at 29°C. The tests have shown that most of the synthetic drilling mud base fluids are biodegraded both aerobically and anaerobically by the organisms in near shore sediment.

Microbes from deep-sea sediments are also expected to degrade synthetic base fluids, but the low temperatures and high hydrostatic pressures characteristic of deep-sea environments will have an effect on microbial activity. Therefore, an essential question is what is the time required for biodegradation of the different types of SBF. Tests with many more sediments, specifically with sediments obtained from the deep GOM, will help to improve the understanding of how that population will react (and has reacted) to the addition of drilling mud base fluids. A model to predict how fast the sediment will recover under realistic conditions would be invaluable to both legislators and industry alike.

CONCEPTUAL MODEL DEVELOPMENT

Figure 2A.7 depicts the major chemical and biological processes that are expected to play a role in the recovery of the deep gulf environment from the deposition of synthetic base fluids. Many aspects need to be understood in order to develop the model beyond the theoretical stage. Some of these aspects can be obtained through literature sources and from data that has already been collected by our lab and by other researchers. Some aspects must be determined through new research.

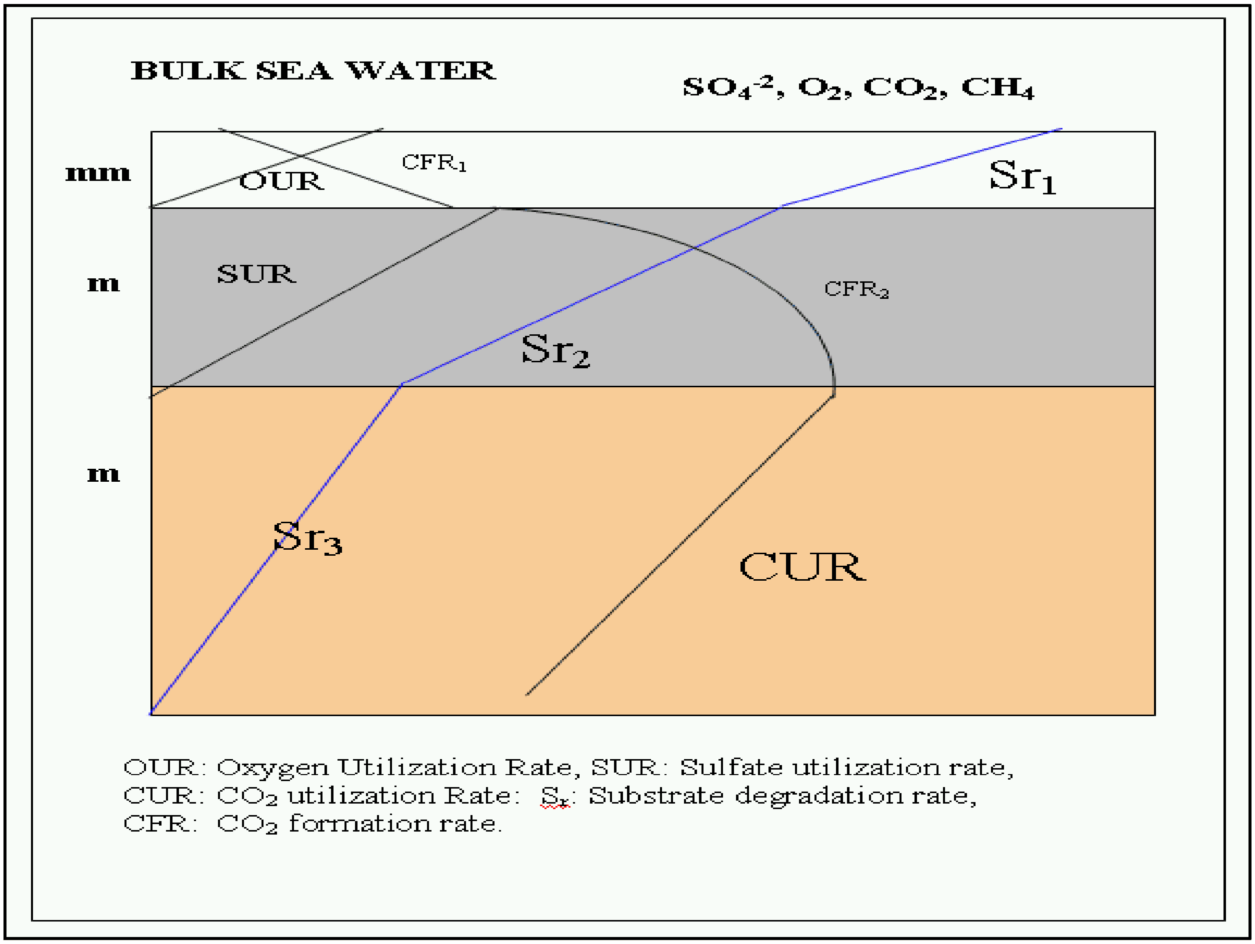

Figure 2A.7. Depiction of the major chemical and biological processes involved in the microbial-mediated removal of synthetic-based drilling mud base fluids in deep GOM sediments.

The model is intended to predict the impact of the disposal of cuttings coated with synthetic based fluids on the deep GOM sediments and the time required for recovery of the sediment from these impacts. The model components include: physical, chemical, and biological elements.

The prediction of the fate of the SBF in the sediment over time and through sediment depth is the goal of the model. The fate of SBF in the deep-sea sediment will depend on many factors, including:

1. The original deposition concentration and rate. This is governed by drilling practices and will be determined through conversations with industry representatives.
2. The partitioning of SBF between SBF-laden rock cuttings and sediment pore water. This is governed by dissolution equilibrium and rate kinetics, which are in turn effected by the sorption kinetics of SBF to sediment particles, as well as the kinetics of SBF biodegradation in the sediment.
   a) the kinetics and equilibrium of sorption of SBF to the sediment can be predicted from the chemical and physical properties of the SBF and the sediments.
   b) the biodegradation kinetics can be determined through experimental studies but are known to depend on
      i) the concentration of the SBF,
      ii) the presence of a capable microbial population, and
      iii) the concentration of electron acceptors (O_2, SO_4^{-2}, CO_2) present in the environment. The availability of a particular electron acceptor is dependent on chemical and biological parameters, as described below:
         · O_2 - the initial concentration in the sediment pore waters
         - the oxygen uptake rate (biodegradation kinetics)
         - the rate of oxygen dissolution into the pore waters
         ·SO_4^{-2} - the initial sulfate concentration
         - the oxygen concentration
         - the sulfate utilization rate (biodegradation kinetics)
         - the dissolution of sulfate into the pore waters
         · CO_2 - the initial CO_2 concentration
         - the CO_2 generation rate (biodegradation kinetics)
         - the CO_2 utilization rate (biodegradation kinetics)
         - CO_2 mineral equilibrium

In this project, we will obtain samples of deep GOM sediment. We will measure sorption and desorption of SBF on and off the sediment. We will quantify and characterize the microbial populations of the sediments, before and after exposure to SBF, and measure SBF biodegradation kinetics under aerobic and anaerobic conditions. The information gathered experimentally and the information from the literature will be used to develop a model as a set of linked equations.

The samples of sediment will be incubated at the pressure and temperature (4°C) of their natural seabed. We are in the process of constructing a high-pressure incubation system. This will be placed in a water-cooled bath in a cold room. During the incubations of sediment with SBF we will measure SBF depletion (gas chromatography), electron acceptor consumption (respirometry (O_2), ion chromatography (SO_4^{-2}), or gas chromatography (CH_4)), microbial growth (molecular and cell culture techniques), and the presence of intermediates that may be formed during SBF biodegradation.(gas chromatography).

All of the techniques will be worked out with near-shore sediment to be ready for the deep Gulf samples when they are collected in April or May. This research is unique in that it examines the response of a natural population of cold deep organisms to a contaminant in their environment and will provide a unique opportunity to delineate the populations of deep-sea psychrophilic microbial communities. The majority of deep-sea microbiology is concerned with the populations around hydrothermal vents, which is very different from the deep cold environments. The study also will provide an opportunity to compare the results of degradation studies using natural communities to those from studies using near shore sediments such as the EPA/API closed bottle biodegradation test.

Dr. Deborah Roberts has a B.S. and Ph.D. in microbiology from the University of Alberta, where she worked out the pathway for anaerobic m-cresol degradation. She did post-doctoral work on munitions degradation for three years in Idaho. Dr. Roberts moved to the University of Houston in 1992 where she is now an associate professor.

SESSION 2B

PLATFORM STUDIES II

Chair: Mr. Greg Boland, Minerals Management Service
Co-Chair: Ms. Susan Childs, Minerals Management Service

Date: January 8, 2002

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FOOD WEBS AND ENERGY TRANSFER WITHIN PLATFORM ARTIFICIAL REEFS

Dr. Carl R. Beaver
Dr. Kim Withers
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INTRODUCTION

Nearly 5,000 oil and gas structures in offshore waters of the northwestern Gulf of Mexico (GOM) compose the largest complex of artificial reef structures in the world. Platforms have long been known to increase the biological productivity of sessile attached invertebrates. A portion of this productivity has been assumed to move up the food chain to reef fishes; however, no detailed investigation into the productivity and energy transfer within these systems has been conducted. The biological/ecological contributions of platform reefs to the overall production of fishery-targeted species in the GOM cannot be determined without quantitative study of these system's tropho-dynamics and ecological energetics.

The purpose of this research was to

1. describe qualitatively & quantitatively the energy flow between the fouling community and selected resident reef-fishes;

2. formulate a model of energy flow between fouling-community elements and selected reef fishes; and,

3. develop a food web describing feeding interactions among platform inhabitants and associates.

STUDY SITE

Two platforms in the northwestern GOM were studied to characterize species composition and biomass productivity of their fouling communities and to estimate energy flow between fouling-community elements and selected reef fishes. The structures examined in this study were British Petroleum Exploration's EB165A platform located at 27º 09'13"N, 94º 18'45"W, within the East Breaks (EB) minerals lease block, and Mobil Exploration and Production's HI389A platform, located in the High Island (HI) minerals lease block at 27º54'30" N, 93º35'06" W. The East Breaks 165A platform stands in 243 m of water. The HI389A platform stands in 122 m of water, approximately 2 km southeast of the East Bank of the Flower Gardens National Marine Sanctuary, a natural coral reef environment. Both platforms have been in place for more than ten years. The EB165A platform provides a total of 11,500 m^2 substrate between the surface and 53 m depth, whereas the HI389A platform has approximately 8,350 m^2 surface area between the sea surface and a depth of 53 m.

METHODS

Stomach Content Analysis

Because of the great diversity of fishes associated with both platforms, some criteria had to be established to select representative species for this study. Fish species selected for stomach-content analysis met four criteria.

1. Each had to be a year-round resident of the platform structure.

2. Selected species had to obtain at least a portion of their diet from organisms found within the platform fouling community.

3. Each species also had to be a prey item for a member of the next higher trophic level occurring near the platform.

4. Finally, a selected species had to be present in large enough numbers throughout the year so that removal of individuals during sampling had a minimal likely effect on the population size.

Population levels of selected fishes were assessed using visual survey techniques. These diver-based visual surveys techniques involved point-count surveys for fishes in the water column and swimming transects for those species closely associated with the surface of the structure.

The species selected for stomach-content analysis were *Paranthias furcifer*, the creolefish; *Epinephelus adscensionis*, the rock hind; and *Balistes capriscus*, the gray triggerfish. *Paranthias furcifer* and *Epinephelus adscensionis* are members of the family Serranidae. *P. furcifer* is a common zooplanktivore of offshore reefs in the GOM whereas *E. adscensionis* is known as a common benthic predator of reef systems across the Gulf. The balistid, *Balistes capriscus*, is a common grazer of benthic communities across the Gulf.

Diets for these three species of resident reef fishes were reconstructed using data obtained from analysis of stomach contents. Mean stomach contents for each species were determined quarterly for each of the two platforms. Specimens were collected quarterly by spear and by hook and line. The entire gastrointestinal tract was removed and the contents preserved in a 10% formalin/seawater mixture for laboratory analysis. Prey items were identified to the lowest possible taxon and counted. Prey items were then dried at 60 ºC until a stable weight was obtained. Prey items were assigned to the fouling community, soft-bottom community, plankton community, or classified as unknown, according to the scheme of Ruppert and Fox (1988). The sample number of fishes of a particular species was considered adequate when a plot of the number of diet elements (B) versus the number of samples (N) approached an asymptote, suggesting that additional sampling would provide no substantial additions to the diet.

Length and weight measurements were taken for all fish collected to determine length-weight relationships. Length-weight relationships and population estimates from visual surveys were used to develop biomass estimates for the fish community. Biomass density was calculated from the equation

$$\text{Biomass density} = \sum (P_i \cdot w_i) / m^2$$

where

P_i = the number of individuals of species *i*,
w_i = the mean weight of individuals belonging to species *i*, and m^2 is the surface area in square meters, of the structure from the water surface to a depth of 53 m.

The transfer of energy from the fouling community to the three selected reef fishes was assessed. Food consumption rate for *P. furcifer,* was determined by solving the equation

$$C_t = \frac{(S_t - S_o e^{-k \cdot t}) \cdot k \cdot t}{1 - e^{-k \cdot t}}$$

where

S_o and S_t are the amounts of food in the gut at the beginning and end of a sampling interval t hours long, and k is the instantaneous rate of gastric evacuation (Adams and Breck 1990).

This model is most appropriate for fishes with "fine-grained" diets; it assumes that feeding is more or less continuous and that digestion behaves as an exponential decay process. This method requires estimates of mean stomach contents at the beginning and end of sampling (S_o and S_t) and the instantaneous rate of gastric evacuation (*k*). Sampling is most effective if it extends from periods of feeding activity into periods of inactivity, i.e. from daylight hours into darkness for species that feed during daylight hours only.

Mean stomach contents were determined seasonally from quarterly samples, and prior to evacuation rate experiments. Evacuation rate experiments were performed on *P. furcifer* that were trapped and isolated from their food source. A number of fish were sacrificed at regular intervals to determine mean stomach contents at time *t*. From such data the instantaneous rate of gastric evacuation *k* was determined from the equation

$$k = (1/t) \cdot \log_e (S_0/S_t)$$

where

S_o and S_t are as above, and fish are prevented from feeding during *t* by caging them.

For *E. adscensionis* and *B. capriscus*, food consumption was calculated with the feeding model suggested by Adams *et al*. (1982) for predatory reef fishes:

$$C = \frac{\sum (Pw_i / Bw_i)}{N}$$

where

C = daily ration (% body weight);
Pw_i = estimated total weight at capture of prey when ingested by predator i over a defined 24 hour period;
Bw_i = weight of predator i that consumed those prey; and,
N = total number of predators in the sample, including those with empty stomachs.

This model assumes that feeding is synchronous, and it does not require calculation of feeding frequency provided that time to 90 or 95% of digestion is less than 24 h, as is generally the case in warm-water fishes (Adams and Breck 1990).

Analysis of variance and Tukey's Multiple Range Test were used to evaluate differences in numbers and biomass of selected reef fishes between platforms and among seasons. Analysis of variance was used to test for significant changes in dry weight and caloric value of diet elements from each habitat. The identified sources of variation for this analysis were species, season, platform, depth, light level and water temperature.

ENERGY TRANSFER

For each focal species of fish, we interpreted consumption analysis from the perspective of conventional bioenergetics (Winberg 1956; Brett and Groves 1979; Jobling and Davies 1980; Jobling 1994) to estimate the proportion of consumed biomass and energy resulting in fish growth attributable to each prey compartment.

Due to the difficulties associated with measuring metabolism in a natural setting, certain conventions have been applied to estimate partitions of consumed energy. The convention for standard metabolism (M_S) as computed by Brett and Groves (1979) is 0.5 $kcal \cdot kg^{-1} \cdot h^{-1}$. Winberg (1956) suggests a convention for routine metabolism (M_R) of $2*M_S$, and the cost of metabolic processing or specific dynamic action (SDA) is 15% of total energy ingested (I). Furthermore, Brett and Groves have estimated waste (E) to be 20% of I.

Using these conventions, we developed energy budgets for each species by apportioning the mean daily energy ingested (I) into compartments representing the components metabolism (M), growth (G) and egesta (E) according to the following equation;

$$I = (2*M_S + (0.15*I)) + G + E$$

where

I = the amount of energy ingested,
M_S = standard or basal metabolism,

G = growth, and
E = the amount of ingested energy lost as excretory and fecal wastes.

Numerical data pertaining to feeding rates and prey selection and prey caloric content were used to develop food webs and energy flow diagrams for components of the platform reef community similar to those developed by Polunin and Klumpp (1992) for sections of the Great Barrier Reef off Australia.

RESULTS

Whereas *E. adscensionis* and *B. capriscus* fed almost exclusively upon the fouling community and associated organisms, *P. furcifer* fed primarily upon planktonic organisms throughout the year. However, *P. furcifer* diets did show a significant increase in the number of fouling community organisms consumed during winter and spring sampling periods.

Energy budgets indicated a range of growth efficiencies differing among species and within a single species among seasons. Energy budgets for *B. capriscus*, *E. adscensionis* and both summer and winter stocks of *P. furcifer* are presented in Table 2B.1.

Table 2B.1. Estimates of growth, metabolism and waste for three species of reef fishes at EB165A and HI389A. M_S = 0.5 kcal·kg^{-1}·h^{-1}; M_R = 2 x M_S ; SDA = 15% of I; E = 20% of I; M = M_R + SDA, and G = I - M - E. Dimensions of bioenergetic terms are kcal·fish^{-1}·day^{-1}.

Species	Temperature (ºC)	Mean weight of fish (g)	Ingestion I	M_S	M_R	SDA	Metabolism M	Waste E	Growth G
Paranthius furcifer (summer)	27.6	470	42.3	5.9	11.3	6.3	17.6	8.5	16.2
Paranthius furcifer (winter)	20.7	460	24.8	5.5	11.0	3.7	14.8	4.9	5.1
Balistes capriscus	24.78	646	78.6	7.7	15.5	11.8	27.3	15.7	35.6
Epinephalus adscensionis	24.78	496	58.5	5.9	11.9	8.8	20.7	11.7	26.1

Paranthias furcifer was the most common planktivore at either structure. Populations and biomass varied seasonally and between platforms, ranging from a low of 318 (mean weight 0.48 kg) during the winter at HI389A to a summer high of 636 (mean weight 0.43 kg) at EB165A (Table 2B.1).

Consumption rate for *P. furcifer* was calculated at 1.71 g/h or 50.2 g kg^{-1} day^{-1} during summer and fall sampling periods. This is equivalent to 5.02% of body weight. During winter and spring sampling periods, mean stomach contents were reduced by 36% and consumption during this period was estimated to be 1.09 g/h or 20 $g \cdot kg^{-1} \cdot day^{-1}$

Of the total daily energy consumed by the average *P. furcifer* in summer, 13.58 kcal were obtained from cryptic fouling community elements and 28.77 kcal were obtained from the plankton community (Figure 2B.1). During summer, *P. furcifer* utilized approximately 42% of ingested energy for metabolism and 38% for growth.

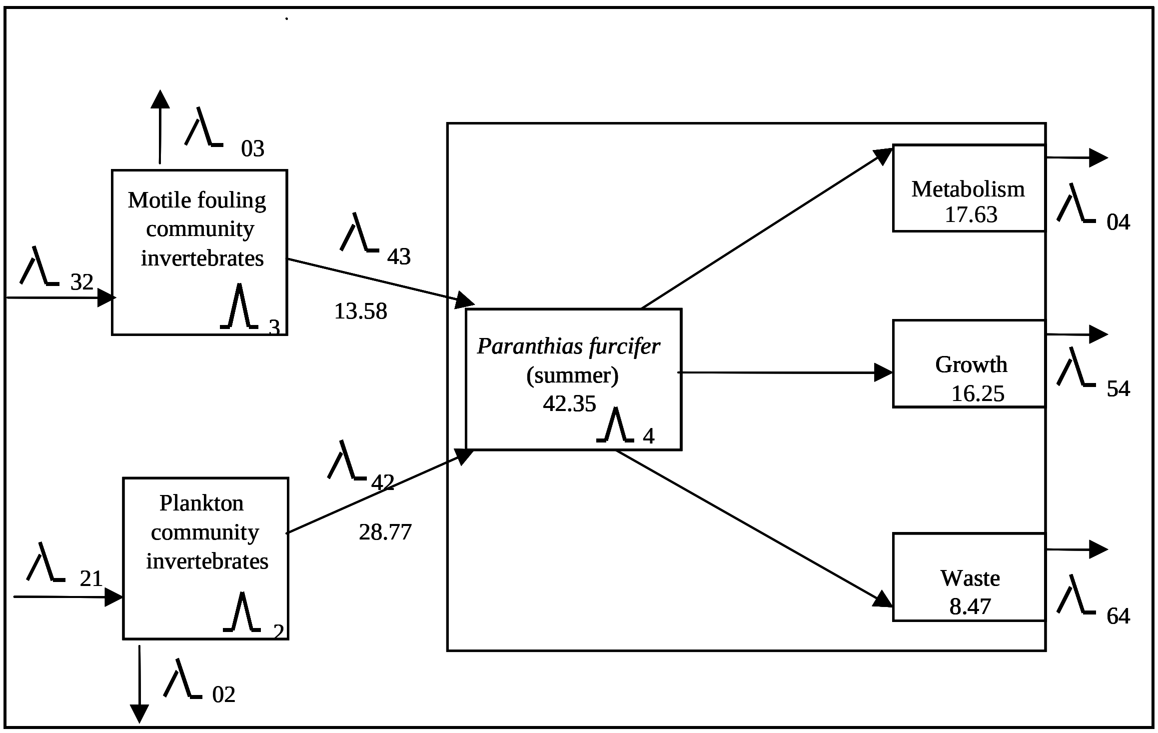

Figure 2B.1. Compartment model of energy ($kcal \cdot individual^{-1} \cdot day^{-1}$) flow (Pianka, 1994) for summer stocks of *Paranthias furcifer* at HI389A from July to September 1995 and EB165A from July to September 1996. λ = rate of energy transfer between levels, subscripts represent trophic level as follows: 0 = world external to system, 1 = autotrophs, 2 = herbivores, 3 = detritivores, 4 = first order carnivores, 5 = top carnivores, 6 = decomposers. Numbers represent kilocalories obtained from each trophic level and/or apportioned to each function.

During winter, *P. furcifer* obtained an estimated 9.0 kcal/day from motile fouling community invertebrates with an additional 15.9 kcal/day from plankton community invertebrates, giving 24.9 kcal/day of total consumption (Figure 2B.2). During these cooler months, *P. furcifer* committed 59.33% of consumed energy to metabolism, leaving 21.29% for growth.

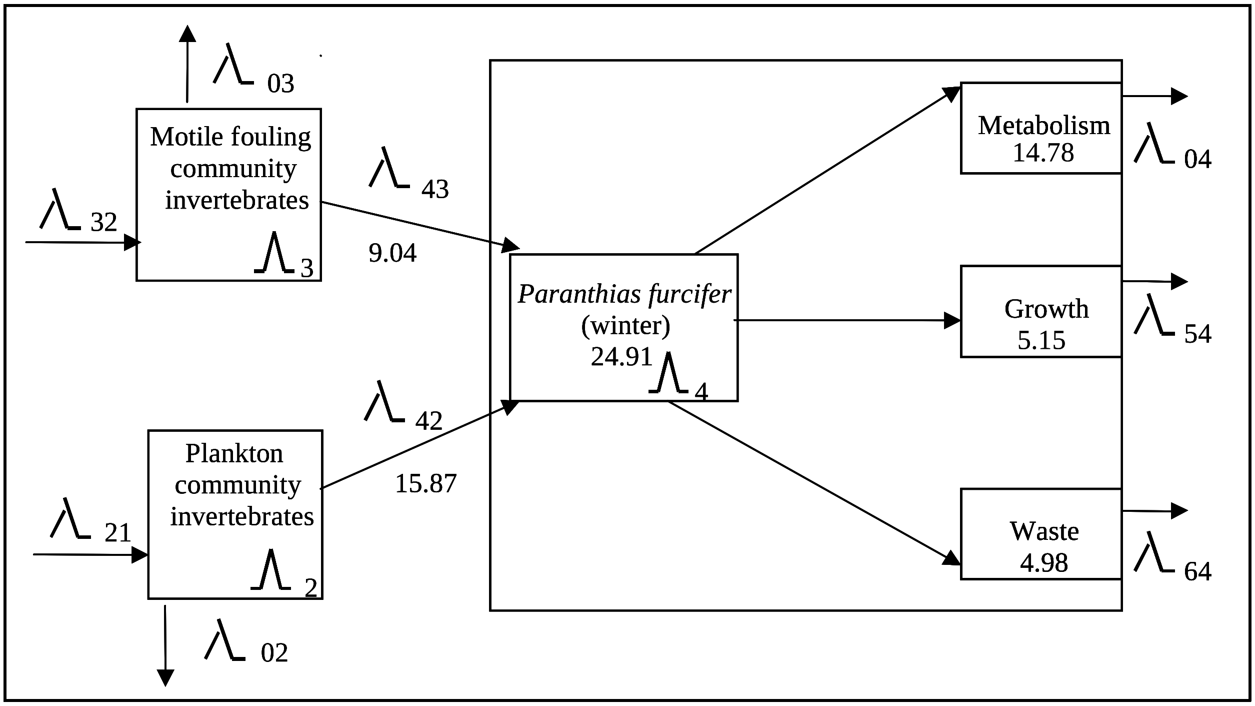

Figure 2B.2. Compartment model of energy (kcal·individual^{-1}·day^{-1}) flow (Pianka, 1994) for winter stocks of *Paranthias furcifer* at HI389A and EB165A from February to March 1996. λ = rate of energy transfer between levels, subscripts represent trophic level as follows: 0 = world external to system, 1 = autotrophs, 2 = herbivores, 3 = detritivores, 4 = first order carnivores, 5 = top carnivores, 6 = decomposers. Numbers represent kilocalories obtained from each trophic level and/or apportioned to each function.

Mean population levels for *B. capriscus* were 86 and 167 at EB165A and HI389A respectively (Table 1B.2). We calculated consumption rates for *B. capriscus* during summer, fall and winter quarters to be 56.5 g/kg fish weight, or approximately 5.6% of body weight per day. *Balistes capriscus* consumed an average 78.7 kcal/day, with 100% of this total being obtained from sessile and motile invertebrates of the fouling community (Figure 2B.3). *Balistes capriscus* diets provided an estimated 35.6 kcal/day for growth.

Although population levels of *Epinephalus. adscensionis* varied between platforms, there was no significant variation between seasons ($P > 0.05$). Population levels were 301 and 214, at EB165A and HI389A respectively. Estimated daily consumption for combined summer, fall and winter quarters was 51 g/kg or 5.1% of body weight. Spring consumption rates decreased by 7%, to 47g/kg fish weight. The average *E. adscensionis* consumed 58.5 kcal/day, 99% of which came from epifaunal and infaunal fouling community organisms. The remainder 1% were elements of the plankton community (Figure 2B.4). *E. adscensionis* used 35% (20.7 kcal) of consumed energy for metabolism and 45% (26.1 kcal) for growth.

Table 2B.2. Table of production estimates for *Paranthias furcifer*, *Balistes capriscus*, and *Epinephalus adscensionis* at EB165A and HI389A (FC= fouling community, PC= plankton community).

Species	Standing Stock (number indiv.)		Mean weight (g)		Consumpt. going to growth g/(indiv. *day)	Portion of cons. going to growth		Growth from FC g/(indiv. *day)	Fish prod. rate from FC kg/(stock *day)		Fish prod. rate from FC/m^2 g/(stock *m^2*day)	
	EB165A	HI389A	EB165A	HI389A		FC	PC		EB165A	HI389A	EB165A	HI389A
P. furcifer (summer)	636	486	430	510	16.25	0.32	0.68	5.2	3.31	2.53	0.29	0.30
P. furcifer (winter)	542	318	440	480	5.15	0.36	0.64	1.85	01.00	0.59	0.12	0.07
B. capriscus	86	167	690	601	35.65	1.00	0.00	35.65	3.07	5.95	0.26	0.71
E. adscensionis	301	214	480	510	26.15	0.99	0.01	25.89	7.79	5.54	0.67	0.66

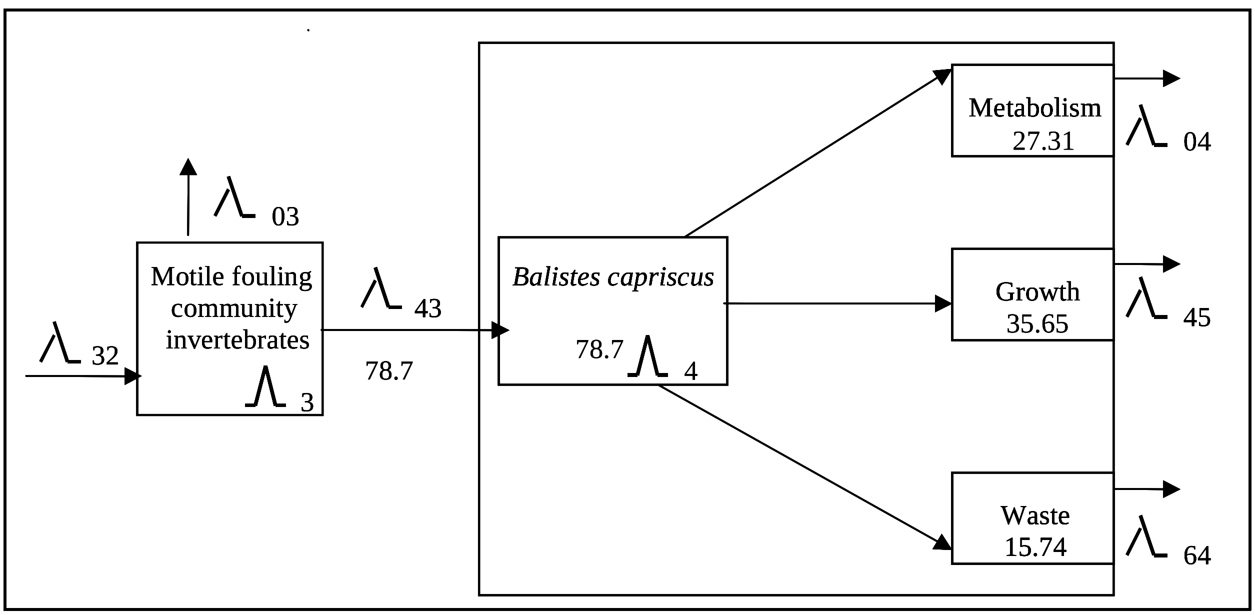

Figure 2B.3. Compartment model of energy (kcal$\cdot$individual$^{-1}\cdot$day^{-1}) flow (Pianka, 1994) for *Balistes capriscus* at HI389A from February 1995 to March 1996 and EB165A from September 1996 to July 1997 and HI389A. λ = rate of energy transfer between levels. Subscripts represent trophic level as follows: 0 = world external to system, 1 = autotrophs, 2 = herbivores, 3 = detritivores, 4 = first order carnivores, 5 = top carnivores, 6 = decomposers. Numbers represent kilocalories obtained from each trophic level and/or apportioned to each function.

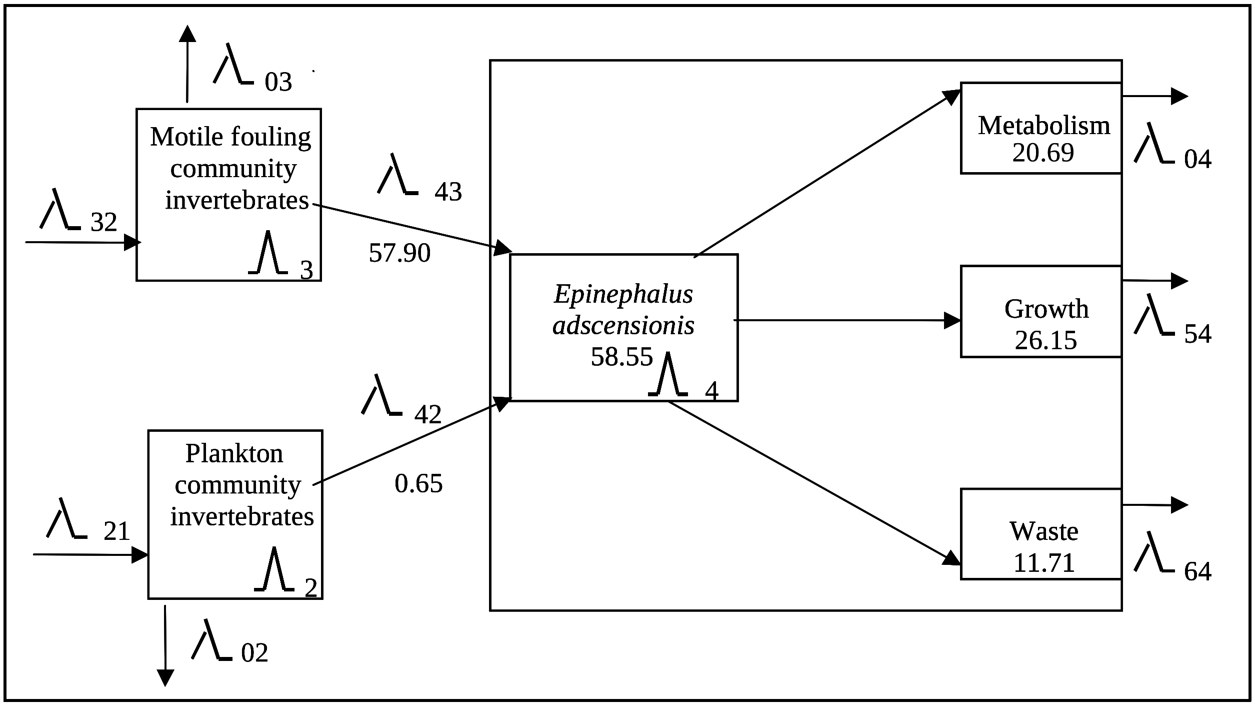

Figure 2B.4. Compartment model of energy (kcal·individual^{-1}·day^{-1}) flow (Pianka, 1994) for *Epinephelus adscensionis* at HI389A from February 1995 to March 1996 and EB165A from September 1996 to July 1997. λ = rate of energy transfer between levels, subscripts represent trophic level as follows: 0 = world external to system, 1 = autotrophs, 2 = herbivores, 3 = detritivores, 4 = first order carnivores, 5 = top carnivores, 6 = decomposers. Numbers represent kilocalories obtained from each trophic level and/or apportioned to each function.

Fish production rate from fouling community diet elements ranged from <0.1 g/(stock·m^2·day) for *P. furcifer* during the winter to 0.7 g/(stock·m^2·day) for *B. capriscus*. Production rates for *P. furcifer*, *B. capriscus* and *E. adscensionis* are given in Table 1B.2.

Data from examination of fouling and fish communities were used to construct food webs and energy flow diagrams for the artificial reef ecosystem. Results indicate that platform artificial reefs are allochthanous, obtaining the majority of their energy from the plankton community. Food chains were generally short, containing 4 to 5 nodes and 3 to 4 links, with the shortest chains being those containing planktivorous fishes.

DISCUSSION

It is clear from this study that elements of the fouling community contributed substantially to the diet of certain reef fishes. The amount of the contribution varied with species and was dependent on the effect of daily and seasonal environmental conditions on both prey and predator.

Seasonal decreases in percent composition of planktonic diet elements by *P. furcifer* were likely related to decreased availability of preferred diet elements and/or a wider dispersion of plankton due to increased wave action during the winter. Diet often shifts in response to seasonal changes in the availability of preferred food resources (Winemiller and Polis 1995). Increased foraging on caprellid amphipods may have served to offset the loss of preferred planktonic diet elements, possibly maintaining population levels of fishes through the winter. In addition to a reduction in prey availability, the decrease in the estimated daily consumption by *P. furcifer* during winter is a consequence of at least two other factors, including number of hours spent foraging, and water temperature. Since *P. furcifer* is a sight-feeding planktivore, foraging is generally restricted to daylight hours. A reduction in the number of day-light hours during the winter and spring translated into a reduction of the time available for foraging.

Water temperature also affects consumption by *P. furcifer*. Reduced water temperature significantly slows stomach evacuation in fishes (Adams and Breck 1990). Since no experiments were conducted to determine the effects of reduced water temperature on the stomach evacuation rate of *P. furcifer*, the known maximum rate of evacuation was used to calculate winter/spring consumption rates. This likely produced an over-estimation of winter consumption.

Observed diel feeding habits of *P. furcifer* seemed to be related to light levels and predation pressure. *Paranthias furcifer* is a sight feeder that commonly forages widely for plankton high in the water column just outside the boundaries of the platform structure when light levels are low, as at dawn and dusk. Behavioral response to predation pressure appears to heavily influence feeding location, especially during periods of greatest light intensity. Feeding schools of *P. furcifer* were always most dense on the shaded side of the structure, regardless of current direction. As the sun traversed its arc in the sky, the shadow of the structure would grow increasing longer and shorter on opposite sides of the platform. Feeding congregations of *P. furcifer* would remain near the surface only in the shadow of the structure.

During mid-day when light levels were greatest and shaded areas were the smallest, *P. furcifer* retreated to the horizontal sections within the platform structure, apparently to avoid predation. Feeding would continue within the platform structure. Since this species is reluctant to stray far from the structure until light levels decrease, reduced quantities of food in the gut during periods of greatest light intensity were most likely a consequence of intraspecific competition for limited quantities of prey. The reduction of plankton in the diet during mid-day may also have been a consequence of the depth at which the populations schooled within the platform structure and an increased availability of non-planktonic prey items within the platform structure. Limited plankton samples, collected with static nets, indicated that the greatest concentrations of plankton were in the upper 10 m of the water column.

Fishes schooling during mid-day were commonly associated with areas of complex horizontal structure. Structural complexity in artificial reefs is assumed to moderate the effects of predation on reef fish populations by reducing the foraging efficiency of the predators (Rosenweig and MacArthur 1963; Ware 1972; Menge and Southerland 1976; Hixon and Beets 1989). Complex structure provides visual barriers and reduces backlighting, both of which may give protection from predation. On both platforms, horizontal structure was found below 20 m depth. This was well below the areas of greatest concentration of zooplankton. In addition, it is conceivable that the platform structure may act to disrupt water flow, further dispersing plankton.

The observed increase in fouling-community elements in the stomachs of *P. furcifer* during mid-day was a consequence of continued foraging of the species within the platform structure where abundances of these prey items are greatest.

Although *P. furcifer* has been observed grazing on elements of the fouling community during mid-day, it appears that most fouling-community diet elements are captured in the water column as they are swept away from the structure by water currents. This would likely explain the presence of the stalked hydroid *Bouganvillia inequalis* in the stomachs of *P. furcifer*.

Quantitative description of selective feeding in animals requires knowledge of the relative abundance of potential foods both in the diet and in the available habitat (Ivlev 1961). This is difficult in an open system; it is even more difficult where food resources are as patchy in distribution as plankton. Estimates of numbers of planktonic prey were based on limited static plankton net samples and extrapolated to produce an estimate of numbers of prey/m^3 in water flowing past the platform during feeding hours. This methodology assumes a constant flow and uniform distribution of prey throughout the water column. Plankton prey availability may be over- or under-estimated, due to variable flow rate and concentrations of prey items. Therefore, estimates of electivity of planktonic prey must be viewed critically.

Mysid shrimp were strongly selected by *P. furcifer*. In part, this may have reflected availability since mysids were the second most abundant prey item; however, selection likely was also a consequence of prey size in comparison to other planktonic prey species. Since *P. furcifer* is a sight-feeder, prey such as mysids, at the upper end of the predator's acceptable size range, would be more easily seen. In addition, there appears to be little caloric difference between mysids and copepods on a cal/mg basis. Consequently, selecting larger prey items may provide a greater energetic advantage.

The same can be said for *Caprella equilibris*. This species is the largest of the epibenthic amphipods found at the platforms. *Caprella equilibris* is more common during cooler months, a time when mysid shrimp and copepods are less common. Increased consumption during cooler months and a decrease in availability of similar planktonic prey, i.e. mysids, probably accounts for the greater selectivity for caprellids during this time.

Plankton concentrations around the platforms were significantly reduced during winter and early spring. Plankton concentrations typically show seasonal fluctuations in density (Tait and Dipper 1998). This decrease in density, coupled with intense mixing action of increased wave energy and decreased water temperature, forced the feeding to shift from plankton toward reef amphipods. From these, it can be assumed that reductions of winter-time plankton populations occurred at nearby natural reefs as well. Consequently, populations of planktivores at natural reefs must compensate for the lack of normal prey items by selectively feeding on more available prey items, by utilizing stored energy leading to a reduction in biomass, or by reducing population levels, thus reducing competition for limited food resources.

Strong selection for fouling-community elements by *B. capriscus* and *E. adscensionis* suggests that these species feed almost exclusively on organisms associated with the fouling community. This is not surprising, as both of these species are known to be benthic grazers and/or ambush feeders.

Food webs and energy budgets are useful tools for furthering our understanding of the trophic interactions occuring on artificial reefs. Understanding regulation of populations and regional biodiversity usually requires knowledge of community structure and population interactions (Winemiller and Polis 1995). Understanding the response of predators to prey populations should be a basic consideration in any fisheries management scheme, yet little quantitative information is available on the interactions of pelagic predatory fishes and reef communities. The development of energy budgets for fish in the wild is extremely difficult and must rely on several assumptions. When the development of energy budgets is designed to estimate production, as in this case, the parameters of ingestion, metabolism and waste must be known or estimated so that growth may be determined by difference. Although the amount of ingested energy is relatively easy to measure, metabolic rates in wild fish are quite difficult to estimate.

Many studies of the metabolic rates of fishes have been conducted under controlled laboratory conditions (Winberg 1956; Fry 1971; Brett and Groves 1979); however, these studies cannot replicate the natural conditions under which wild fishes must live. Estimation of natural metabolic rates is so difficult that Soofiani and Hawkins (1982) suggest that this component is perhaps the weakest link in any energy budget developed for wild stocks. Since metabolism under field conditions can only be approximated, growth estimates determined from field-derived energy budgets likely tend to over-estimate or under-estimate growth by substantial amounts.

Growth efficiencies for summer stocks of *P. furcifer* were higher than most estimates reported in the literature. This is likely due to an over-estimation of ingested energy related to high quantities of indigestible chitin in the species. Chitin, the main component of the exoskeleton of most crustaceans, is a polysaccharide that has a mean caloric density of 4.0 kcal/gram, but is largely indigestible. Considering that chitin can account for between 35 and 47% by weight for some prey items of *P. furcifer* at EB165A and HI389A, it is likely that assimilated energy was lower than reported herein. Consequently, growth efficiencies are likely over-estimated.

A reduction in energy available for growth in winter *P. furcifer* stocks indicate that these fish are utilizing stored energy during colder months, and consequently might be expected to exhibit a decrease in body weight and/or a decrease in caloric density of tissues. However, estimates of metabolism for *P. furcifer* were comparable to published literature, with values for summer stocks accounting for 41% of ingested energy whereas metabolism of winter stocks accounted for 59% of ingested energy. Since growth was determined by difference between ingested energy and the sum of estimated metabolism and evacuation, any over-estimation in the latter parameters would result in an under-estimation of growth.

Growth efficiencies for both *B. capriscus* and *E. adscensionis* were similar to those reported in published studies. Growth efficiency estimates of 34% for *B. capriscus* and 35% for *E. adscensionis* are slightly higher than the 20-25% values accepted as typical for carnivorous fishes (Winberg 1956; Brett and Groves 1979). Again, this discrepancy, if due to error, suggests either an under-estimation of metabolism and/or waste or an over-estimation of assimilated energy.

Planktivores inhabiting artificial reefs may have a feeding advantage over planktivores inhabiting deeper natural reefs in the GOM. There is an energetic advantage in seeking habitat in the upper water column near the greatest concentrations of food as less energy need be invested in metabolism associated with swimming between the food source and shelter. Assuming an adequate ration, any significant reduction in metabolic cost represents a potential increase in growth, both somatic and reproductive, hence an increase in fitness.

Less of an advantage is expected for benthic carnivores feeding on motile invertebrates. Predator avoidance is related to habitat complexity in that complex surface features offer many hiding places, making prey acquisition more difficult and energetically costly for the predator. Compared to most natural reefs in the GOM, artificial reefs offer less complexity of surface features (i.e. rugosity). Fouling community complexity or rugosity is often enough to shelter small benthic invertebrates without providing shelter for larger invertebrate-feeding fishes. As these fishes are generally both predator and prey, the lack of complexity may translate into increased metabolic costs associated with prey acquisition and predator avoidance, hence reducing fitness compared to like species living on natural reefs.

Balistes capriscus benefits greatly from feeding on platforms. Biomass/m^2 of this species is far greater at most platform artificial reefs than at natural reefs in the northwestern GOM (Q. Dokken, Texas A&M University-Corpus Christi). Likewise sessile prey items identified in this study are also significantly more numerous at platform artificial reefs than at nearby natural reefs (Dokken *et al*. 1998). For example, at HI389A, the filter-feeding bivalve *Isognomon bicolor*, and the barnacle *Banalus reticulata*, both common diet elements of *B. capriscus*, comprise less than 0.005% of benthic organisms at the East Flower Garden Bank less than 2 km to the northeast.

With the exception of *B. capriscus*, rates of fish production from the fouling community were comparable to rates for other species of reef fishes. Estimated growth rates for 5 species of fish found on a California artificial reef ranged from 0.09 to 0.49 g/stock·m^2·day (DeMartini *et al*. 1994). A production rate of 0.27 g/stock·m^2·day was reported for the serranid *Paralabrax clathratus*. This is very similar to the summer production rates of 0.34 and 0.36 g/stock·m^2·day for the serranid *P. furcifer* in the present study.

Nearly all forage consumed by *B. capriscus* came from the fouling community. At HI389A, production rates for *B. capriscus* were more than twice that at EB165A. *B. capriscus* had a production rate of 0.71 g/stock·m^2·day, whereas the rate at EB165A was 0.26 g/stock·m^2. In addition, the population at HI389A was nearly twice the EB165A population. A possible explanation for these differences may be the proximity of HI389A to the Flower Gardens Bank National Marine Sanctuary. Numbers of *B. capriscus* observed at HI389 may be part of a larger population that moves between the HI389A structure and the nearby Flower Garden Banks. Whereas *P. furcifer* and *E. adscensionis* are obligate structure-associated fishes, adult *B. capriscus* is often seen in open water far from any structure. If the *B. capriscus* seen at HI389A also utilize habitat at the nearby natural bank, it is possible that the carrying capacity of this system is much greater for this species than if the species were restricted to the platform reef alone.

Among the three remaining cases--summer *P. furcifer*, winter *P. furcifer*, and *E. adscensionis*-- rates of fish production per m^2·day were remarkably similar between platforms. Despite the fact that EB165A had 39% more surface area above 53 m, the two structures displayed nearly identical fish production rates. With the exception of *B. capriscus,* stocks at EB165A were greater than at HI389A. Production rates combined with the stability of fish populations suggest that this community is at or near its carrying capacity.

Miller and Falace (2000) state that marine food webs can be classified in the following manner: (1) those in which the principle energy source is benthic plant material generated by photosynthesis, (2) those in which primary production is generated in the water column and supports a community of filter-feeding invertebrates and planktivorous fish and (3) those in which the basic food source is detrital material. Platform artificial reef systems are allochthanous in nature with only a small fraction of primary productivity actually occurring at the reef substrate. Primary productivity on platforms is minimal and restricted to the upper regions of the structure. In addition, herbivores usually comprise <1% of the biomass of platform fishes. Consequently the textbook case for transfer of energy from *sunlight to plant to herbivore to carnivore to top predator* is poorly established on platform reefs. Instead, platform reef food chains are dependent on a steady flow of energy from a much larger area of the sea, in the form of plankton. Phytoplankton are the dominant primary producers and, along with grazing zooplankton, are responsible for the vast majority of energy input to the system, supporting secondary production of a diverse community of sessile filter-feeding invertebrates and planktivorous fishes. Because plankton productivity is generally greatest within the top 30 m of the water column (Tait and Dipper 1998), organisms growing attached to or sheltering in the upper parts of the platform structure have access to an almost endless supply of energy. For this community, the limiting factor may be structure for attachment, rather than food availability.

This plankton-based food web is predictable based on geographic location and hydrography. Miller and Falace (2000) describe how high planktonic production in warm temperate regions attenuates light penetration and provides a food source for filter-feeding invertebrates leading to the development of plankton-based food webs. These food webs can increase fish production in plankton-rich waters by trapping plankton productivity in benthic filter-feeders and planktivorous fishes, making this productivity available to benthic invertebrate-feeding and piscivorous fishes (Fang 1992). In addition, food chains involving planktivorous fishes tend to be short, adding to the efficiency of energy transfer (Hobson 1991). For example, this study identified two platform food chains containing only four nodes and three links between primary production and top predators (Figure 2B.5).

The incidence of planktivores at artificial reefs may benefit other species as well. Bray and Miller (1985) suggest that productivity of artificial reefs may be increased by maximizing the number of sheltering planktivores since these fish can add significant amounts of nutrients to the artificial reef food chain.

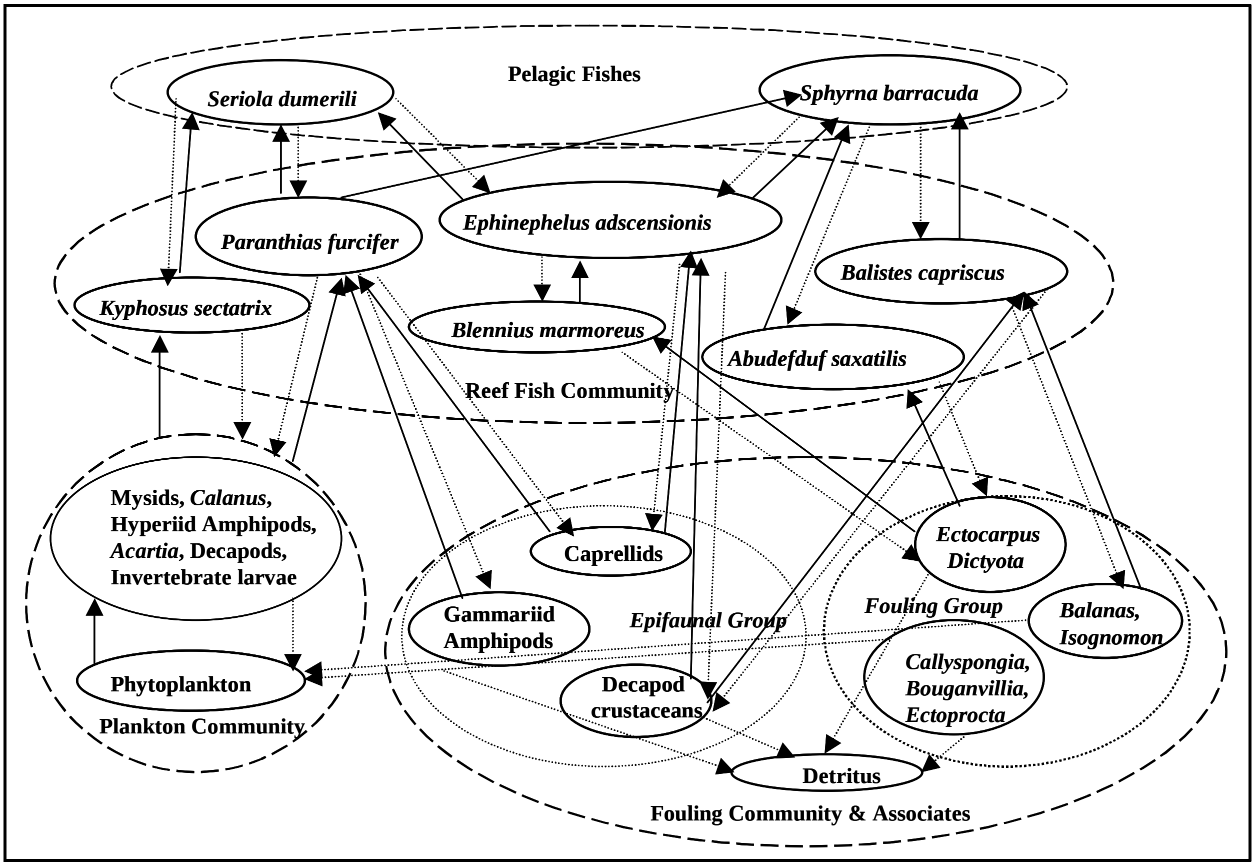

Figure 2B.5. Food web and energy flow diagram for platform artificial reefs EB165A and HI389A in the northwestern Gulf of Mexico. Solid arrows represent energy flow. Dotted arrows represent feeding links. March 1995- July 1997.

The fouling community and planktivorous fishes capture energy produced at the ocean surface, redirecting it into the reef ecosystem. Without this redirective action most energy would be lost to the detritus food chain at the bottom of the ocean. This action is important to fisheries since detrital food chains are generally inefficient in supporting fisheries (Russell-Hunter 1970).

CONCLUSIONS & MANAGEMENT IMPLICATIONS

- Platform reefs are allochthanous, obtaining the majority of their energy from the plankton.

- The diet of *Paranthias furcifer* (creolefish, family Serranidae) at platforms contained both plankton and epifaunal fouling community invertebrates and varied with light level and season.

- *Paranthias furcifer* diet displayed a decrease in plankton community organisms during winter and spring.

- *Balistes capriscus* (gray triggerfish, family Balistidae)and *Epinephelus adscensionis* (rockhind, family Serranidae) obtained virtually all of their energy requirements from sessile and motile fouling community invertebrates and small fishes.

- Both structures appear to be at or near carrying capacity for the species *P. furcifer* and *E. adscensionis*.

- At HI389A *B. capriscus* may be part of a population that moves between the platform structure and the nearby Flower Garden Banks reef.

- Food chains on platforms EB165A and HI389A were generally short, containing 4 to 5 nodes and 3 to 4 links.

- The shortest food chains were those containing planktivorous fishes as secondary consumers.

A platform's main contribution to fisheries productivity lies in its ability to redirect the flow of externally produced energy into food chains more efficiently utilized by fishes. The more a platform structure functions to promote secondary and tertiary productivity, aiding the transport of this productivity to higher trophic levels, the more it functions as an energy trap. It is clear that the secondary productivity of the fouling community is of significant importance to the diets of certain reef fishes. Through the contribution to productivity of reef fishes, many of which are prey for pelagic species, platform reefs also affect commercially and recreationally important fish stocks.

The ability of reef fishes to exploit platform productivity is influenced by several factors, including but not limited to, life history strategies, predator interactions, complexity of the reef structure and proximity of the reef to productive feeding areas. Some of these issues could be addressed during the design and construction phases of artificial reef development; however, because current artificial reef management practices are designed to be as cost-effective as possible, issues pertaining to productivity are often secondary in the design process.

Life history strategies of target species as well as prey items must be investigated and understood to develop and manage productive artificial reefs. Knowledge of the food and habitat requirements of commercially and recreationally important species that artificial reefs are intended to produce is often lacking or ignored to meet economic constraints or to appease groups such as the shipping and shrimping industries. Furthermore, placement of reefs is often based on ease of access to user groups while issues of productivity go unconsidered. When considering placement and design of reefs, issues related to productivity must have equal consideration to maximize the productive potential of these structures.

The most cost-effective method of platform removal is the use of explosive charges to sever the steel pilings below the mud line. The concussive force of the explosives, however, tends to strip the fouling community from virtually all of the steel supporting structure. Abrasive cutting techniques are available and cause far less damage to the fouling community than other methods. This should be the preferred technique for platform removal to retain platform productivity immediately following decommissioning of the structure if it is to be used as an artificial reef. Aside from cleaning structures to meet current governmental pollution guidelines, little additional preparation is put forth to increase the productive potential of these structures. Effort directed at increasing the complexity of these structures would likely return dividends in increased productivity.

The greatest expense in managing an artificial reef is placement and maintenance of aids to navigation. These aids are required of any structure less than 23 m below the surface. Since structures that do not reach within the upper 23 m of the water column do not require permanent aids to navigation, many artificial reefs are placed in deep water below this depth. Since placement of reefs at such depths negates a major portion of their productive potential (by removing structure from the most productive water where plankton concentrations are greatest), deep unmarked structures become primarily fish aggregation devices. Even communities dominated by filter-feeding invertebrates experience greater development in the area of higher primary productivity near the ocean's surface. Therefore, it is recommended that since reef structures in the upper 23 m of the water column are the most productive, artificial reef placement should take advantage of the increased productivity of these shallow Gulf waters. If this type of placement leads to increased expense associated with placement and maintenance aids to navigation, then this expense should be incurred.

The most common objective of artificial reefs is enhancement of fishery harvests. Fisheries harvests do increase around artificial reefs. Whether this enhancement is a result of attraction of existing stocks or of increased productivity, it is essential for the protection of fish stocks that the harvest of fishes from these structures be managed. Until the attraction versus production issue can be completely understood, and this knowledge utilized in effective management strategies, uncontrolled or unmitigated exploitation of critical fish stocks is a significant risk with the potential consequences being the loss or destruction of the entire fisheries.

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DRILLING PLATFORMS AS ENVIRONMENTAL ASSETS: DEVELOPING AN ASSESSMENT PROTOCOL USING ADULT AND JUVENILE CORALS

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ABSTRACT

Because of the Gulf of Mexico's (GOM) rich deposits of oil and gas, there are presently >4,000 drilling platforms deployed offshore. The lifespan of each platform is limited by either the size of the deposit or the platform's condition after exposure to the elements over a long period of time. Some platforms have been colonized by hermatypic corals, organisms protected from harvest or removal by the U.S. federal government, and from trade or transport by international treaty. This colonization is significant, since the only major coral reefs in the northern GOM are the deep-water NOAA Flower Garden Banks National Marine Sanctuary (FGB). Each platform must, by law, be removed at the end of its lifespan. Other options for decommissioning include cutting-and-toppling and leaving-in-place after partial removal. The purpose of this study is to examine the coral communities on these platforms and their relationship to distance from the FGB, platform age, and direction from the FGB. Their depth-distribution on the platforms was also assessed. Other objectives of this study and their associated techniques are also discussed. The study is designed to assist the MMS in the development of a protocol for assessing the environmental value of a platform with respect to its associated coral communities. Preliminary results indicate that neither coral abundance nor number of coral species is related to distance between the platform and the FGB, or direction with respect to the FGB. Both coral abundance and diversity were clearly and positively correlated, however, with platform age. Corals were found to vary significantly from a uniform distribution with respect to depth down to 28 m. This was not the case with number of species. *Tubastrea coccinea*, a species which is absent on the FGB, occurs commonly on the platforms. It exhibited no relationship, however, to distance from the FGB, platform age, or bearing from the FGB. The coral communities documented on many of the platforms sampled were considerable. Continuing studies on both adult coral populations and coral recruitment to the platforms will provide additional important information regarding the environmental value of the platforms.

INTRODUCTION

It has been known for some time that offshore oil and gas platforms can act as important habitats for fish populations (Sonnier *et al.* 1976; Boland *et al.* 1983; Pattengill *et al.* 1997; Rooker *et al.* 1997; Childs 1998; but see Schroeder *et al.* 2000). The platforms act as artificial reefs and provide fish habitat that otherwise would not be present in an area dominated by soft-bottom. The platforms appear to attract fish larvae that eventually recruit there (Love *et al.* 1991). This adds economic value to the platforms by providing a resource which can be used by the recreational fishing community (Love *et al.* 2000), including the charter fishing industry. This interaction is strong and has helped to form the basis of the "Rigs to Reefs" Program adopted by a number of coastal states along the GOM, with assistance from the Minerals Management Service (Dauterive 2000).

Natural coral reefs in the northern GOM are rare. In fact, the only two major reefs which occur in this region are the East and West Flower Garden Banks, ~110 nm S-SW of Galveston, TX (Rezak *et al.* 1985). These reefs developed on the top of salt diapers which occur at the edge of the continental shelf (Gross and Gross 1995). They are relatively deep reefs (≥18 m) possessing healthy, well-developed coral communities ([Gittings 1992), which are characterized and dominated by climax species of scleractinian corals (e.g. *Montastrea cavernosa*, *M. annularis*, *Diploria strigosa*, etc.). The reefs have been well-studied (Bright *et al.* 1991; Holland *et al.* 1992; G.S.B., pers. obs; unpub. data; K. Deslarzes, pers. comm.). There are also a number of other deep-water banks in the northern GOM (e.g. Rankin-1, Rankin-2, MacNeil, Bright, Geyer, Elvers, Stetson, Claypile, etc; Rezak *et al.* 1985; Boland, pers. obs.; Lugo-Fernandez 2001), but these do not possess well developed coral communities.

Most of the continental shelf in the northern GOM is characterized by soft bottom comprised of fine sediments (Rezak *et al.* 1985). Such an environment is not conducive to the development of coral reefs. Therefore, the coral reefs of the Flower Garden Banks have remained relatively isolated for many thousands of years and are considered to be among the most isolated coral reefs in the western Atlantic (Rezak *et al.* 1985; Snell *et al.* 1998). Over the past 60 years or so, thousands of drilling platforms have been installed in the northern GOM and more than 4,000 remain in place today (Francois 1993). Some of these structures provide a hard-bottom habitat to sessile epibenthic organisms such as corals (Bright *et al.* 1991) in areas of the outer continental shelf which would not otherwise be available to them. Thriving benthic communities, including corals, have developed on them (G. Boland 2002; K. Deslarzes, pers. comm.; pers. obs., all authors). The mere presence of these structures may make it possible for coral populations in the northern GOM to expand their range considerably if platforms are in place long enough to provide that larvae suitable substratum for colonizization, survival, and reproduction. If this were the case, it would contribute to expansion of the distribution of corals in this region and the stabilization of these populations (see Lugo-Fernandez, *in press*; Deslarzes 1998; Futuyma 1998) in the event of a major environmental perturbation resulting in massive local coral mortality.

It is now well accepted that the health of coral reefs is declining on a global scale (Sammarco 1996; Birkeland 1997; U.S. Coral Reef Task Force Report 2001, *http://coralreef.gov/*; Souter and Linden 2000). It is estimated that as many as 75% of the world's reefs have now been affected negatively by a number of both natural and anthropogenic disturbances (Loya 1976; Grigg and Dollar 1990; Pain 1996; Mumby *et al.* 2001), including increased sea-surface temperatures and bleaching (Browne 1990; Glynn 1991; Hayes and Goreau 1991; Goreau and Hayes 1994; Wilkinson 1999; Pockley 2000) potentially causing local extinction (Glynn 1983; Glynn and de Weerdt 1991; Aronson *et al.* 2000; Knowlton 2001), tropical storms (Proffitt 1999; Ostrander *et al.* 2000), coral diseases (Richardson 1998; Richardson *et al.* 1998), over-fishing and fishing techniques which destroy habitat (Woodley 1977; Munro 1983; Galzin 1985; Sammarco 1987 1996; Ohman *et al.* 1993), coral collection/extraction for trade (Batibasaga 1997; Rajasuriya 1997; Smith 1997; Franklin *et al.* 1998), run-off (Cortes and Risk 1985; Soekarno 1989; San Diego-McGlone *et al.* 1995), pollution (Johannes 1975; Gibson *et al.* 1998; Cavanagh *et al.* 1999), etc. Combinations of these factors can result in negative synergistic effects, enhancing their respective impacts (Hughes and Connell 1999; Porter *et al.* 1999). This decline of coral communities has resulted in a number of initiatives to protect coral reefs both in the U.S., to the point where corals have been protected from harvest or removal (Magnuson-Stevens Fisheries Conservation Management Act, 1975, amended 11 October 1996; Public Law 94-265).

In general, it has been considered that the value of an offshore drilling platform is intrinsic with respect to its function—i.e., its ability to extract a natural resource such as oil or gas. The cost-effectiveness of deploying a long-term production platform is based on the size and projected return and longevity of the resource reservoirs discovered by exploratory drilling. If the reserves are not sufficiently large or not predicted to produce a requisite volume based on the costs of deployment and drilling production wells, the deployment will not occur. If development occurs, a platform's projected lifespan is generally predicted both by the extent of the reserve (projected date of depletion to the point where it is no longer cost-effective to continue extraction) and the lifespan of the platform itself (projected date at which the platform is no longer considered a viable work-structure). When a facility reaches the end of its production lifespan, the platform must be scheduled for decommissioning. Under the original U.S. federal regulations governing decommissioning and the auspices of the U.S. Department Interior Minerals Management Service (see www.mms.gov), this means cutting the platform at its base (beneath the seabed) and its removal by vessel to land where it will be either refurbished or scrapped. More recently, other options have been made available to platform operators. These include cutting-and-toppling, which entails the cutting of the platform below the seabed and tipping the structure on its side; leaving the bottom support structure in place, cutting the upper structure at a depth of 26 m (85 ft.), and laying the upper portion near the base of the structure or at some other location. This would create a large artificial reef structure at depth. A third option is leaving the platform in place, as is.

Each of these four (4) decommissioning options carries with it a different cost. The first option, complete removal, is the most costly, certainly in the short term, because of the type of underwater work required and transport costs. The second option would probably be most cost-effective, as it only requires relatively shallow-water cutting and manipulation of the upper portion of the platform at sea, with no transfer costs. The third option of non-removal is very cost-effective in the short term but very expensive in the long term, due to the costs of maintenance of the platform as a potential shipping hazard (painting, lights, horns, power, etc.).

The purpose of this study is to determine whether scleractinian coral communities have developed on the offshore drilling platforms in the north central GOM and the extent of that development. This information may eventually become important in assessing the environmental value of such platforms as artificial reefs, assisting managers to decide how some platforms which have reached the end of the useful lifetime might be handled. In this paper, we provide information regarding the means by which we assess coral communities and new coral settlement on the platforms. This includes how we assess coral abundance, coral species number, and coral recruitment. We also provide preliminary data on the relationship between these variables and a) distance to the nearest natural coral reef perimeter; b) platform age; c) depth; and d) bearing or direction to the Flower Garden Banks (an indicator of the role of dominant currents).

MATERIALS AND METHODS

Study Site

The study was conducted in the north-central region of the GOM. A number of platforms were selected as target sites for the study, and 11 were visited during 2001 (see Table 2B.3 for list). The results of earlier physical oceanographic drifter studies by Lugo-Fernandez *et al.* (2001, pers. comm.) suggested that, at many times, the predominant ocean currents flow easterly from the Flower Garden Banks. For this reason, more platforms were selected east of the FGB than west. In addition, because benthic communities develop and mature through time, older platforms were given preference for sampling over time. Nevertheless, some younger platforms were sampled, along with some to the west. The sampling area extended from 38 km W-NW of the center of the FGB to 68 km E-NE of the center. Thus far, nine platforms have been sampled to the east and two to the west.

Table 2B.3. Details regarding 11 drilling platforms sampled in the northern Gulf of Mexico. Given are (1) platform number, also indicating its lease site; (2) platform age (yrs); (3) distance of the platform to the nearest reef perimeter within the Flower Garden Banks (kms); (4) bearing of platform the center of the FGB complex (degrees True North); (5) coral abundance on the platform (no. coral colonies); and (6) coral diversity (no. coral spp.). No significant relationship found between coral abundance and distance ($p > 0.05$, Pearson's product-moment correlation) or bearing ($p > 0.05$, one-way ANOVA). The same lack of relationship was found between coral diversity and these factors ($p > 0.05$, Pearson's product-moment correlation; and $p > 0.05$, one-way ANOVA, respectively).

Coral Abundance and Number of Species					
Platform	Age (yrs)	Distance (km)	Bearing (Degrees True N)	Coral Abundance	No. Coral Spp.
HI-A-382	15	4	94	16	2
HI-A-385 C	7	2	119	1	1
HI-A-330A	26	8.75	226	12	4
HI-A-376A	20	1.25	227	39	6
HI-A-349B	24	8	231	66	4
EC-317B	12	32.5	245	0	0
HI-A-368B	2	3.25	246	0	0
HI-A-370A	25	6.75	248	15	4
WC-618	15	18.75	252	7	2
WC-630A	24	15	254	28	4
WC-643A	26	30.25	262	35	4

Broad-Scale Underwater Surveys

Underwater surveys were performed by SCUBA divers to effect visual reconnaissance of coral communities on each of 11 drilling platforms examined thus far. Divers were divided into two teams of 3-4 persons each, one surveying primarily the shallow portion of the platform "jacket" (0-18 m), and the other the deeper water section (18-~35 m). Divers surveyed all legs of the platform, vertical, diagonal, and horizontal in orientation for the presence of coral colonies, recording the following criteria: species, number of colonies, colony size, depth, and location on the platform. Surveys were performed with the assistance of underwater still and video cameras.

Data from Broad-Scale Underwater Surveys will be presented here. Results of statistical analyses will be presented in figure and table legends.

Underwater Video Transects

Underwater video transects were also performed on the horizontal supports of the jacket to obtain a quantitative assessment of the sessile epibenthic community. Two to three transects were performed on each platform on the most shallow set of horizontal support structures, generally at 10-15 m depth. A 12 m transect line was secured around the horizontal strut. A diver-operated, high-resolution, digital color video camera in an underwater housing with lights was oriented vertically over the support beam at a fixed distance, using a weighted line. The camera used was a Sony® DCR-TRV 900 digital video recording with three (3) separate color chips. The tape format was mini-DV. The underwater housing for the video camera was a "Top Dawg," manufactured by Lights and Motion®. A monitor-back was also attached to the camera inside the housing to facilitate viewing the subject. A 30 cm wide belt-transect was photographed, moving horizontally along the beam. The tapes were returned to the laboratory for analysis.

Assessment of Coral Settlement

Coral settlement is being assessed via coral settlement racks on those drilling platforms with an appropriate physical structure (i.e., with horizontal supports at appropriate depths). The purpose of this was to determine comparative levels of coral recruitment with respect to their nearest potential source – the Flower Garden Banks. The base of each rack was a 0.9 m long piece of medium-gauge, galvanized, drilled, steel angle-iron. To this were attached four (4) 22 cm long stainless steel all-thread rods in an alternating pattern at 90^{o} to each other at regular intervals. Terracotta tiles were drilled at their center and attached to the distal end of each steel pin with a series of stainless steel washers, lock-washers, and nuts. Additional teflon washers were used to insulate the tile from the metal washers. Versatile® (Canton, OH) terracotta tiles (unglazed, vitreous - partially glass, ceramic quarry tiles) were used, with each plate measuring 15.2 x 15.2 x 1.2 cm, providing a total surface area of 277 cm^2.

Two settlement racks were attached to neighboring horizontal platform supports, oriented at approximately right-angles to each other. They were attached at depths of 10-15 m and secured by large stainless steel hose-clamps. The beams were cleared of most epifauna beneath the clamps prior to attachment to insure a secure fit.

The plates are scheduled to be collected after one year (in May/June 2002) and replaced with new ones, before the coral spawning season (Bright *et al.* 1992; Gittings *et al.* 1992). The new plates will be exposed for an additional year for purposes of comparing annual settlement patterns. The retrieved plates will be placed in individual Ziploc bags containing a high-salt buffer solution for preservation and returned to the laboratory for processing. Each plate will be analyzed with a dissecting microscope, and the juvenile corals (spat) will be identified as best as possible to genus and often species, using reference samples collected by Sammarco (1977, 1980, 1982). The tissue from each spat will be removed and placed in individual micro-centrifuge tubes. Using PCR (polymerase chain reaction), minute amounts of the coral tissue will be processed to amplify the DNA, and then use DNA finger-printing techniques (AFLPs) in an attempt to determine its probable origin with respect to surrounding populations. This technique is a powerful tool for distinguishing between closely related individuals within the species. From data collected previously from adult coral communities of the Flower Garden Banks, the data gathered here will be compared with those from the adults to determine origin of the recruits.

RESULTS

Adult corals were observed to occur on most drilling platforms. The number of corals ranged from 0 to hundreds of corals per platform (total; Figure 2B.6 and Table 2B.6). Coral abundance showed no relationship, positive or negative, with distance from the perimeter of the nearest Flower Garden Bank (Table 2B.3).

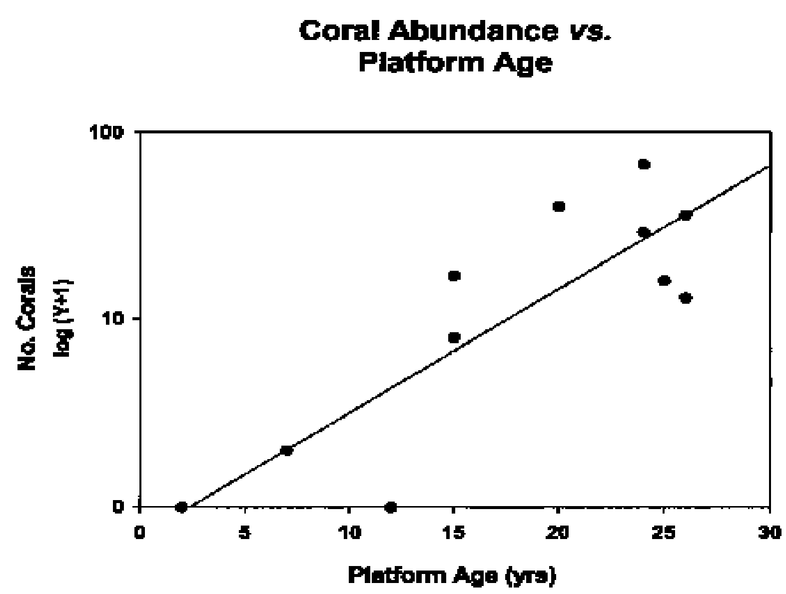

Figure 2B.6 Coral abundance as a function of age of 11 drilling platforms sampled in the northern Gulf of Mexico. Highly significant increase in coral abundance with platform age ($p < 0.001$, Pearson's product moment correlation; $p < 0.01$, linear regression). Abundance data transformed by log (Y+1) for purposes of normalization.

The number of hermatypic coral species (S) occurring on the platforms ranged between 0 and 7 (Figure 2B.7). Number of coral species also exhibited no relationship with distance from the perimeter of the nearest Flower Garden Bank (Table 2B.3). The coral species observed on the platforms are listed in Table 2B.4.

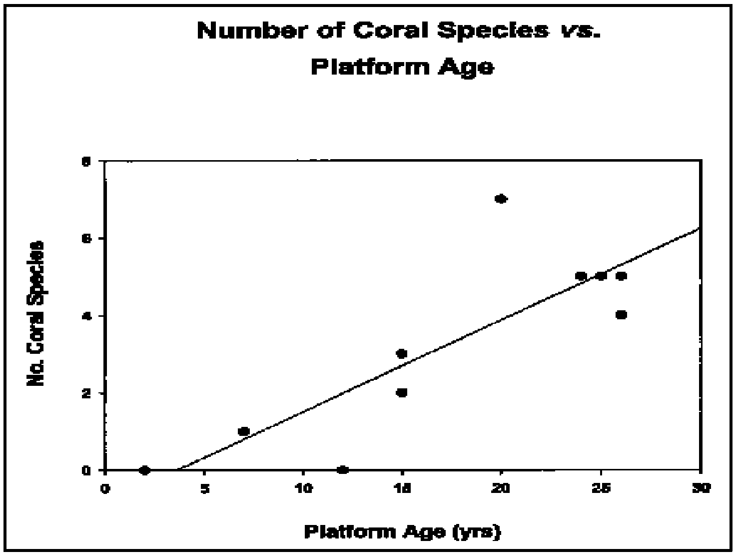

Figure 2B.7. Number of coral species as a function of age of 11 drilling platforms sampled in the northern Gulf of Mexico. Highly significant increase in number of coral species with platform age ($p < 0.01$, Pearson's product moment correlation; $p < 0.01$ linear regression).

Table 2B.4. List of coral species found inhabiting 11 drilling platforms in the northern Gulf of Mexico, in the vicinity of the Flower Garden Banks.

Coral Spp	Authority
Colpophyllia natans	Houttuyn, 1772
Diploria strigosa	Dana, 1846
Madracis decactis	Lyman, 1859
Madracis formosa	Wells, 1973
Millepora alcicornis	Linnaeus, 1758
Montastraea cavernosa	Linnaeus, 1767
Phyllangia americana	Edwards & Haime, 1849
Porites astreoides	Lamarck, 1816
Stephanocoenia intercepta	Lamarck, 1816
Stephanocoenia mechelinii	Edwards & Haime, 1848
Tubastraea coccinea	Lesson, 1829

It was believed that direction from the FGB may have affected the coral communities developing on the platforms due to predominant currents. This factor was assessed preliminarily by determining the bearing of any given platform to the center of the Flower Garden Banks group, and then considering our measured variables against that factor. Data are limited at this point, but preliminary analyses indicate that neither coral abundance nor number of coral species is correlated with direction from the Flower Garden Banks (Table 2B.3).

The ages of the platforms ranged from 7 to 26 years—a span of 19 years. A significant positive correlation was found between coral abundance and platform age (Figure 2B.6). The variance around this trend was relatively small, indicating that it was a strong and predictable relationship. Likewise, the number of species was found to exhibit a highly significant correlation with platform age (Figure 2B.7). This relationship exhibited even less variance than that of coral abundance with age.

Corals were found to occur between depths of 3m and 27m, which was the maximum depth of the surveys on these cruises. Their abundance varied significantly with depth (Figure 2B.8), when tested against an expected uniform distribution. Coral abundance exhibited peaks at depths of 12 m and 21 m. The data shown are limited in scope, as surveys were not taken below 27 m. Number of coral species exhibited a depth-distribution that was not significantly different from uniform (Table 2B.5).

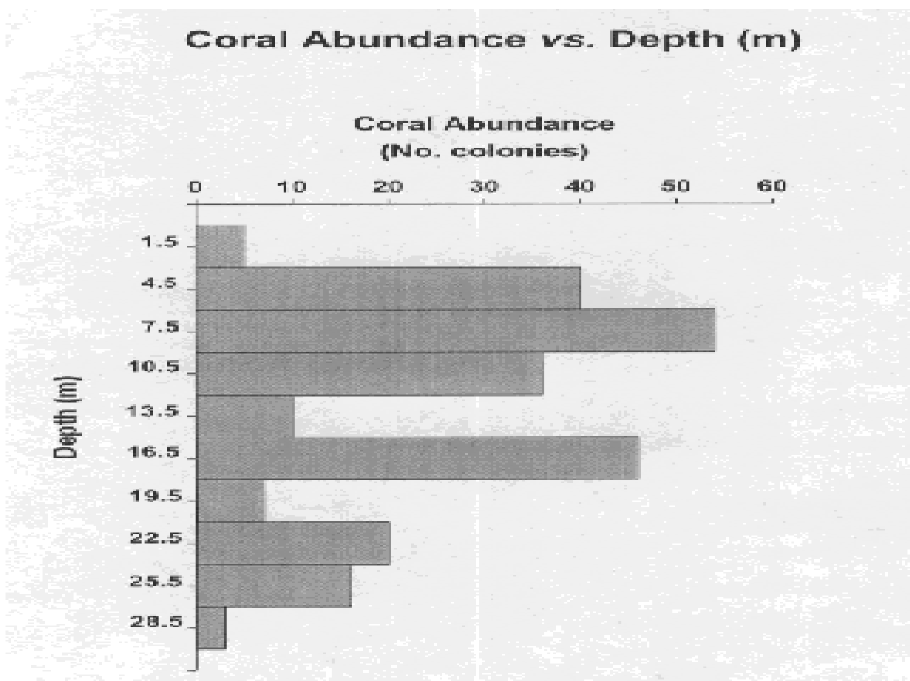

Figure 2B.8. Coral abundance as a function of depth on 11 drilling platforms sampled in the northern Gulf of Mexico. Depth distribution of corals varied significantly from that expected under a uniform distribution ($p < 0.001$, G-test of independence).

Table 2B.5. Number of coral species found at a variety of depths on 11 drilling platforms sampled in the northern Gulf of Mexico. Corals placed into depth categories in 3 m intervals. Depth distribution of corals did not vary significantly from that expected under a uniform distribution ($p > 0.05$, G-test of independence).

Depth Distribution of Coral Species	
Corresponding Depth Range (m)	No. Coral Spp.
0-3.0	0
3.1-6.0	1
6.1-9.0	3
9.1-12.0	7
12.1-15.0	6
15.1-18.0	5
18.1-21.0	5
21.1-24.0	5
24.1-27.0	7
27.1-30.0	1

One ahermatypic scleractinian cora, Tubastraea coccinea, appeared on many of the platforms surveyed. It sometimes covered all available substratum with hundreds of colonies on some of the platforms. Unlike the hermatypic corals observed here, the abundance of this species was not significantly correlated with platform age (Table 2B.6). This coral exhibited no pattern of distribution with respect to distance to the perimeter of the nearest Flower Garden Bank, nor did its abundance exhibit any clear relationship with bearing (Table 2B.6).

DISCUSSION

The data presented here are a preliminary report of initial results. We were originally scheduled to assess more platforms than these during this first year of the study. Due to weather conditions and suitability of some platforms for study (determined upon arriving on-site), the data are limited. Nonetheless, some results were clear, even at this early stage.

A number of interesting findings emerged from the study. The first was that no colonies of *Agaricia* spp. or *Porities* spp. were observed on any of the platforms assessed thus far. This is important for several reasons. Firstly, both of these genera may be considered pioneer species in terms of community succession (Miller and Ricklefs 1999) and are usually among the first to colonize new substratum when it is made available on coral reefs in the Caribbean (Sammarco 1987). Secondly, both of these genera are noted to colonize and dominate settling plates in experiments on the FGB in the past (Bright and Baggett 1983; Baggett and Bright 1985; Sammarco and Brazeau 2001; Brazeau, Sammarco, and Gleason, *in prep*.). Thirdly, both of these genera are known to reproduce via brooding in the Caribbean (Van Moorsel 1983; Sammarco 1985; Sammarco 1987; Hughes 1988; Soong 1991; McGuire 1995; see Harrison and Wallace 1990 for a review).

Table 2B.6. Details regarding *Tubastrea coccinea* on 11 sampled drilling platforms in the northern Gulf of Mexico. Given is (1) the platform identification number, also indicating the lease site; (2) platform age (yrs); (3) distance of the platform to the nearest reef perimeter within the FGB (kms); (4) bearing of platform to the center of the FGB complex (degrees True North); and (5) abundance of *T. cuccinea* colonies (no. colonies). No significant relationship between abundance of this species and platform age ($r = 0.151$, $p > 0.05$, Pearson's product-moment correlation analysis), distance from the nearest reef perimeter ($r = 0.113$, $p > 0.05$, Pearson's product-moment correlation analysis), or bearing from the center of the FGB complex ($p > 0.05$, one-way ANOVA; $p > 0.05$, multiple regression analysis).

Abundance of *Tubastrea Coccinea* on Drilling Platforms, Northern Gulf of Mexico

Platform	Age (yrs)	Distance (km)	Bearing (Degrees true N)	No. Tubastraea
HI-A-382	15	4	94	3
HI-A-385C	7	2	119	0
HI-A-330A	26	8.75	226	57
HI-A-376A	20	1.25	227	62
HI-A-349B	24	8	231	27
EC-317B	12	32.5	245	7
HI-A-368B	2	3.25	246	114
HI-A-370A	25	6.75	248	8
WC-618	15	18.75	252	75
WC-630A	24	15	254	5
WC-643A	26	30.25	262	52

All species observed on the platforms, except for *Tubastrea coccinea*, occur on the Flower Garden Banks (see Bright *et al.* 1991; Gittings 1992; Holland *et al.* 1992; Snell *et al.* 1998; Boland 2002, pers. obs, unpub. data; Bassim *et al. in press*; K. Deslarzes, pers. comm.). They are, however, known to recruit only rarely to natural substrates (Sammarco 1980, 1982). These species are characteristic of medium- or late-seres in coral community succession. Thus, the corals seen on the platforms appear to represent an older, more mature coral community than one might expect to have developed in the short period of time they have been operating. The pioneer species (*Agaricia* and *Porites* spp.) are certainly present on the FGB (Sammarco and Brazeau 2001; Brazeau *et al. in prep*.; Sammarco *et al.* work in progress). It is possible that these genera, both brooders, have either more limited dispersal capabilities, or are disadvantaged from the release of a lower number of reproductive propagules than broadcasting species, or both. We should gain more insight into this phenomenon when recruitment data from the settling plates become available. At this time, the reasons for their apparent absence are not known.

The coral *Tubastraea cuccinea*, an ahermatypic brooder (Ayre and Resing 1986), appears to be a highly successful opportunist which can colonize these platforms and survive under a variety of conditions. In addition, its dominance appears to be sporadic and seemingly random. This could indicate patchy, random recruitment patterns. Analyses of the quantitative video transects should lend additional insight into the abilities of this species to compete for space in this environment. This represents perhaps one of the more interesting findings of the study, since this species does not occur on the FGB (F. and J. Burek, *www.sanctuaries.nos.noaa.gov/ pgallery/pgflower/living/ living_5.html*). Perhaps the platforms provide a more suitable environment for its settlement and growth than the FGB for a variety of reasons, including differences in levels of predation, grazing, competition for space, etc. Clearly, additional research is required to help explain this difference in occurrence.

It was surprising that coral abundance did not decline with distance from the FGB, irrespective of direction. The total linear distance considered here was 106 km, and one would have expected to see some trend over this distance. A negative relationship was observed between species diversity as measured by number of species and distance from the center of the FGB. This variable appears to be more sensitive to the effects of distance and other potential factors of influence. Differences in species numbers with respect to direction from the FGB may be due to currents, as has been suggested by Lugo-Fernandez *et al*. (1998, 2001). The predominant currents in this region have been demonstrated to flow from the W-SW, particularly during the coral spawning season – during August and September (Bright *et al.* 1992; Gittings *et al.* 1992; Lugo-Fernandez *et al.* 1998, 2001), but drifters have also demonstrated that currents can loop back to the FGB, potentially carrying coral larvae with them (for discussion of meso-scale eddy effects, also see Sammarco and Andrews 1988 1989; Andrews *et al.* 1989; Gay and Andrews 1994; Pattiaratchi 1994; Sammarco 1994). Coral species numbers were higher east of the FGB than in the west. Additional data will be needed before this can be attributed to dominant currents.

The highly significant positive relationship between coral abundance with platform age is logical, as is the similar relationship between coral species numbers and platform age. The older the platform, the more time has been permitted for colonization by corals, and by corals of more species. In fact, this most likely explains the reason for lack of correlation between distance and coral abundance. The platform age was randomly distributed around the FGB. Thus, the strong effect of platform age over-rode any weaker effect of distance and direction with respect to the FGB which may have been present. If all platforms had been deployed at the same time, perhaps one would see the effects of distance and direction; but, even within the platform age-range chosen for this study, age was still revealed to be the over-riding factor, at least as far as these preliminary data indicate.

The depth-distribution of coral abundance and species number indicate that settlement, survival, and successful growth may occur over a wide range of depths (see Sammarco 1994). Also, these coral species may occur on both the shallow portion of the jacket (5-30 m) and the deeper portion (>30 m). After platform surveys and coral recruitment studies have been completed in coming years, we will hopefully have achieved a more comprehensive level of understanding of how numerous and how well developed coral communities can become on oil and gas drilling platforms in the GOM. At that point, these results can be utilized to address questions of what considerations should be given to decommissioning platforms bearing extensive or significant coral community development (see Dauterive 2000 for a discussion of decommissioning options and the U.S. Department of Interior Minerals Management Service “Rigs to Reefs Program”).

CONCLUSION

Clearly, the different options available for decommissioning drilling platforms (Dauterive 2000) may affect these organisms in different ways. To enhance the distribution and survival of corals in the northern GOM, perhaps cutting and toppling would be beneficial to the environment for platforms with a well-developed coral community at $\geq$ 26 m depth. For those platforms which have coral communities which are well-developed homogeneously with respect to depth, cutting and toppling, or leaving-in-place, may represent the best options. If a well-developed coral community is developed only at > 26 m depth, leaving-in-place may be the only viable option. It should be noted that a well-developed coral community exists on the FGB down to a depth of 36 m and somewhat less developed coral communities exist down to 52 m. For those platforms which have a poorly developed coral community or none at all, removal may be the best option.

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THE ROLE OF OIL AND GAS PLATFORMS IN PROVIDING HABITAT FOR NORTHERN GULF OF MEXICO RED SNAPPER *LUTJANUS CAMPECHANUS*

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The management of the red snapper *Lutjanus campechanus* in the Gulf of Mexico (GOM) remains among the more problematic issues facing fishery managers of the region. Commercial landings increased from 1950 to 1965 and subsequently exhibited a constant decline until regulations were imposed in the 1990s (Figure 2B.9). Both the commercial and recreational red snapper fisheries are now limited by size limits, creel or trip limits, seasonal closures, and quotas as formulated by the Gulf of Mexico Fisheries Management Council in response to reports of overfishing (Schirripa and Legault 1999). Shrimp trawlers have also been required to install bycatch reduction devices in their nets to curtail mortality among juvenile red snapper.

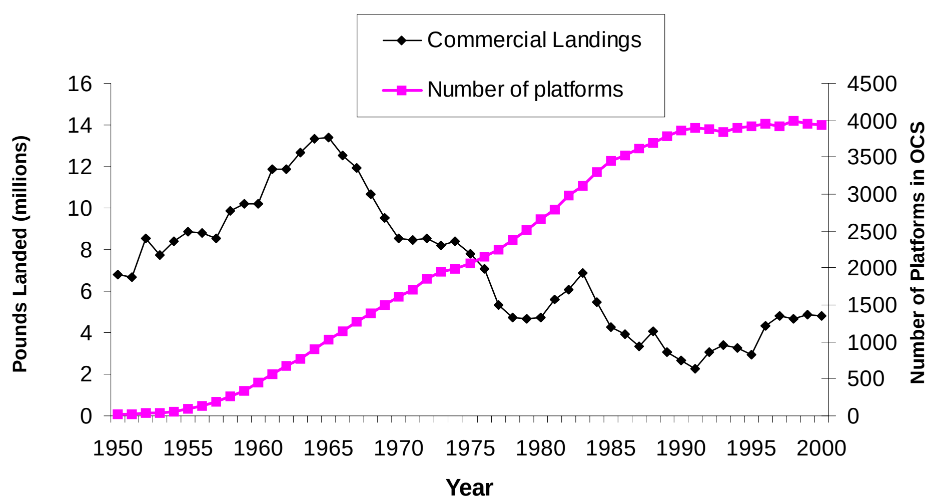

Figure 2B.9. Commercial landings of red snapper from 1950 to 2000 (NMFS) and cumulative number of platforms in the northern Gulf of Mexico (MMS).

A significant portion of the current commercial and recreational harvests come from the central GOM and at or near oil and gas platforms; however, this has not always been the case. The development of the offshore oil and gas industry was concomitant with the growth and subsequent decline of GOM commercial red snapper landings (Figure 2B.9). However, commercial landings by state (Figure 2B.10) suggest a pattern indicating that the fishery has shifted from the east to the central GOM since 1970. Florida, Alabama, and Mississippi have exhibited declines in landings since 1965, yet Louisiana and Texas have realized increases since the 1970s; this shift is coincident with the rapid expansion of offshore oil and gas development. Although the placement of extensive steel structure in the water column and shift of the snapper fishery to Louisiana and Texas may be coincidental, we need to better understand the role of oil and gas platforms in red snapper life history.

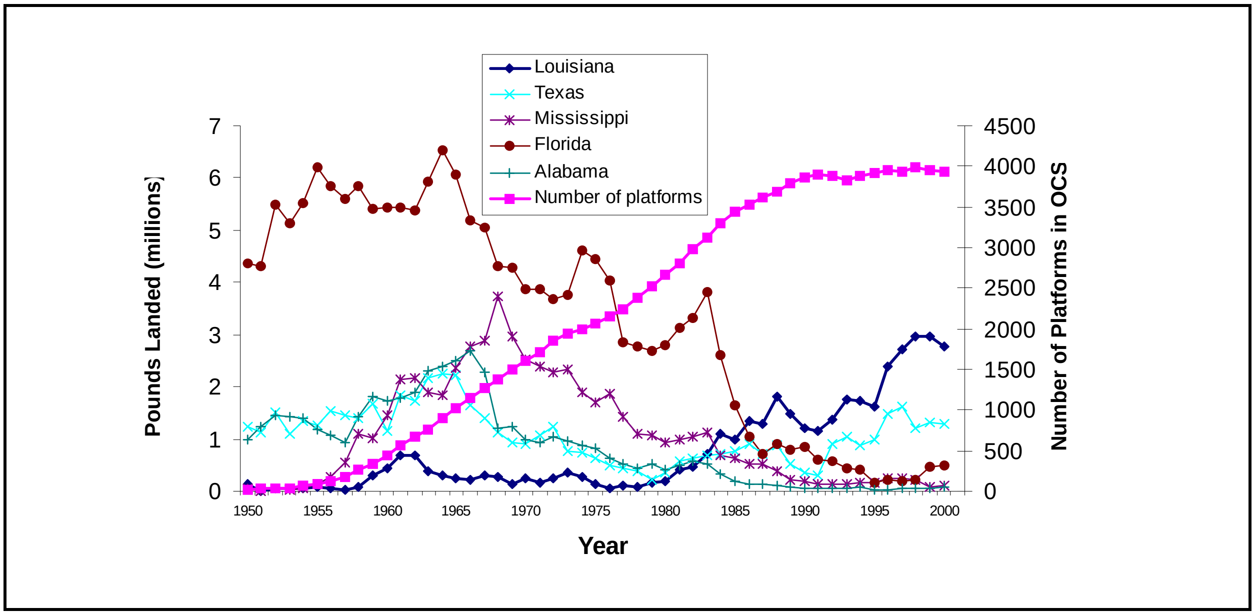

Figure 2B.10. Commercial landings of red snapper (by state) from 1950 to 2000 (NMFS) and cumulative number of platforms in the northern Gulf of Mexico (MMS).

Both qualitative and quantitative assessments of fish populations have shown that platforms situated in the northern GOM can hold large and diverse populations of fish species. Among these the red snapper repeatedly has been identified as a major user group targeted component of the platform-associated fauna. In visual surveys conducted by SCUBA divers at platforms off central Louisiana, the species was characterized as common by Sonnier *et al*. (1976) and as numerous by Bull and Kendall (1994); Putt (1982), using video cameras, found red snapper to constitute 2-4% of the total fishes inhabiting platforms off Texas. The recent fusion of hydroacoustic and visual (either with divers or with camera-equipped remotely operated vehicles) survey methods has produced estimates not only of total numbers of fishes around platforms, but also of species composition and their numerical or proportional representation within the total population. With these combined methodologies Stanley (1994) and Stanley and Wilson (1996, 1997) showed red snapper numbers to vary from 521 to 8,202 individuals at a platform off western Louisiana. Similarly, among estimated total fish populations of ~26,000 and ~13,000 individuals at two platforms off Central Louisiana (Stanley and Wilson 1998), 4.4% and 19.2%, respectively, were red snapper (Stanley and Wilson 2000).

A fishery independent sampling of fishes at Ship Shoal 209 (SS 209) based on collection of moribund fish resulting from the explosive removal of an obsolete gas rig revealed a proportionally large population of red snapper. Fully 37% (n=373) of the fish mortalities recovered subsequent to the explosive detonation were red snapper. Analysis of the fishery independent data gathered from the SS 209 detonation must be tempered with the recognition that it is indeed a chronological "snapshot" of the red snapper population (Nieland and Wilson, *in press*). In a hydroacoustic study of the fish population around a much larger (45 m X 20 m; 19,800 m^3 volume), but nearby, platform, Stanley (1994) reported the red snapper population varying from 1,200 to 8,200 individuals.

Previous estimates of fish populations, including red snapper, associated with platforms have shown conclusively that numbers can vary significantly among seasons (Putt 1982; Stanley 1994; Stanley and Wilson 1997, 2000) and among platforms at different depths (Stanley and Wilson 1998, 2000). Red snapper are also known to stratify by size at different depths around platforms; further, larger individuals are less obligate in their association to platforms than are smaller individuals (Render 1995).

Juvenile red snapper are known to inhabit hard- and soft-bottom areas of low relief where they are vulnerable to capture in trawls. This behavior is illustrated in fishery independent trawl data from the GOM, specifically the Fall Groundfish Survey and the Summer SEAMAP Survey, in which the great majority of red snapper captured are age 0 and 1 (Schirripa and Legault 1999). It has been hypothesized that the disappearance of age 1 red snapper from the trawl data represents migration to high relief structures such as natural reefs, wrecks, and platforms which presumably provide refuge from large predators (Render 1995). It might also be postulated that platforms, in the absence of other preferred habitats, are essential habitat for young red snapper.

Quantitative estimates of the inhabitation of platforms by red snapper can be derived from both the efforts of the National Marine Fisheries Service which has conducted periodic assessment of the effects of explosive platform removal on the associated fish populations at select sites in the GOM and the acoustic surveys done by personnel from Louisiana State University. Gitschlag *et al*. (2001) collected moribund fishes following explosive detonations at nine sites off Louisiana and Texas (14-36 m water depth) and found an average of 19% (n=500) were red snapper (Figure 2B.11). Stanley and Wilson (various) have reported on the fish communities of ten sites (22-110 m depth) to which a total of 38 trips were made and found an average of 21% (n= 2100) were red snapper (Figure 3).

MMS reports that there are approximately 2,500 platforms in the northern Gulf of Mexico water at depths ranging from 20 m to 100 m . Based on the estimated numbers of red snapper given above, from 1.2 to 7.2 million red snapper live around platforms placed in this depth range. Many of these may be relatively young individuals given that Nieland and Wilson (*in press*) reported that the red snapper around the SS209 platform were predominantly 2-4 years old. These estimates are based on a limited number of surveys, but they suggest a range of red snapper abundances that reflect the ubiquitous presence of red snapper at oil and gas platforms. We should continue this line of investigation to determine if platforms have become "essential' to the persistence of a large population of red snapper in the northern GOM.

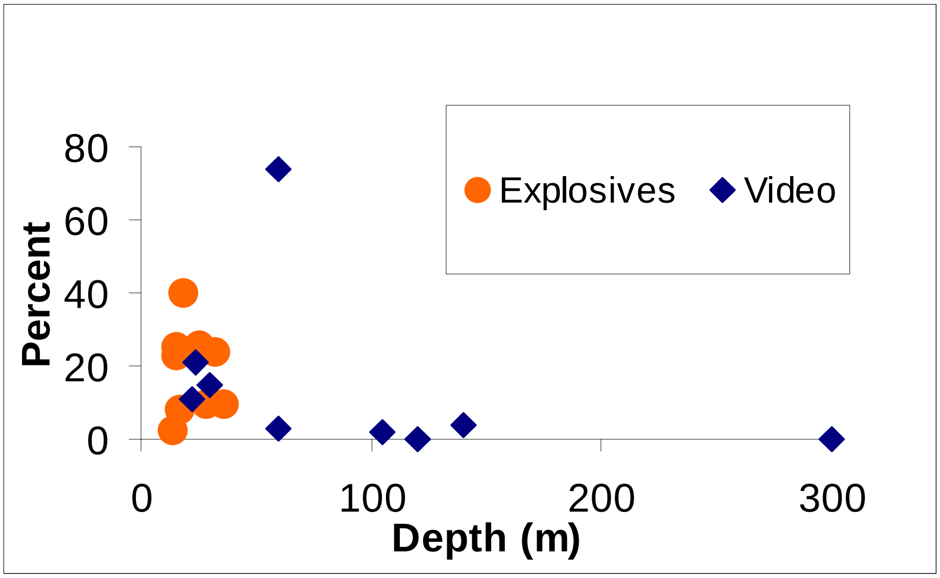

Figure 2B.11. Estimated percent of red snapper among the fish mortalities recovered following an explosives removal or based on video surveys (video) at platforms in various depths of the northern Gulf of Mexico.

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PLATFORM-RECRUITED REEF FISH, PHASE I: DO PLATFORMS PROVIDE HABITAT THAT INCREASE THE SURVIVAL OF JUVENILE REEF FISHES?

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INTRODUCTION

The recent reauthorization of the Fisheries Management and Conservation Act contains language calling for understanding and conservation of Essential Fish Habitat (EFH) for federally managed marine finfish and shellfish. One of the most pressing federal fisheries management concerns in the Gulf of Mexico (hereafter GOM) region is the overfished status of red snapper *Lutjanus campechanus*, which may be driven by an EFH issue (Schmitten 1999). National Marine Fisheries Service (NMFS) data collection and population modeling provide evidence that the primary cause of overfishing on red snapper is bycatch of age-0 and age-1 (juvenile) red snapper by shrimp trawls (Goodyear 1995; Schirripa and Legault 1999), with high bycatch rates concentrated in specific locations off Alabama, Mississippi, Louisiana, and Texas (Gallaway *et al.* 1999). Although there is concern over the accuracy of NMFS estimates of shrimping effort in these areas, the fact remains that juvenile red snapper are very abundant in specific locations that are presumed to be juvenile red snapper EFH (Gallaway *et al.* 1999; Szedlmayer and Conti 1999; Workman and Foster 1994).

Among these habitats are naturally-occurring open-sand bottom and low-relief, shell rubble reefs, as well as oil and gas platforms and other artificial reefs. However, the way in which different life stages of red snapper utilize these various habitats as they grow, e.g. for feeding, protection or both, once they settle from the plankton as small juveniles is unknown. Moreover, some researchers question whether or not artificial reefs (of any type) are a positive influence on reef fish stock dynamics because of doubts about whether they produce or attract fish (see papers published in *Fisheries*, April 1997 for review). Artificial reefs may be useful tools for fishery managers if they increase production; however, if they are simply attracting fish, they may be promoting overfishing. Consequently, resolution of this question is essential to the management of reef fish stocks because current knowledge of artificial reefs as EFH is not adequate for managers to consider them as a viable management tool in all situations (Seaman 1997).

While it has been demonstrated that juvenile red snapper have a strong preference for habitats with some vertical relief (Gallaway *et al.* 1999; Szedlmayer and Howe 1997; Szedlmayer and Conti 1999; Workman and Foster 1994), it has been hypothesized that oil and gas platforms and their adjacent footprints or ‘shadows’ provide exceptionally high-quality habitat, such that fishes located there have a survival advantage over conspecifics located in other artificial and natural environments.

Increased habitat quality on, or immediately around, oil and gas platforms is believed to be derived from increased *in situ* food production associated with encrustation by fouling organisms, and by increased physical habitat via structures that extend from the bottom to the surface of the water column. However, this hypothesis remains to be tested at spatial and temporal scales relevant to juvenile red snapper production, even though estimates suggest that high numbers of reef fishes are located in 'refuge' around platform legs (Stanley and Wilson 1997; 1998).

For the Minerals Management Service we, in partnership with research scientists from the University of Hawaii (CoPIs DeCarlo and Spencer) and the Victoria University in Wellington, New Zealand (CoPI Gauldie), will perform a novel test of the hypothesis that oil and gas platforms in the northern GOM provide high-quality habitat for juvenile reef-associated or reef-dependent species such as red snapper and gray triggerfish *Balistes capriscus*, respectively. First, we will test whether association with oil and gas platforms during early life imparts a detectable 'trace element isotope ratio fingerprint' in the otoliths of juvenile reef fishes (Phase I of the project). Secondly, we will test whether adult fishes containing the 'platform fingerprint' in their otoliths contribute disproportionately to adult stocks on nearby natural and artificial reefs (Phase II of the project).

Results of this project will enhance our understanding of reef fish life history and provide much needed EFH information to state and federal fishery managers. Additionally, this project will establish methods and protocols for future research concerning the role platforms may play as essential fish habitat. We will employ the latest analytical techniques to develop 'elemental isotope ratio fingerprints' of juvenile reef fish otoliths, and then compare the elemental fingerprints between fishes collected in association with, and distant from, oil and gas platforms in the northern GOM. We have used otolith microchemical techniques similarly to distinguish (for the first time) between juvenile red snapper collected in different nursery regions of the shallow GOM (Patterson *et al.* 1998). The results are briefly summarized below as a 'proof of concept'. We reason that if oil and gas platforms provide high quality habitat and refuge from shrimp trawls, then high numbers of adult recruits should be derived from the pool of individuals who utilize said habitat, particularly off Louisiana and other areas where natural habitat is scarce. By focusing on recruitment to adult populations in Phase II, our quantitative approach will provide a more direct assessment of the relative contribution of different juvenile reef fish habitats than is possible via traditional habitat suitability approaches. If this method proves successful, we will be able sub-sample from otoltihs of adult fish to determine age-specific habitat affinity, and to determine if the new recruits now expanding into the eastern GOM as the red snapper population rebuilds were associated with oil and gas platforms during some portion of their early life.

Introduction to Otolith Microchemistry

Otoliths have been used traditionally as a hard-part with which to age fish, but for many reasons otolith trace element chemistry has also been considered as a natural bio-geochemical marker of fish populations (Odum 1957; Gauldie and Nathan 1977; Campana and Gagne 1995). Otoliths are principally calcium carbonate (aragonite) and mixed protein and carbohydrate matrices which are laid down as a fish grows (Casselman 1987; Tagaki *et al.* 2000). Once formed, otoliths are not re-metabolized like bone, and are metabolically inert except under extreme physiological stress (Mugiya and Uchimura 1989). Many of the elements typically found in otoliths are unstable and can leak in, and leak out, of the otolith, which is a rather porous structure (Proctor and Thresher 1998; Gauldie and Cremer 2000). Therefor special care has to be exercised when selecting the elements to be analyzed and when handling, storing and processing the otoliths. In addition, the endolymph of the fish inner ear goes through cycles of pH changes (Romanek and Gauldie 1996; Payan *et al.* 1997; 1998) that are likely to result in short-term instabilities of some elements paralleling the effects of washing and handling on unstable elements described by Proctor and Thresher (1998) and Thresher (1999). Therefore, the elemental composition of otoliths reflects the elemental composition of the water body in which the fish lives, the elemental composition of the food of the fish and the short and long term behavior of the pH of the fish inner ear resulting in changes in otolith chemsitry in response to food, otolith growth rate, temperature, salinity and even stress induced by chasing (Mugiya and Satoh 1995; Kakuta 1996: 1999; Kakuta *et al.* 1999; Babaluk *et al.* 1997; Arai *et al.* 1996). The results of many of the simple analyses of otolith chemistry undertaken to differentiate fish from separate populations or stocks, even those within relatively close geographic proximity to one another (Kalish 1990; Edmunds *et al.* 1992; reviewed in Gunn *et al.* 1992; Sie and Thresher 1992; Thresher *et al.* 1994; Campana *et al.* 1994; Campana and Gagne 1995) have been compromised by the biological properties of otoliths (see the review by Thresher 1999).

Fortunately, a group of elements including lead, strontium, barium and some of the rare earths such as lanthanum, and the thorium-uranium series, form carbonates whose crystal structure is isostructural with that of aragonite, which is the basic mineral of the teleost otolith. By having carbonates that are isostructural with aragonite, these elements are embedded in the crystal matrix of the aragonite itself, and therefore cannot be mobilized by minor pH changes or by the effects of washing and handling (Proctor and Thresher 1999). Consequently, the elements useful for site-specific, chemical location markers in otoliths are: Pb, Sr, Ba, La and the elements of the Th-U series. Lead is a particularly attractive element to consider as a site- specific marker where industrial activity is, or has been, involved. All kinds of combustion engine operations, electrical motors and some kinds of metal priming paints result in lead residues, albeit in small amounts. Similarly, drilling operations usually involve the use of drilling muds based on bentonite (mostly the mineral montmorillionite) that has traces of rare earths and barium. A further advantage for site-specific marker studies are that industrial lead compounds, and montmorillionite, are both derived from a single lead mine in Wisconsin, and a single montmorillionite mine in Wyoming, respectively. Thus, both industrial lead compounds and montmorillionite-containing bentonite will have mine-specific isotope ratios that reflect the unique geochemical histories of the mines involved. The mine-specific effect was exploited by Spencer *et al*. (2000) who used the characteristic isotope ratio signature of petrol lead additives that is quite different from the isotope ratio signature of lead from the volcanic rock substrate of Oahu. Thus, both existing oil and gas platform operations, and their prior history of drilling operations, are likely to produce trace amounts of residues of Pb, Ba and La whose isotope ratio signatures will be quite different from those typical of the GOM seafloor. We can use this effect as a harmless “tag” in the otoliths of fish that have spent their juvenile phase (or, indeed, all of their lives) in close association with oil and gas platforms.

PROOF OF CONCEPT

Because the new project has only recently been funded, we have no results specific to this effort. As proof of concept, however, we offer the following brief summary of results obtained from other previous and ongoing work on juvenile red snapper otolith microchemistry. In these studies, age-0 red snapper were collected from five areas (Figure 2B.12) in the northern GOM during the months of October and November from 1996 through 2000, otolith elemental finderprints were derived by using an inductively-coupled plasma mass spectrometer, then univariate and multivariate statistical techniques were employed to determine if otolith microchemical fingerprints were unique to each nursery area. As such, we have been primarily interested in analyzing elements that substitute directly for Ca in otolith aragonite. Among these, Sr, P, Mg, Mn, Na, Ba, B, Cd, Mn, Ca, Zn, Pb, K, and Ni were detected in otolith samples, but only Sr, Mg, B, Ba, Mn, P, Na, and K concentrations were consistently above detection limits.

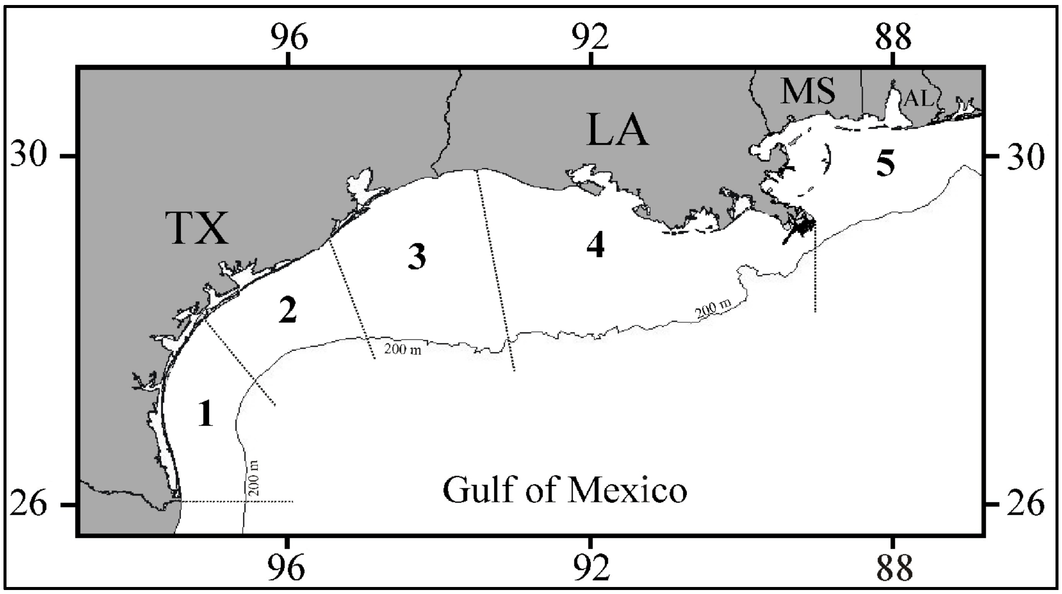

Figure 2B.12. Five areas in the northern Gulf sampled for age-0 red snapper during 1996 through 2000: Area 1 = Brownsville (BRN) , Area 2 = Aransas (ARN), area 3 = Galveston (GAL), area 4 = Louisiana (LA), area 5 = Alabama/Mississipppi (ALMS).

Table 2B.7 gives the mean concentrations of each of the nine elements at each of the five locations for each year. Based upon these concentrations, results of the MANOVA indicate that Year (Pillai's trace; d.f. 36; 2,908, p<0.001), Area (Pillai's trace; d.f. 36; 2,715; p<0.001), and Year*Area (Pillai's trace; d.f. 36; 6,588, p<0.001) were significant effects on elemental signature. Results further indicate that elemental signatures are different among nursery areas but also years; thus, statistical analysis proceeds by analyzing each year separately (Tables 2B.8 through 2B.12). As can be seen, classification is high in most cases, but there are isolated instances where there is significant classification error to adjacent areas. This result can be explained by the fact that the nursery areas were chosen based upon the predominant oceanography and freshwater input, and this can change among years. We are encouraged, however, by the fact that the error is mostly to adjacent areas and can be corrected in future analyses by collapsing some of the adjacent nursery areas into regions. Similarly, we are confident that we will be able to detect a platform 'fingerprint' unique in the otoliths of rig-associated reef fishes, thus allowing these fish to be identified later in life.

Table 2B.7. Otolith elemental concentrations (±SE) of age-0 red snapper sampled during 1996 through 2002.

YEAR=1996 LOCATION=ALMS			YEAR=1996 LOCATION=ATCH		
Variable	Mean	Std Error	Variable	Mean	Std Error
B	818.8525000	44.0819967	B	902.1062083	63.8047648
BA	6.9152333	0.3166701	BA	6.1834583	0.3877409
CA	0.3670767	0.0066301	CA	0.3884167	0.0151865
K	596.7086667	9.6380109	K	615.5104167	15.8084023
MG	43.2151333	0.9169287	MG	42.1814167	1.0359636
MN	4.2324333	0.2810438	MN	3.3687917	0.1352468
NA	3.1082333	0.0296662	NA	3.0295000	0.0453703
P	47.2623000	0.7954331	P	49.5292083	1.0789999
SR	1.7271000	0.0194721	SR	1.8588333	0.0285573

YEAR=1996 LOCATION=BROWN			YEAR=1997 LOCATION=ALMS		
Variable	Mean	Std Error	Variable	Mean	Std Error
B	931.2181429	42.0549053	B	652.9178421	18.8639525
BA	7.4367857	0.3525585	BA	5.0155088	0.1391620
CA	0.3788714	0.0090942	CA	0.3725719	0.0039084
K	604.4242857	9.5009501	K	515.2749123	5.8358151
MG	49.0065000	1.3144022	MG	39.7490702	0.6247512
MN	4.1638929	0.2220627	MN	4.5892807	0.1956810
NA	3.1881786	0.0378564	NA	2.8112105	0.0308966
P	48.6519643	1.1400808	P	46.8233684	0.8185532
SR	1.8800357	0.0288409	SR	1.4494561	0.0180448

Table 2B.7 (continued)

YEAR=1997 LOCATION=ARAN			**YEAR=1997 LOCATION=ATCH**		
Variable	Mean	Std Error	Variable	Mean	Std Error
B	669.3571818	31.1581966	B	674.3507857	24.9601937
BA	8.1875909	0.3937245	BA	6.8621786	0.3521707
CA	0.4440364	0.0740133	CA	0.3812679	0.0044779
K	490.2363636	7.4923236	K	458.0714286	9.6873111
MG	47.0566364	1.0535871	MG	36.4733214	0.5840438
MN	4.8846818	0.2446471	MN	3.7276786	0.2252318
NA	2.8184545	0.0636978	NA	2.6202500	0.0292402
P	52.3309545	1.7900888	P	46.1820000	0.9988536
SR	1.6164545	0.0331755	SR	1.5783571	0.0214536

YEAR=1997 LOCATION=BROWN			**YEAR=1997 LOCATION=GALV**		
Variable	Mean	Std Error	Variable	Mean	Std Error
B	708.6689286	22.8235663	B	778.0714138	48.7557645
BA	11.0977857	0.4758510	BA	6.3766552	0.2101610
CA	0.3647393	0.0038767	CA	0.3806966	0.0047153
K	495.4621429	6.1073251	K	486.6631034	8.6630204
MG	43.6931071	0.5315296	MG	41.7172759	0.8522562
MN	4.3050714	0.2161826	MN	4.3417586	0.2204108
NA	2.7313214	0.0329597	NA	2.7650690	0.0463206
P	49.3841071	0.7600310	P	47.2604828	0.9689256
SR	1.5959286	0.0163436	SR	1.6412069	0.0282989

Table 2B.7 (continued)

YEAR=1998 LOCATION=ALMS			YEAR=1998 LOCATION=ARAN		
Variable	Mean	Std Error	Variable	Mean	Std Error
B	471.9525405	20.1020466	B	458.3497273	16.5976862
BA	6.4544595	0.2666933	BA	7.0423333	0.3555177
CA	0.3815270	0.000970570	CA	0.3846152	0.0012165
K	515.8148649	15.4900049	K	414.1354545	12.9676567
MG	38.1954865	0.8010467	MG	37.7383636	0.8207021
MN	3.3721351	0.1177677	MN	2.7299091	0.1877251
NA	2.8348108	0.0464829	NA	2.5505152	0.0423255
P	42.1259730	0.9373089	P	46.3761515	0.7657546
SR	1.5239189	0.0242532	SR	1.6249394	0.0191991

YEAR=1998 LOCATION=ATCH			YEAR=1998 LOCATION=BROWN		
Variable	Mean	Std Error	Variable	Mean	Std Error
B	485.1350303	12.0857139	B	480.9830667	32.7386669
BA	5.9638485	0.2286925	BA	6.2705333	0.1843711
CA	0.3798939	0.000790629	CA	0.3818900	0.0014302
K	418.7018182	9.8536303	K	459.5190000	15.1842876
MG	35.3390606	0.5543595	MG	40.0193000	0.9002217
MN	2.7774848	0.1028890	MN	4.0518667	0.1835265
NA	2.5200606	0.0235875	NA	2.7112000	0.0394550
P	45.8033939	0.6374652	P	48.1592333	0.8937139
SR	1.5879697	0.0158523	SR	1.6225333	0.0197886

Table 2B.7 (continued)

YEAR=1998 LOCATION=GALV			**YEAR=1999 LOCATION=ALMS**		
Variable	Mean	Std Error	Variable	Mean	Std Error
B	602.9803529	21.2664394	B	465.2538158	13.7716767
BA	6.5983235	0.2760359	BA	8.9645789	0.3631342
CA	0.3853912	0.000994597	CA	0.3892132	0.0046383
K	456.3667647	13.8432226	K	509.6436842	11.4669898
MG	36.6990588	0.5093042	MG	35.4560000	0.5133011
MN	2.8015882	0.1716876	MN	4.0057632	0.1592636
NA	2.7325588	0.0262854	NA	2.8433158	0.0303847
P	53.1797941	0.8754921	P	36.8007632	0.6388329
SR	1.8170588	0.0154546	SR	1.5395000	0.0180494
YEAR=1999 LOCATION=ARAN			**YEAR=1999 LOCATION=ATCH**		
Variable	Mean	Std Error	Variable	Mean	Std Error
B	475.8550909	13.1968643	B	492.7149394	20.5784796
BA	6.8983333	0.3271202	BA	8.3851515	0.4668509
CA	0.3843788	0.0015731	CA	0.3883606	0.0037042
K	480.0827273	7.4973023	K	483.4445455	17.2707082
MG	41.7907576	0.7791115	MG	36.4070606	1.2753582
MN	3.0834848	0.0960593	MN	3.0266364	0.1627617
NA	2.8487879	0.0224677	NA	2.8419697	0.0855761
P	44.8260000	0.7354836	P	42.3763939	1.3336755
SR	1.6851515	0.0185702	SR	1.5005152	0.0443018

Table 2B.7 (continued)

YEAR=1999 LOCATION=BROWN			YEAR=1999 LOCATION=GALV		
Variable	Mean	Std Error	Variable	Mean	Std Error
B	513.4534194	13.1051451	B	470.9389706	15.3518470
BA	6.9119677	0.3027008	BA	6.3550588	0.1848602
CA	0.3792065	0.000981473	CA	0.3815324	0.0037798
K	492.8412903	9.0115476	K	460.5594118	11.6809347
MG	41.9480645	0.6669530	MG	36.9215294	0.7045658
MN	3.2866452	0.1217891	MN	2.8261471	0.1651062
NA	2.8196452	0.0282631	NA	2.7785588	0.0361821
P	42.6590645	0.9849167	P	40.3754118	0.5573791
SR	1.6143548	0.0219618	SR	1.5032647	0.0147550

YEAR=2000 LOCATION=ALMS			YEAR=2000 LOCATION=ARAN		
Variable	Mean	Std Error	Variable	Mean	Std Error
B	726.5751818	26.2375025	B	864.3291563	52.5431915
BA	9.8452045	0.2383162	BA	16.9675625	0.5991225
CA	0.3773841	0.0067126	CA	0.3798438	0.0070818
K	612.1336364	8.5550034	K	518.6934375	12.3607415
MG	54.4594091	0.8857640	MG	53.2786875	1.1620582
MN	4.6296364	0.1472428	MN	3.7597188	0.1560481
NA	4.1227727	0.0436211	NA	3.9467813	0.0453105
P	61.7654773	1.1309016	P	60.4109375	1.1384126
SR	2.3955682	0.0264441	SR	2.4590313	0.0305999

Table 2B.7 (continued)

YEAR=2000 LOCATION=ATCH		
Variable	Mean	Std Error
B	881.7103438	39.4247636
BA	11.8512813	0.2896489
CA	0.3786031	0.0061527
K	522.6381250	9.2608713
MG	49.2008125	0.7686712
MN	4.5988438	0.2259851
NA	3.8130625	0.0475256
P	62.0376563	1.0294396
SR	2.4111875	0.0231884

YEAR=2000 LOCATION=BROWN		
Variable	Mean	Std Error
B	910.0653939	45.6762769
BA	15.2918788	0.4992873
CA	0.3601424	0.0104239
K	535.1857576	9.9983966
MG	52.4709091	0.9502086
MN	3.9499394	0.2059087
NA	3.9586667	0.0216782
P	61.7667576	1.0701005
SR	2.3926061	0.0298598

YEAR=2000 LOCATION=GALV		
Variable	Mean	Std Error
B	887.2810938	72.2217210
BA	13.5101250	0.6507832
CA	0.3740281	0.0051140
K	500.7790625	9.4062520
MG	52.2596563	1.0974935
MN	4.2930000	0.2206413
NA	3.9038125	0.0344387
P	61.8772500	1.1354437
SR	2.4623750	0.0249243

Table 2B.8. Classification accuracies (in bold) and misclassification percentages from LDFA of age-0 red snapper to sample area in 1996. Elements included in the model are B, Ba, K, Mn, P, and Sr.

From: To:	**ALMS**	**LA**	**BRN**	**Overall Accuracy**
ALMS	**87**	3	10	
LA	4	**96**	0	
BRN	0	7	**90**	
				91

Table 2B.9. Classification accuracies (in bold) and misclassification percentages from LDFA of age-0 red snapper to sample area in 1997. Elements included in the model are B, Ba, K, Mg, Mn, Na, P, and Sr.

From: To:	**ALMS**	**LA**	**GALV**	**ARAN**	**BRN**	**Overall Accuracy**
ALMS	**88**	3	5	3	0	
LA	3	**93**	4	0	0	
GALV	6	14	**73**	4	3	
ARAN	8	5	0	**78**	9	
BRN	0	0	7	3	**93**	
						85

Table 2B.10. Classification accuracies (in bold) and misclassification percentages from LDFA of age-0 red snapper to sample area in 1998. Elements included in the model are Ba, Ca, Mg, Mn, Na, P, and Sr.

From: To:	**ALMS**	**LA**	**GALV**	**ARAN**	**BRN**	**Overall Accuracy**
ALMS	**87**	5	0	5	3	
LA	0	**85**	9	3	3	
GALV	3	6	**83**	8	0	
ARAN	3	30	6	**49**	30	
BRN	6	6	7	0	**80**	
						77

Table 2B.11. Classification accuracies (in bold) and misclassification percentages from LDFA of age-0 red snapper to sample area in 1999. Elements included in the model are B, Ba, Ca, K, Mg, Mn, Na, P, and Sr.

From: To:	**ALMS**	**LA**	**GALV**	**ARAN**	**BRN**	**Overall Accuracy**
ALMS	**77**	8	2	5	8	
LA	6	**70**	24	0	0	
GALV	5	3	**77**	9	6	
ARAN	0	0	6	**88**	6	
BRN	0	0	0	9	**91**	
						82

Table 2B.12. Classification accuracies (in bold) and misclassification percentages from LDFA of age-0 red snapper to sample area in 2000. Elements included in the model are Ba, Ca, K, Mg, Mn, Na, P, and Sr.

From: To:	**ALMS**	**LA**	**GALV**	**ARAN**	**BRN**	**Overall Accuracy**
ALMS	**91**	2	2	3	2	
LA	0	**75**	13	0	12	
GALV	6	16	**66**	6	6	
ARAN	0	3	4	**75**	18	
BRN	3	6	9	21	**61**	
						74

RELEVANCE OF THE NEW STUDY

Beyond examining juvenile red snapper habitat requirements, our study will have a greater significance in its contribution to the evolution of defining the *essential* part of EFH. In the past, habitat quality assessments have been more qualitative than quantitative, and in actuality most only have suggested what type of habitats may be suitable for a given species or life stage. To determine what habitats are *essential*, a more critical and quantitative approach is needed than simply correlating presence/absence or relative abundances of individuals with physical characteristics of different habitats. Methods developed here, as well as study results, will contribute much to the national effort to define more clearly what is necessary for a given habitat to be labeled essential. Ultimately, if we are successful under Phase II, the relative percentage contribution of ‘rig-reared recruits’ to the total adult population/production may be quantifiable. Therefore, oil and gas platforms, along with suitably expanded, non-trawling halos around them, may play a significant role in future fisheries management.

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SEA URCHIN EXCLUSION EXPERIMENTS ON AN OFFSHORE PETROLEUM PLATFORM, NORTHWESTERN GULF OF MEXICO

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INTRODUCTION

Sea urchins are known to be important components of natural reef systems and are often conspicuous members of offshore platform reef communities. Literature concerning sea urchins on offshore petroleum structures is scant and, as a result, the impact of sea urchins on platform fouling communities is relatively unknown. Information concerning the impact of sea urchin grazing may be useful to further understanding platform community food web dynamics. The objectives of the present study were to

1. Investigate aspects of the sea urchin population on a selected offshore petroleum platform;
2. Elucidate the effects of sea urchin grazing on the corresponding fouling community.

The platform selected for study was Matagorda Island-686 (MI-686). MI-686 is a four-pile structure located at N 27.957243^0 / 96.559226^0 W, or approximately 50 km ENE of Port Aransas, Texas. Water depth at the site is 30 m. Data collection began 26 July 2001 and was completed 03 September 2001. A final sampling day was scheduled for late September, but unfortunately, weather conditions and logistical difficulties prohibited access to the study site until 12 November 2001.

URCHIN POPULATION

The sea urchin population of MI-686 was sampled via visual surveys conducted by scuba divers. Observations indicated that two species of sea urchin, *Arbacia punctulata* and *Echniometra lucunter*, inhabit the platform. Data analysis is still in progress; however, it is apparent that *Arbacia* outnumbers *Echinometra* and that, when present, *Echinometra* is generally restricted to shallower depths. More detailed information concerning species abundance, zonation, and microhabitat preference will be available following further analysis.

URCHIN GRAZING

Caging experiments were utilized to investigate the effects of sea urchin grazing on the fouling community. By excluding sea urchins, it was possible to monitor certain areas of the platform fouling community in the absence of sea urchin grazing. Three caging treatments (cages, fences, open) were employed in the experiment. Cages excluded all grazers, fences excluded sea urchins but allowed access to fishes, and open areas served as controls. Experimental plots were monitored biweekly, using digital photography.

Analysis of photographic data is currently in progress. Cursory visual comparison of photographs indicates a general progression towards a more algal dominated community throughout the study period. Analysis of the percent cover of organisms in caged areas from 26 July to 03 September shows a decrease in bare substrate and an increase in algal cover. Percent cover of sponges and colonial ascidians also decreased during this time period. Fenced areas show similar trends for algal cover and bare substrate, but show slight increases for both tunicates and sponges. Analysis of selected control plots during this period show increased algal cover and decreased cover of bare substrate, sponges, and ascidians.

Presently, results seem to indicate that control plots showed a community progression intermediate between caged and fenced areas. Such evidence suggests that overall change in the platform community during the study period may be a confounding factor in this research; however, it would be unwise to draw any decisive conclusions until all experimental data can be analyzed. Data from intermediate sampling periods (09 August, 19 August) has yet to be investigated and may contain some important information. Furthermore, statistical analysis of photographic data will be necessary to determine if observed changes in percent cover of organisms is statistically significant.

Completion of the present research is expected in June 2002.

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Thesis Committee:	Dr. Quenton R. Dokken, Asst. Director CCS/TAMU-CC Dr. John W. Tunnell, Director CCS/TAMU-CC Dr. Edward R. Jones, TAMU-CC Dr. David A. McKee, TAMU-CC
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SESSION 2C

ENVIRONMENTAL STUDIES AND IMPACTS

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Co-Chair: Mr. Dave Moran, Minerals Management Service

Date: January 8, 2002

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MECHANISMS OF TOXICITY OF WATER-BASED DRILLING FLUID CHEMICALS

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INTRODUCTION

Exploration for and development of oil and gas resources in coastal and offshore waters throughout the world causes physical disturbance to the local marine environment. More important, several solid and liquid wastes are generated, some of which are discharged intentionally to the ocean. Physical disturbance and waste discharges may lead to deleterious impacts to local biological resources, particularly in shallow waters.

The major ocean discharge (in terms of volume and environmental concern) associated with drilling is drilling fluids (also called drilling muds) and drill cuttings. Drilling fluids are specially formulated mixtures of natural clays, barite, and other materials in water, petroleum, or a synthetic hydrocarbon material. They are an essential component of the rotary drilling process and function mainly to carry the chips of rock produced by the drill bit (drill cuttings) to the surface and to counteract the pressure in the geologic formation being drilled, preventing a blowout (National Research Council 1983; Hinwood *et al.* 1994; Patin 1999).

If permitted by the NPDES permit, water-based drilling fluids in volumes of about 20 to 30 m^3 are discharged intermittently at rates of 80 to 300 m^3/hour during drilling. There may be a larger discharge of as much as 200 m^3 of used drilling fluid at the end of drilling, particularly following drilling of an exploratory well. Drill cuttings are separated from the drilling fluid and discharged continuously to the ocean during actual drilling. Drill cuttings containing a small amount of adsorbed drilling fluid usually are discharged at a rate of about 0.2 to 2 m^3/hour.

The volumes of water-based drilling fluid and cuttings discharged during drilling of a well depend on the depth and diameter of the hole drilled, properties of the geologic formations being drilled, and characteristics of the drilling fluid handling system on the platform. The National Research Council (1983) estimated that approximately 800 to 5,000 m^3 of drilling fluid and 500 to 1,000 m^3 of drill cuttings are discharged during drilling of a typical well. An estimated 4,897 m^3 of used water-based drilling mud and 1,018 m^3 of drill cuttings were discharged to the ocean during drilling of a 4,970 m exploratory well on the Middle-Atlantic OCS (Ayers *et al.* 1980).

A considerable amount of research and monitoring has been performed during the past 25 years in the U.S. and abroad to characterize the effects of these drilling fluid and cuttings discharges on marine organisms and ecosystems. This paper summarizes our current knowledge about the causes of toxicity of water-based drilling fluids and cuttings.

COMPOSITION OF WATER-BASED DRILLING FLUIDS

The five major ingredients in water-based drilling muds (barite, clay, lignosulfonate, lignite, and sodium hydroxide) account for more than 90 percent of the total mass of additives used in drilling muds (National Research Council, 1983; Neff *et al.* 1987). High molecular weight polymers, mostly of plant origin (cellulose), may be used in addition to or instead of clay in some drilling muds. The other major ingredient is freshwater or seawater. Most water-based drilling muds contain 75 to 85% water by volume. There is a large variety of specialty additives that may be added in small amounts to drilling fluids to solve particular down-hole problems.

During drilling, the drilling mud engineer on the platform continually evaluates the properties of the mud and adjusts its composition so that it will perform its different functions optimally. Thus, the composition of the drilling mud on a platform is changed continually during drilling and no two drilling muds have exactly the same composition.

The components of major environmental concern in drilling muds and drill cuttings are metals and petroleum hydrocarbons. The metals most often found in drilling mud and cuttings at concentrations significantly higher than the concentrations usually found in natural marine sediments include barium, chromium, lead, and zinc (Table 2C1: Neff *et al.* 1987). Other metals sometimes found in drilling muds at elevated concentrations and that are of concern because of their potential toxicity to marine organisms are arsenic, cadmium, copper, mercury, nickel, and silver. Some of these metals are added intentionally to drilling muds as metal salts or organometallic compounds. Others are trace contaminants of major drilling mud ingredients.

Table 2C.1. Ranges of metals concentrations in drilling fluids and marine sediments. Concentrations are mg/kg dry wt. From Neff *et al.* (1987).

Metal	Drilling Fluids	Marine Sediments
Aluminum (Al)	10,800	10,000 – 90,000
Arsenic (As)	1.8 – 2.3	2 – 20
Barium (Ba)	720 – 449,000	28 – 8,100
Cadmium (Cd)	0.16 – 54.4	0.3 – 1.0
Chromium (Cr)	0.1 – 5,960	10 – 200
Copper (Cu)	0.05 – 307	8 – 700
Iron (Fe)	0.002 – 27,000	20,000 – 60,000
Mercury (Hg)	0.017 – 10.4	0.05 – 3.0
Manganese (Mn)	290 – 400	100 – 10,000
Nickel (Ni)	3.8 – 19.9	2 - 10
Lead (Pb)	0.4 – 4,226	6 – 200
Vanadium (V)	14 – 28	10 – 500
Zinc (Zn)	0.06 – 12,270	5 – 4,000

Drill cuttings contain metals derived from the rocks being penetrated by the drill bit (usually as insoluble heavy mineral salts), metal chips from the drill string (particularly the drill bit which is continuously abraded during drilling), and drilling-fluid solids that adhere to the cuttings. For the most part, these metals are in inert mineral forms and do not dissolve when the cuttings are discharged to the ocean.

The petroleum hydrocarbons sometimes detected in water-based drilling fluids and drill cuttings are derived from two possible sources:

1. refined oil added intentionally to the drilling mud; and
2. crude oil from the geologic formations being drilled.

Refined petroleum products may be added to the water-based drilling mud to lubricate the drill string, particularly when a slant or deviated hole is being drilled, and to aid in freeing stuck drill pipe. Diesel fuel or a mineral oil may be used for this purpose. Mineral oil contains low concentrations of aromatic hydrocarbons and is much less toxic than diesel fuel (Breteler *et al.* 1988). As much as 2 to 4% diesel fuel or mineral oil may be added to the bulk drilling mud to reduce torque and drag of the drill string (National Research Council 1983). If the drill string becomes stuck in the hole, a pill of oil or an oil-based drilling mud may be injected down the drill string and spotted in the area of the annulus where the pipe is stuck. Ordinarily, the pill and some drilling mud on either side of the pill are kept separate from the bulk drilling mud system and are recovered and shipped to shore for disposal. However, some oil usually gets into the bulk drilling mud system.

TOXICITY OF WATER-BASED DRILLING FLUIDS

Many laboratory toxicity tests have been performed since the mid 1970s on the acute and chronic toxicity of water-based drilling fluids to freshwater and marine animals. By 1983, 62 species of marine animals from the Atlantic and Pacific Oceans, the Gulf of Mexico, and the Beaufort Sea have been tested in 400 bioassays with 72 different water-based drilling fluids (National Research Council 1983). Nearly 80% of the median lethal concentrations (96-h LC_{50}) were greater than 10,000 mg/L (parts per million: ppm) drilling fluid. A chemical or mixture with an LC_{50} of 10,000 ppm or greater is considered practically non-toxic (IMCO 1969).

Subsequently, eight generic water-based drilling muds, representative of the types of drilling fluids used offshore in U.S. waters, were identified and characterized chemically and toxicologically (Ayers *et al.* 1983). The mysid (*Americamysis [Mysidopsis] bahia*), a small shrimp-like crustacean, was identified as one of the most sensitive species to drilling fluids. A suspended particulate phase preparation was recommended as the best simulation of the type of drilling fluid dispersion encountered by water column organisms (Neff *et al.* 1980). Bioassays performed with the suspended particulate phase of eight generic muds and mysids gave 96-h LC_{50}s ranging from 3,300 mg/L to >1000,000 mg/L mud added (Duke *et al.* 1984) (Table 2C.2), similar to results obtained by Ayers *et al.* (1983). The most toxic drilling fluid was a KCl-polymer mud; lime mud and a freshwater lignosulfonate mud also were slightly toxic. The results of these tests were used by EPA to set the toxicity limit for water-based drilling muds of 3,000 ppm drilling mud added (30,000 ppm suspended particulate phase) in the current effluent limitations guidelines.

Table 2C.2. Acute toxicity of the suspended particulate phase (SPP) of eight generic drilling muds to mysids. 96-hour LC_{50} Concentrations are mg/L mud added. From Duke e*t al*. (1984).

Drilling Mud Type	96-Hour LC_{50}
KCl Polymer Mud	3,300
Seawater Lignosulfonate Mud	62,100
Lime Mud	20,300
Non-Dispersed Mud	>100,000
Seawater Spud Mud	>100,000
Seawater/Freshwater Gel Mud	>100,000
Lightly Treated Lignosulfonate Mud	68,200
Freshwater Lignosulfonate Mud	30,000

All U.S. offshore operators are required by the NPDES permit to perform suspended particulate phase bioassays on used drilling fluids each month during drilling and at the end of the well. Data collected by EPA between 1986 and 1989 showed that 99.9% of 10,397 Gulf of Mexico drilling fluid bioassays yielded a 96-h LC_{50} in excess of the 30,000 ppm suspended particulate phase limit (Science Applications International, Inc. 1992). Thus, the vast majority of water-based drilling muds used offshore in U.S. waters are not toxic to marine organisms.

CAUSES OF DRILLING FLUID TOXICITY

As expected from the low toxicity of whole used water-based drilling fluids, the toxicity of most individual drilling fluid ingredients also is low (Table 2C.3). Of the major drilling mud ingredients, only chrome- or ferrochrome-lignosulfonate may be moderately toxic to marine animals (Neff 1987; Parrish *et al.* 1989). However, Conklin *et al.* (1983) showed that the toxicity of a whole drilling mud could be attributed primarily to chrome only when chromate plus chrome lignosulfonate concentrations in the mud were very high. Several minor additives, such as zinc salt H_2S scavengers, tributyl phosphate surfactant defoamer, and fatty acid high temperature lubricant are toxic, but usually are not present in used drilling fluids at concentrations high enough to contribute significantly to whole mud toxicity.

The acute toxicity of water-based drilling fluids containing petroleum additives increases as hydrocarbon concentration increases. Conklin *et al.* (1983) observed a statistically significant inverse relationship between the toxicity to estuarine shrimp of 18 samples of drilling fluids from a coastal drill site in Alabama and the concentrations in the drilling fluids of diesel fuel (the drilling fluids contained between 170 and 8,040 ppm total petroleum hydrocarbons) (Figure 2C.1). Breteler *et al.* (1988) showed that petroleum additives increased the toxicity of water-based drilling fluids to water column and benthic marine animals. Drilling fluids containing a high-sulfur diesel fuel (containing 25 % total aromatic hydrocarbons) were the most toxic, followed closely by drilling fluids containing a low-sulfur diesel (containing 8.7 % total aromatics); drilling fluids containing a low-aromatic mineral oil were the least toxic.

Table 2C.3. Acute toxicity of some important water-based drilling mud additives. LC_{50}s are percent of the SPP of a lightly treated lignosulfonate mud containing the additive. From Leuterman *et al.* (1989).

Additive	96-Hour LC_{50}
Barite	>100
Bentonite	>100
HEC Polymer Viscosifier	7.8 - 29
Quebraco Thinner	95.2
Chrome Lignosulfonate Deflocculant	50 - >100
Chrome-Free Lignosulfonate	31 - >100
Modified Chrome Lignite	20.1
Potassium Lignite	>100
Blended Organic Ester Lubricant	10.4 - 49.4
Fatty Acid High Pressure Lubricant	3.5 - >100
Modified Fatty Acid Emulsifier	23.8 - 30.2
Non-Ionic Surfactant	16.2 - >100
Tributyl Phosphate Surfactant Defoamer	5.1
Ammonium Busulfate Corrosion Inhibitor	75
Zinc Salt H_2S Scavangers	3.1 - 7.8
Polyacrylate Scale Inhibitor	77.3
Biocide	45

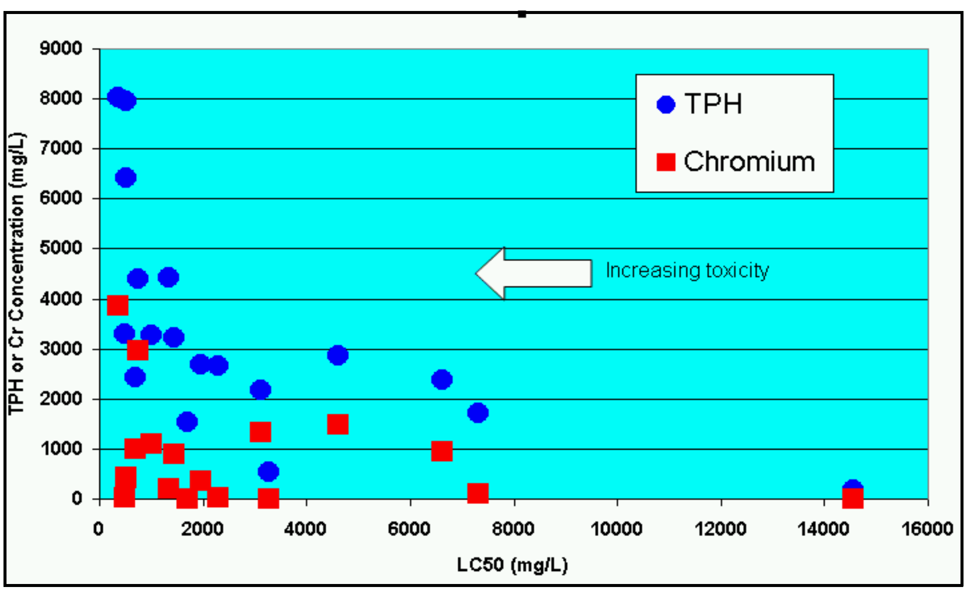

Figure 2C.1. Relationship between the toxicity to grass shrimp of water-based drilling fluids collected at 18 depths in a Mobile Bay, Alabama, well and concentrations of chromium and total petroleum hydrocarbons (TPH) in the muds. From Conklin *et al.* 1983.

Although water-based drilling fluids may contain high concentrations of several metals (Table 2C.1), the metals are present primarily in highly insoluble forms. EPA regulates concentrations of mercury and cadmium in drilling fluid barite at 1 mg/kg and 3 mg/kg, respectively, in order to ensure that only clean, low trace metal barite is used as a weighting agent in muds destined for offshore disposal. Insoluble metals associated with barite and clay matrices are not readily bioaccumulated by marine animals living in close association with high concentrations of drilling fluid solids in sediments (Neff 1987; Neff *et al.* 1989a, b). Neff *et al.* (1989b) showed evidence of a slight accumulation of mercury by clams and shrimp and of cadmium by clams during exposure for 13 weeks to a high trace metal barite (15 ppm Hg and 11 ppm Cd) in sediments (Table 2C.4). In most cases, metals accumulated by marine animals from drilling fluid barite remain in the tissues in insoluble, inert concretions, probably of the original barite particles (Jenkins *et al.* 1989). Thus, metals in drilling fluids probably do not make a significant contribution to their toxicity.

Table 2C.4. Bioaccumulation of mercury and cadmium by a fish (*Pleuronectes americanus*), a clam (*Mya arenaria*), a worm (*Neanthes virens*), and a shrimp (*Palaemonetes pugio*) during exposure for 13 weeks to clean sediment (Control), low trace metal barite (LTMB), and high trace metal barite (HTMB). Metal concentrations in the substrates are included. All concentrations are mg/kg dry wt. From Neff *et al.* (1989b).

Species	**Mercury**			**Cadmium**		
	Control	**LTMB**	**HTMB**	**Control**	**LTMB**	**HTMB**
Substrate	0.02	0.12	15.23	0.02	0.03	11.17
Fish	0.24	0.23	0.21	0.05	0.05	0.05
Clam	0.17	0.30[a]	0.69[a]	0.34	0.31	0.75[a]
Worm	0.10	0.10	0.15	0.22	0.31	0.36
Shrimp	0.15	0.35[a]	0.27	0.13	0.25	0.20

[a] Significantly higher than control.

CONCLUSIONS

- Water-based drilling fluids have a low toxicity to marine animals.
- In those drilling fluids that are toxic, the toxicity is caused by petroleum products added to increase lubricity, high ionic strength (KCl or lime), zinc H_2S scavengers, or biocides.
- Metals associated with drilling fluids have a low bioavailability to marine animals and so do not contribute much to mud toxicity.
- Dilution to non-toxic concentrations following discharge is rapid.

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PRODUCED WATER: TOXICOLOGICAL MECHANISMS

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INTRODUCTION

Produced water is the largest waste stream from oil and gas production operations. During oil production, water pumped from the geological formation and generated in the production process must be separated from the oil and discarded. This aqueous fraction, commonly called "produced water" or "oil-field brine," is often discharged into the marine and freshwater environments from both onshore and offshore activities. Onshore development activities often discharge produced water through re-injection of the waste stream back into the oil-field reserve. Over 90% of produced waters from onshore operations are discharged in this manner. The remaining 10% of wastes are discharged into surface waters.

Offshore development generates the largest volume of produced water. In 1988 the daily discharge of produced water in the North Sea was approximately 900 million liters per day (Stephenson 1992). In 1991, the United States operations in the Gulf of Mexico discharged approximately 549 M L/d (Stephenson 1992). A single platform can generate as much as 1.5 M L/d.

PRODUCED WATER CONTAMINANTS

Each produced water effluent is different depending on the operation and the oil formation. Some formations have vastly larger amounts of water in the geological reserve than others. Typically, older oil production operations generate larger amounts of water than younger ones. Offshore production facilities generate more aqueous waste due to the nature of drilling under water that is under pressure with depth. Many different types of contaminants are typically found in produced waters. Organic constituents make up the largest group. The largest organic constituent group is the petroleum compounds. These compounds include aliphatic hydrocarbons, phenols, organic acids and low molecular weight aromatic hydrocarbons.

Another important group of organic contaminants are treatment chemicals used in the production process. These include scale and corrosion inhibitors, biocides, surfactants (i.e., emulsion breakers), coagulants, and flocculants. Treatment chemicals are often proprietary, and the specific formulations are not always known. A large number of metals, both from the oil reserve and from the production process are also present in produced water. The predominant metals found in produced water are: Ca, Cr, Cu, Pb, Ni, and Zn. Barium (Ba) is also found in large amounts in produced water. Drilling fluids often contain large quantities of barite and account for much of the Ba in produced waters. Radionuclides, while not a large constituent of produced water, are often found, especially when the drilling process passes through certain types of geological formations. Finally, produced waters contain large groups of the major ions. These can include: Na^+; Cl^-; Ca^{2+}; Mg^{2+}; SO_4^{2-}; and NO_3^-.

TOXICITY OF PRODUCED WATER

The toxicity of a substance can be observed to occur at several different biological levels, but is often broken down into lethal and sublethal endpoints. The LC_{50} (Lethal Concentration 50) is defined as the concentration of a substance that will produce mortality in 50% of a test population. Similarly the EC_{50} (Effective Concentration 50) is defined as the concentration that will elicit a non-lethal toxic response in 50% of the test population. Sublethal endpoints often occur at the reproduction, development, and ecological (e.g., recruitment) level.

Toxicity can occur over different time frames. Acute toxicity is generally defined as toxicity that occurs over a short time period. This can be operationally defined from hours to days, but usually occurs over a brief period that is shorter than four days (Rand and Petrocelli1985). Chronic toxicity is generally defined as toxicity that occurs over a longer time frame of days to years, and often occurs over an entire life cycle or generation of an organism (Rand and Petrocelli 1985).

Toxicity from Onshore (Freshwater) Discharges

Major Ion Toxicity: Produced waters are characteristically high in total dissolved solids (TD S) as compared to surface waters. This is especially true for produced waters that are generated and discharged from land-based operations (Mount *et al.* 1997). Acute toxicity is often observed using freshwater bioassays on organisms such as Cladocerans (e.g., *Daphnia* sp.) and fish. Salinity changes and elevated TDS concentrations in freshwater matrices can often lead to toxicity that may not be related to the traditional “toxic” components of produced water. Therefore, toxicity found in these systems is often a confounding issue resulting from the use of an inappropriate salinity or ionic matrix rather than from a contaminant compound. For example, Mount *et al.* (1997) demonstrated significant toxicity from major ions and developed statistical models to predict toxicity from high TDS produced waters. The major ion mode of toxicity is observed as a change in the salinity tolerance of the organisms. The organisms simply cannot regulate, on a cellular or organ level, the change in ionic strength of the medium.

Toxicity from Offshore (Marine) Discharges

Major Ion Toxicity: Marine organisms exhibit salinity tolerance issues similar to those observed in freshwater organisms. These are often dealt with more easily in the laboratory and result in less confounding issues in the bioassay results Douglass and Horne (1997) found that Mysid bioassays were sensitive to excess Ca, K, Br, and Mg.

Studies from West Coast Produced Waters

A series of studies has been conducted on produced water from rigs located off Santa Barbara, Calofornia. Oil and water generated at offshore rigs are delivered to an onshore processing facility in Carpinteria, CA where they are separated. The effluent is discharged through a diffuser system located approximately 300 m offshore in approximately 10-12 m of water. Produced water generated on the west coast of the United States is typically low in TDS. Salinity ranges between 14 to 25 ppt., and generally contains elevated H_2S concentrations from offshore production. Water is typically sent to onshore processing facilities where aeration techniques remove H_2S.

Krause *et al.* (1992) investigated the effects of produced water on reproduction and development of marine invertebrates using purple sea urchins *(Strongylocentrotus purpuratus).* A short-term (e.g., 10-minute) exposure to eggs and sperm found that fertilization success was diminished with concentrations as low as 0.0001%. Furthermore, effects on eggs and sperm were additive. In a secondary experiment in which sperm, eggs, and zygotes were exposed to produced water either before fertilization or during development for 48 hours it was found that embryonic development was also affected at concentrations as low as 0.0001%. As was found before, the effects of produced water on sperm, eggs, and zygotes was additive. Finally, Krause *et al.* (1992) found that if the developing larvae were followed through an entire 96-hour development period, all larvae developed to the pluteus larval stage. This finding indicated that the effects of produced water were to elicit a delay in development rate, rather than a lethal toxic effect on the larvae.

Garman *et al.* (1994), using produced water from the Carpinteria facility, found that key cellular events were affected during the early development of the zoospores of the giant kelp *(Macrocystis pyrifrra)* after exposure to produced water. Germination, germ tube growth and nuclear migration were affected at produced water concentrations ranging from 4%to 8%.

Raimondi *et al.* (1992) used a field experiment to investigate effects on recruitment of the larval red abalone *(Ha liotis rufescens)* offshore of the Carpinteria facility. Recruitment was studied by placing competent abalone larvae in cages and placing them in the water column downfield from the produced water discharge. Both larval swimming and settlement was observed following the field exposure. In the field, swimming ability was affected as far away as 100 m from the outfall. Subsequent larval settlement was affected by 0.01% produced water treatments.

Krause (1994) addressed the effects of produced water exposure on gametogenesis and gamete function in the purple sea urchin. Experiments consisted of caging adult urchins downfield from the Carpinteria outfall at distances ranging from 5 to 1,000 m downfield for a period of 8 weeks. Gonad mass and gamete function were measured following the field exposure. Both males and females had significantly larger gonads in organisms caged closer to the outfall. When gamete function was tested in a fertilization bioassay it was found that in organisms caged closer to the outfall sperm function and fertilizability of eggs decreased relative to those caged farther away.

Effects of Barium (Ba) in Produced Water: Barium is found in elevated concentrations in drilling fluids and produced waters (Schiff *et al.*1992) primarily because of the use of barite ($BaSO_4$) in the drilling process and the natural source of Ba in sediments. Barium is highly insoluble in seawater and is found primarily as $BaSO_4$; however, small concentrations of Ba^{2+} in the range of 13 mg/L have been determined from west coast produced waters (Spangenberg and Cherr 1996). Barium has also been shown to act functionally as a Ca analog in cellular functions, and can often displace Ca atoms in key biochemical mechanisms. Spangenberg and Cherr (1996) studied the effects of soluble concentrations of barium on the development of the California mussel *(Mytilus californianus).* Fertilized embryos were exposed to concentrations of Ba between 100 and 100,000 µg/L, and actual Ba concentrations were verified by analytical chemistry. Adverse effects occurred between 200 and

900 µg/L, and higher concentrations were associated with decreased toxicity from the apparent precipitation of Ba salts from the seawater.

SUMMARY

Freshwater toxicity from produced waters is driven primarily by changes in the major ion concentrations when effluents are discharged into surface waters. Marine organisms exposed to produced waters, both in the laboratory and in the field, show effects that are primarily driven by cellular skeleton events such as flagella activity (e.g., sperm swimming, abalone larvae swimming), and in cytoskeleton development (e.g., kelp nuclear migration, urchin development and spicule formation, abalone post-settlement development). Cellular skeleton activity relies heavily on the availability of Ca atoms within the biochemical mechanisms of development. Laboratory experiments suggest that toxicological effects found in many marine organisms may be related to the very low concentrations of soluble Ba contained within the produced waters. This finding remains controversial and requires further investigation.

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TWO TO FIVE RING PETROLEUM POLYCYCLIC AROMATIC HYDROCARBONS: BIOCHEMICAL EFFECTS

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INTRODUCTION

Polycyclic aromatic hydrocarbons (PAH) are a series of compounds consisting of the elements carbon and hydrogen that contain at least two or more fused benzene rings. These compounds range in molecular weight from 128 to 300. PAH are common environmental contaminants, persistent, toxic, mutagenic, and carcinogenic in nature (Moore *et al.* 1989). Consequently, the US EPA includes 16 PAH in the list of priority pollutants to be monitored in aquatic and terrestrial ecosystems. The chemical structure of the 16 EPA priority pollutant PAH are shown in Figure 2C.2. Because they are probable human carcinogens, PAH have been studied extensively to understand their fate and distribution in the environment and their toxicity to animals and humans.

The mechanism of PAH formation during combustion is complex, but apparently is due primarily to pyrolysis and pyrosynthesis (Neff 1979; Mastral and Callen 2000). On heating, organic compounds are partially cracked to smaller and unstable fragments (pyrolysis). These fragments are highly

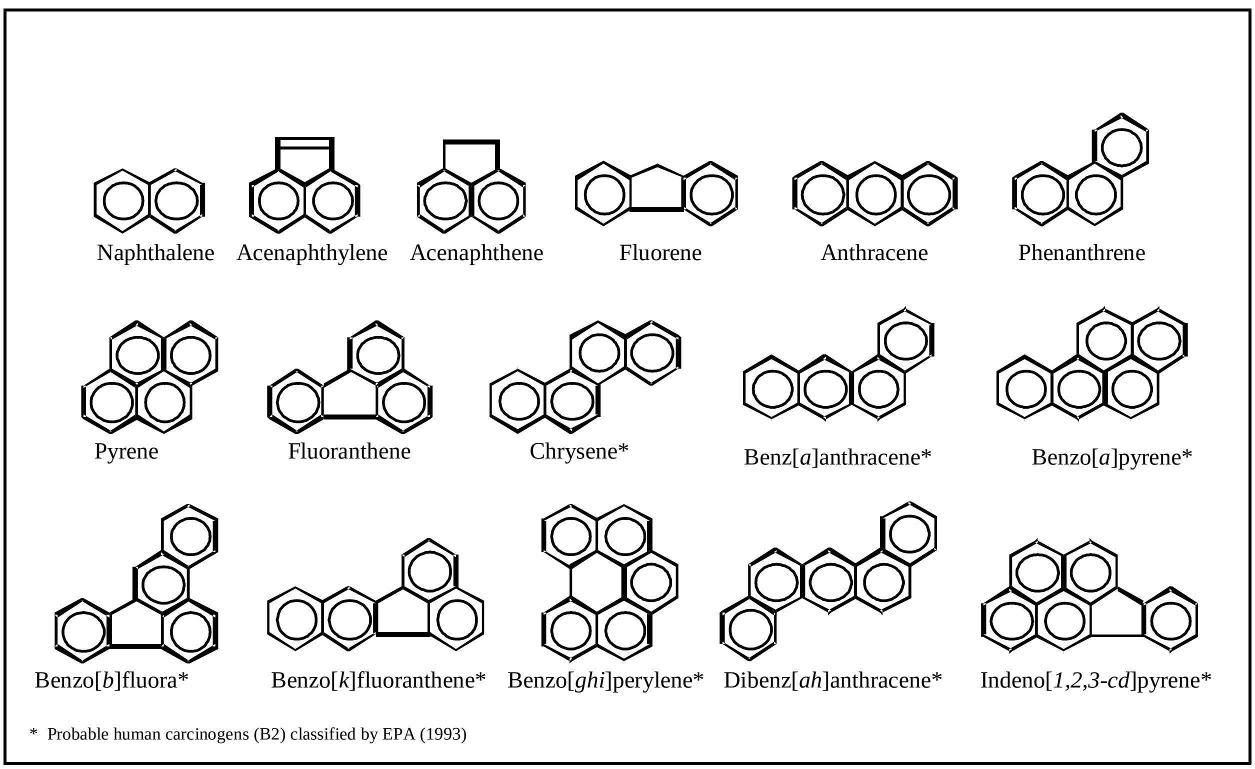

Figure 2C.2. EPA priority PAH compounds.

reactive free radicals with a very short lifetime and are converted to more stable PAHs through pyrosynthesis. PAHs are also found in petroleum and can result from natural processes (e.g., volcanic activity, forest fire), but human activities are generally considered to be the major sources. Industrial activities that produce PAHs include coal coking, production of carbon blacks, creosote, and coal tar, petroleum refining, synthetic fuel production from coal, and the use of Soderberg electrodes in aluminum smelters and ferrosilicum and iron works (NRC 1983). Domestic activities that produce PAHs include home heating with wood or fossil fuels, waste incineration, and use of internal combustion engines (Baek *et al.* 1991). Among domestic activities, fossil fuel burning to operate vehicles is the largest source of PAHs. In general, PAHs produced by incomplete combustion or pyrolysis at high temperature have two to six rings and less alkylated substitution. Petrogenic PAHs, which are produced at relatively low temperature, have preferentially two to three rings and a predominance of alkylated PAHs (Blumer 1976; NRC 1983; Masclet *et al.* 1987), see Figure 2C.3.

PAHs with two to five rings are generally of most concern for environmental and human health effects (ATSDR 1995). Many of these PAHs are known to function as precarcinogens that require metabolic activation before they are able to bind to DNA, RNA, or proteins (Hall and Grover 1990). Multiple forms of cytochrome P450 monooxygenase enzymes are known to catalyze formation of arene oxides, which are initial products of the oxidation of PAHs (Guengerich 1992). Exposure to PAHs has been demonstrated to produce cancer in humans (ATSDR 1995). The most notorious and common carcinogenic PAH is benzo(a)pyrene. The first finding of association of the occurrence of scrotal cancer in chimney sweeps in London with PAH containing soot was in the 1750s. However, PAHs have been recognized specifically as carcinogens after Cook *et al.* (1933) purified the yellow crystals of benzo[a]pyrene from coal tar and found that they induced tumors in experimental animals. Chronic exposure to PAHs can cause dermatitis and hyperkeratosis and possibly affect placental endocrine and hormonal function (ATSDR 1995).

PAHs are hydrophobic compounds with very low water solubilities. Therefore, their concentrations in water are very low; however, PAHs tend to accumulate in biota (Frank *et al.* 1986; Sericano 1993; van Hattum 1998). For example, PAHs may be accumulated to a concentration in bivalves 102 to 105 times higher than that in water (Farrington *et al.* 1983). Although photo and microbial degradation can reduce some PAHs rapidly under certain conditions, PAHs may persist for long periods in oxygen-poor environment (Sutherland *et al.* 1995). However, unlike other persistent organic contaminants, such as PCBs, DDTs, and TBT, PAH concentrations generally decrease with increasing trophic level (Broman *et al.* 1990). This decrease can be attributed to increasing metabolic activity with increasing trophic level.

HISTORICAL TRENDS IN PAH CONCENTRATION

According to sediment core analysis, PAH concentrations peaked in the 1940-1950 (Bates *et al.* 1984; Zhang *et al.* 1993; Santchi *et al.* 2001) probably due to transition from coal to petroleum fuel sources (Gschwend and Hites 1981). Though in some metropolitan areas, PAH contaminations have increased over the past 20-40 years due to population growth and increased urban activity (van Metre *et al.* 2000; Santchi *et al.* 2001), the environmental levels of PAHs generally have declined (Latimer and Quinn 1996; USEPA 2000) due to change in fuel usage and enhanced emission

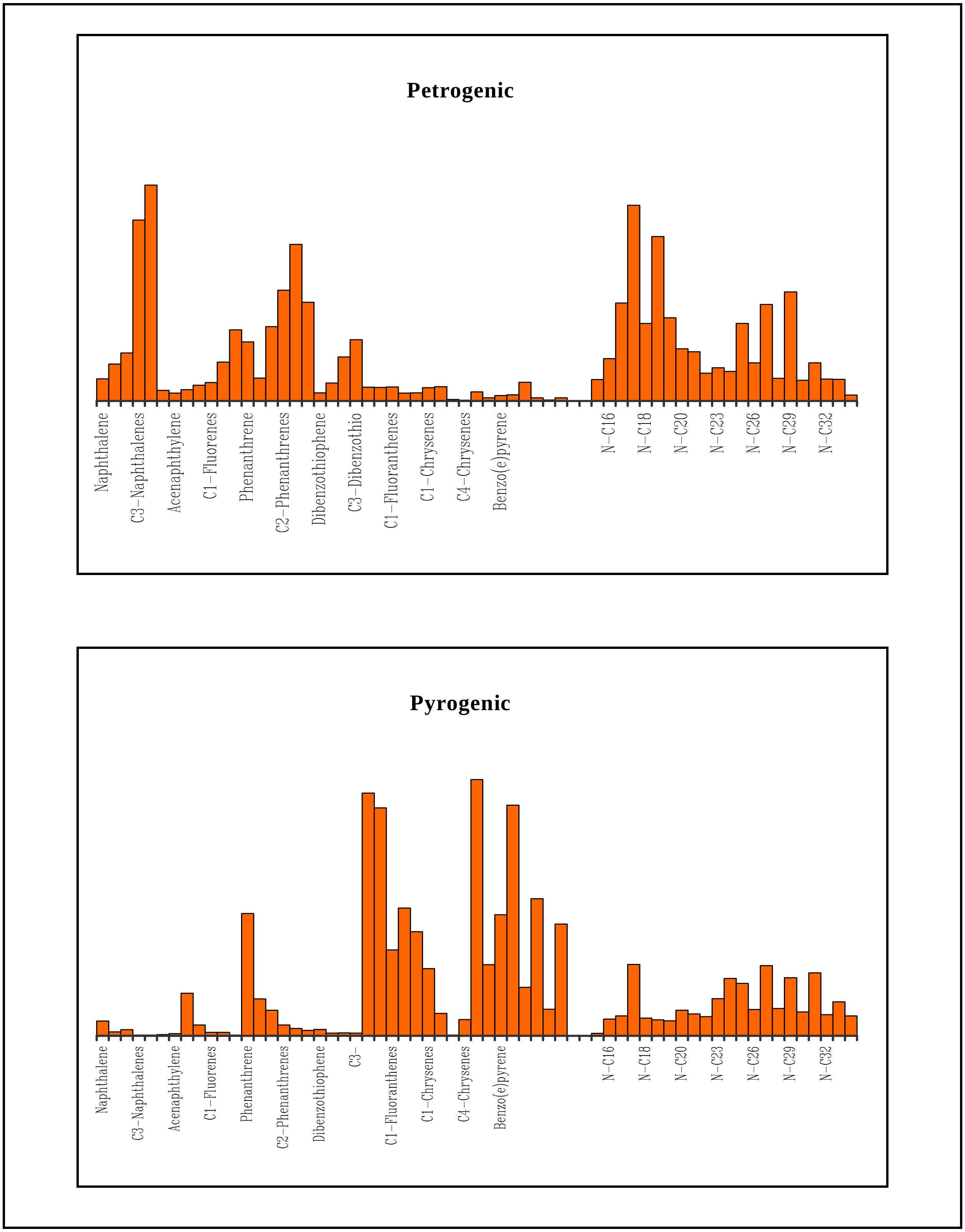

Figure 2C.3. Examples of pyrogenic and petrogenic PAH distributions.

control, resulting in decrease of the ecotoxicological damage like tumor instances in fish and bivalves (Baumann and Harshbarger 1998). Examples of a sediment core analysis of total PAH (Santchi *et al.* 2001) are presented in Figure 2C.4. These cores are from regions in the Northern Gulf of Mexico; the Mississippi Delta, Louisiana; Tampa Bay, Florida; and Galveston Bay, Texas.

LYSOSOMAL DESTABILIZATION: PAH

Studies have showed a positive relationship between the lysosomal destabilization and body burden of selected organic analytes including PAH (Hwang *et. al.* 2002). The lysosomal destabilization was measured using hemocytes of eastern oysters (*Crassostrea virginica*) collected along a chemical concentration gradient in Galveston Bay, Texas, USA (Figure 2C.5). Results of the lysosomal response were compared to concentrations of organic compounds and trace elements in oyster tissue. Concentrations (on a dry wt basis) ranged from 288 to 2,390 ng/g for PAHs. The percentage of destabilized lysosomes ranged from 34 to 81%. A significant positive correlation ($p < 0.05$) was observed between lysosomal destabilization and body burden of organic compounds (PAHs, PCBs, TBT, and chlorinated pesticides). No significant correlation was found between metal concentrations and lysosomal destabilization. Based on lysosomal destabilization, the study sites can be placed in one of three groups - healthy (GBHR, GBCR), moderately damaged (GBOB, GBTD), and highly damaged (GBYC, GBSC). Lysosomal destabilization which is consistent with toxic chemical body burdens supports previous observations that lysosomal membranes are damaged by toxic chemicals and indicates that this method can serve as an early screening tool to assess overall ecosystem health using oysters. Coupling of lysosomal assay and chemical analysis provides valuable information for environmental interpretation, which is essential for future management actions. Additional aquarium studies (Hwang 2001) indicate that PAH can elicit lysosomal destabilization. It is clear that increased burdens of PAH and other compounds in oyster have a degrading effects on their lysosomes.

CONCLUSIONS

PAH with two to five rings are ubiquitous contaminants of near shore environments. The PAH are derived from many sources, most of which are anthropogenic. PAH can exert adverse effects on biota including humans. Fortunately, seafood is a minor source of PAH to most humans when compared to other foods. The concentrations of PAH are likely to increase with increased human population. PAH are likely to continue to have deleterious effects on organisms living in urban/industrial near shore environments. Their continued input to the near shore areas violates the principals of sustainable development.

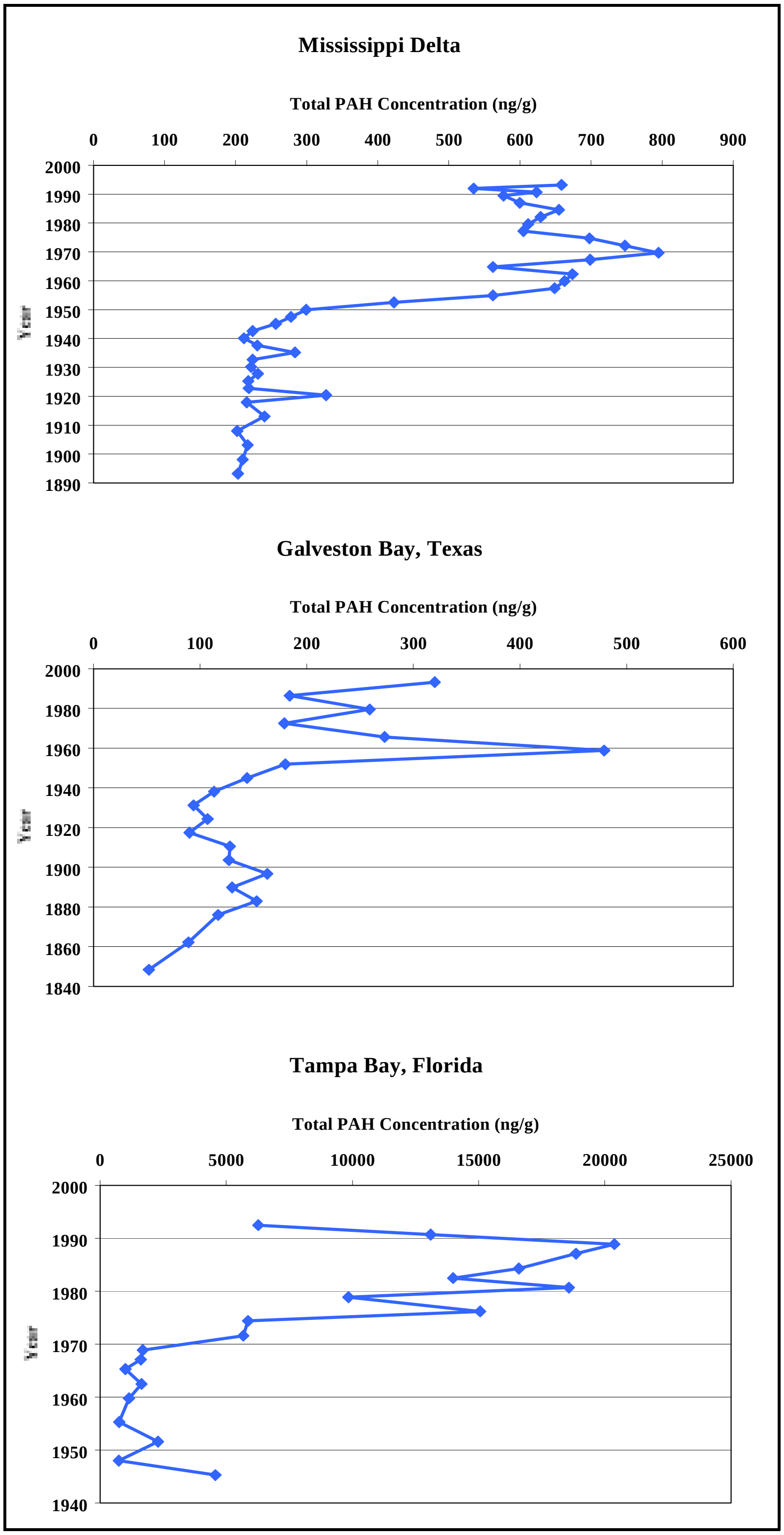

Figure 2C.4. Sediment core data from three regions in the northern GOM.

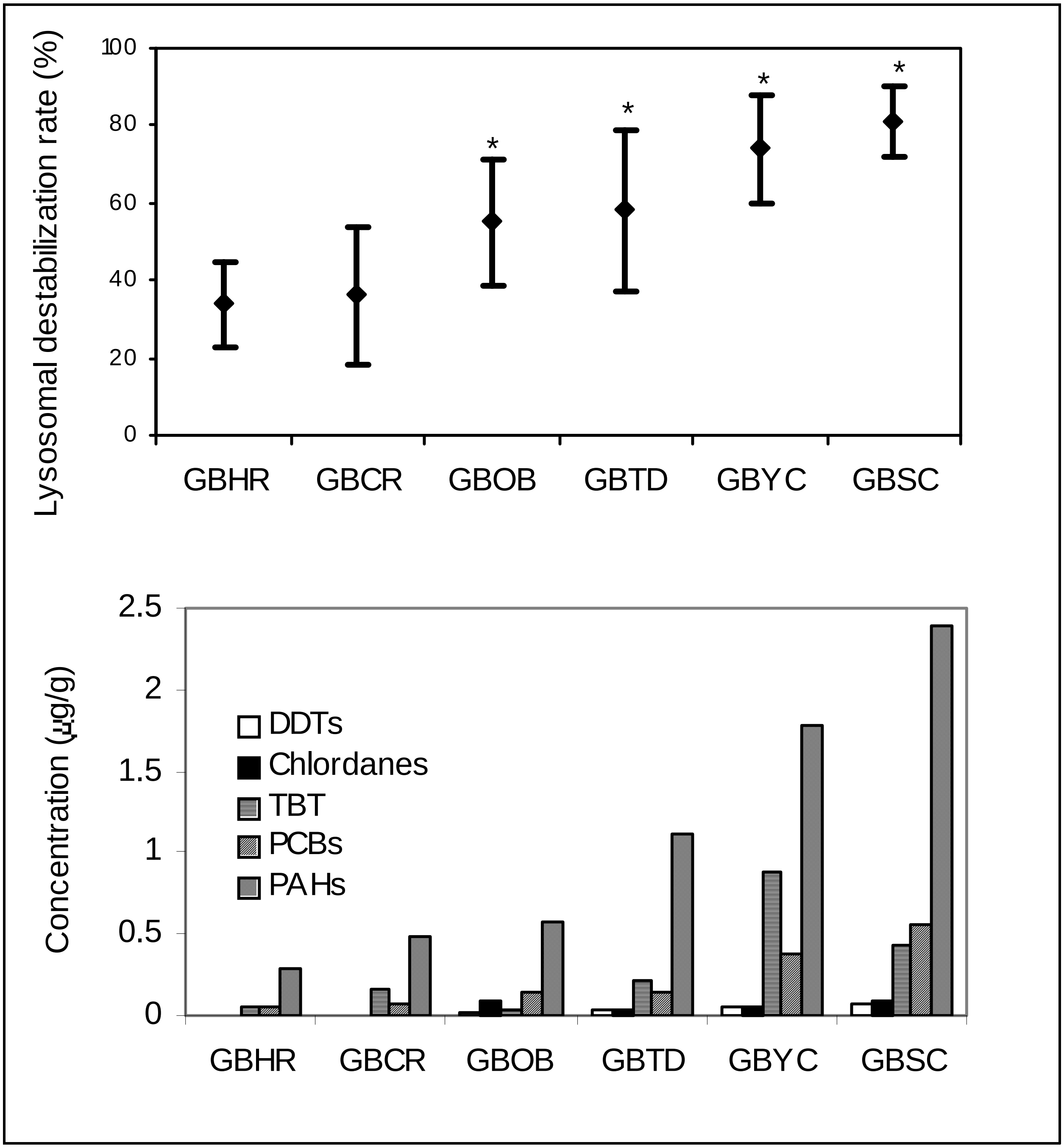

Figure 2C.5. Lysosomal destabilization rate (* indicates significantly different from reference site (GBHR), ($p < 0.05$)), organic analytes oysters (*Crassostrea virginica*) from Galveston Bay, Texas.

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PHOTOENHANCED TOXICITY OF SPILLED OIL

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INTRODUCTION

Traditionally, toxicological studies used to define the hazards of PAHs and oil have been conducted under fluorescent light, which has minimal ultraviolet radiation (UV) (Arfsten *et al.* 1996). Photoenhanced toxicity is the increase in chemical toxicity in the presence of UV compared to toxicity measured under conditions of minimal UV. Polycyclic aromatic hydrocarbons (PAHs) and heterocyclic aromatics present in petroleum have been shown to exhibit a 2 to greater than 1000 fold increase in toxicity in the presence of UV (Landrum *et al.* 1987; Pelletier *et al.* 1997). This photoenhanced toxicity occurs at the UV wavelengths that occur in the water column of aquatic environments: UVB (280 to 320 nm) and UVA (320 to 400 nm) (Barron *et al.* 2000). Not all chemicals exhibit photoenhanced toxicity because specific structural features are necessary for phototoxicity. Research has only recently begun identifying the phototoxic components of oil. For example, dibenzothiophenes, important components of petroleum, have only recently been indicated as phototoxic. Known phototoxic PAHs and heterocycles include anthracene, pyrene, fluoranthene, and acridine. Aromatic ring conjugation is an important determinant of the phototoxicity of a polycyclic aromatic compounds. For example, the three ring aromatic compound anthracene exhibits a several order of magnitude increase in toxicity in the presence of UV, while its three ring homolog phenanthrene does not. QSAR modeling of the effect of substituents on the electronic structure of PAHs indicates that alkylation (i.e., addition of carbon groups) will have little effect on the photoenhanced toxicity of PAHs (Veith *et al.* 1995). This indicates that the more abundant alkyl PAHs present in petroleum will have similar photoenhanced toxicity as the parent chemical (non-alkylated homolog).

PHOTOACTIVATION OF PETROLEUM

Petroleum products and weathered oil exhibit a 2 to greater than 100 fold increase in toxicity under simulated natural sunlight (Pelletier *et al.* 1997; Calfee *et al.* 1999). Prudhoe Bay crude oil, Arabian crude oil, fuel oil #2, and Bunker C were phototoxic to shellfish larvae (Pelletier *et al.* 1997). For example, the water accommodated fraction (WAF) prepared from 0.1 g/L of Prudhoe Bay crude oil caused 100% mortality of larval shrimp and shellfish embryos with UV exposure, whereas no mortality occurred under fluorescent lighting or UV alone (Pelletier *et al.* 1997). An environmentally weathered middle distillate oil low in known phototoxic PAHs was 2 to 12 times more toxic to zooplankton, larval shrimp, larval fish, and amphibian tadpoles (Calfee *et al.* 1999; Cleveland *et al.* 2000; Little *et al.* 1999; Little *et al.* 2000). Total PAH concentrations of less than 1 ug/L were phototoxic at environmentally relevant levels of UV. Recent research by Barron *et al.* (unpublished) demonstrates that weathered Alaska North Slope crude oil (ANS) is phototoxic to Alaskan marine species at 2 ug/L total PAHs or less under a few hours of sunlight exposure.

Ho *et al*. (1999) evaluated the photoenhanced toxicity of spill water collected between 2 and 13 days after the Rode Island North Cape spill of fuel oil #2. In these experiments, bivalve embryos were exposed to spill water for 48 hours under UV or fluorescent lighting. Under fluorescent lighting, there was 60% survival of shellfish embryos exposed to spill water collected three days after the spill, indicating partial recovery (loss of toxicity) of the water column (Ho *et al.* 1999). In contrast, there was no survival of embryos that were exposed under UV, indicating that the spill water remained acutely toxic three days after the spill. Samples collected 13 days after the spill were not toxic to embryos in either light treatment. These data suggest that estimates of the extent of toxic concentrations of petroleum in spill water based on tests performed under fluorescent lighting may underestimate actual injuries to aquatic organisms.

MECHANISM OF PHOTOENHANCED TOXICITY OF OIL

The photoenhanced toxicity of oil and PAHs in fish and aquatic invertebrates occurs through a photosensitization mechanism. In *photosensitization,* the bioaccumulated chemical transfers light energy to other molecules causing tissue damage. The other mechanism that may contribute to photoenhanced toxicity is *photomodification,* which is the structural modification of chemical in water to more toxic/reactive compounds. However, photoenhanced toxicity through a photomodification mechanism has only been demonstrated with plants under high UV levels. Little *et al*. (2000) have reported experimental data for an environmentally weathered oil showing that the photoenhanced toxicity of oil occurs through a photosensitization mechanism in mysid shrimp. Barron *et al*. (unpublished) have recently confirmed a photosensitization mechanism of ANS in Pacific herring, with no enhancement of toxicity through photomodification.

The postulated mechanism of photosensitization is initial bioaccumulation of photoactive PAHs, followed by absorption of UV energy by the chemical in the organism causing subsequent tissue injury; no change in chemical structure occurs (Landrum *et al.* 1987). Early life stages of aquatic organisms are sufficiently transparent to UV to allow photoactivation of the bioaccumulated chemical. Light energy excites the photosensitizing chemical to a triplet energy state, which is then transferred to molecules within the cell or cell membrane, possibly generating reactive oxygen species (Landrum *et al.* 1987). Energy transfer can occur when the excited state energy of the photosensitizing chemical (e.g., PAH) exceeds that of an acceptor molecule such as oxygen which has a lower excited energy state (Zepp, 1980). The reactive oxygen species (e.g., superoxide anion) can then cause tissue damage that would not be observed in the absence of UV light.

DETERMINANTS OF PHOTOENHANCED TOXICITY

Determinants of photoenhanced toxicity will include the chemical composition, physical properties, and environmental fate of the oil, environmental conditions, oil exposure and bioaccumulation by aquatic organisms, and exposure of the oil residues in the organism to UV. Factors affecting UV exposure include photoperiod, sun angle, light reflectance, and cloud cover. Decreasing light penetration in the water column is termed attenuation and is affected by turbidity, shading, phytoplankton concentrations, and dissolved organic carbon. The potential hazard of photoenhanced toxicity may be greatest for planktonic organisms and larval stages that are relatively translucent to UV and inhabit the photic zone of the water column and intertidal areas.

Decreasing light penetration in the water column is termed attenuation, and is affected by turbidity and shading (e.g., surface foam), phytoplankton concentrations (e.g., chlorophyl-a levels), and dissolved organic carbon (DOC). Biological factors affecting UV exposure include refuges (e.g., reefs, vegetation, sediments) and armoring (e.g., exoskeleton of crustaceans). Organisms may also exhibit avoidance of or attraction to light that will influence their exposure to UV. Organism exposure to UV may also be influenced by the organisms' vertical distribution in the water column, which can be affected by ocean currents and mixing. Oil slicks and dispersed oil may also alter UV exposure to aquatic organisms by preventing UV penetration into the water column (e.g., below an oil slick) or by refracting or reflecting light (e.g., attenuation of light through dispersed oil).

IMPLICATIONS FOR ECOLOGICAL RISK AND DAMAGE ASSESSMENT

Arfsten *et al*. (1996) concluded that photoenhanced toxicity should be considered in assessing the ecological risks of phototoxic PAHs. This concern for photoenhanced toxicity is also applicable to spilled oil because oil and specific components of oil can be phototoxic, resulting in a greater than 100 fold increase in toxicity (Pelletier *et al.* 1997; Little *et al.* 2000; Barron *et al.* unpublished). Photoenhanced toxicity should also be considered in the selection of spill counter measures and oil recovery operations. Oil spill responses will influence the temporal and spatial extent of petroleum exposure to aquatic organisms, and the subsequent bioaccumulation of phototoxic components of oil. Barron and Ka'aihue (2001) have concluded there is potential for photoenhanced toxicity in Prince William Sound, Alaska, based on PAH concentrations measured after the Exxon Valdez spill and ambient UV levels.

Estimates of the temporal and spatial extent of injury to aquatic organisms from an oil spill may be greater if photoenhanced toxicity is considered. Existing laboratory toxicity thresholds for oil have been derived under fluorescent lighting (minimal UV) (e.g., Markarian *et al.* 1995), which may substantially underestimate the toxicity of oil in the environment. For example, fluorescent lighting has UV levels 25 to 50 times below the light intensities necessary to cause photoenhanced toxicity (Little *et al.* 2000). To date, photoenhanced toxicity has primarily been demonstrated in small translucent organisms, such as early life stages (e.g., embryos and larvae) of shellfish, crustaceans, and fish. These organisms may lack pigment and have an epidermis of only a few layers, allowing UV to penetrate deeply (Hunter *et al.* 1980). Photoenhanced toxicity has been shown to occur at the UV wavelengths and intensities that occur in the water column of aquatic environments (Barron *et al.* 2000). Laboratory studies demonstrating photoenhanced toxicity have used simultaneous UVB (280 to 320 nm) and UVA (320 to 400 nm) exposures, thus the specific wavelengths of UV that cause photoenhanced toxicity have not been identified.

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COASTAL WETLAND IMPACTS: OCS CANAL WIDENING RATES AND EFFECTIVENESS OF OCS PIPELINE MITIGATION

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The goals of this project are to quantitatively assess the direct and indirect impacts of OCS-related pipelines and navigation channels on coastal habitats along the northern Gulf of Mexico (GOM) coast, and the effectiveness of mitigation techniques used in different coastal habitats at avoiding and reducing OCS-related impacts. The northern GOM study area is subdivided into five coastal subareas: Texas barrier island, Texas chenier plain, Louisiana chenier plain, Louisiana delta plain, and the Mississippi-Alabama coast. During the past 3-4 decades, several improvements in construction techniques have reduced the footprint of pipeline construction activities in coastal wetlands, most notably push-pull construction with backfilling, double-ditching associated with push-pull construction, and directional drilling under coastal habitats. Other mitigation activities include using existing rights-of-way, revegetation by plantings, bulkheads, plugs and dams, and levee removal. Our evaluation of impacts and mitigation effectiveness is based on comparison of aerial imagery from 1956, 1978, and 1988/1990 (and 1995 for Louisiana) using GIS analysis. We selected 5 OCS pipelines and 2 OCS-related navigation channels from each subarea for detailed analysis of habitat change.

Once the GIS analyses are complete, we will determine direct and indirect impacts to wetland habitats by OCS-related activiites. A *direct impact* is the immediate conversion of habitat directly caused by human activity (e.g., dredging and filling resulting in conversion of wetland to open water or upland). An *indirect impact* is an impact related to a direct impact that occurs gradually at a different time and/or place. Examples of indirect impacts include altered hydrology (e.g., impoundment, salt water intrusion, and changes in flooding patterns) and altered sedimentation and erosion patterns (e.g., soil compaction, edge erosion, and changes in sediment deposition patterns). Our analytical approach for determining direct impacts to wetland habitats will be as follows. We will evaluate habitat changes in buffer zones around canals and channels (100-m wide for canals and 300-m wide for channels) from aerial imagery taken most recently before and after construction. Pre- and post-construction habitat analyses will be compared, and data will be analyzed with respect to subarea, construction type, and habitat type. For indirect impacts, we will evaluate habitat change in 1 km-wide buffer zones around canals and channels from aerial imagery taken not only most recently before and after construction, but also all subsequent aerial imagery. Pre- and post-construction habitat analyses will be compared, and data will be analyzed with respect to subarea, construction type, mitigation techniques used, and habitat types crossed.

Preliminary analyses of data from the Texas subareas where GIS analyses is mostly complete indicate that habitat conversion can be reduced by ~ 50% by directional drilling, backfilling, and double ditching. Comparison of habitat types (e.g., chenier plain versus barrier island) suggests that barrier island systems were less impacted than the chenier plain wetlands despite greater OCS activity in the barrier islands. The reduced level of impact in the barrier island systems is likely due, at least in part, to directional drilling under the wetlands. For the Mississippi-Alabama subarea, preliminary analyses indicate that there have been minimal impacts to coastal wetlands by OCS activities. The low level of impacts is due largely to limited wetland areas to be crossed by pipelines and to the fact that pipelines are routinely directionally drilled under the narrow band of wetlands fringing the coast. The GIS analyses for Louisiana are not yet complete so we can make no analyses of habitat change at this time. But the Louisiana delta and chenier plains have the greatest amount of OCS activity of the five subareas (> 500 km of pipelines for each plain), suggesting that OCS-related impacts will be greatest in these subareas. Yet, our ability to discern the level of OCS-related impacts for these subareas is confounded by several factors. There are extensive non-OCS pipelines in Louisiana, and a much higher background rate of habitat change (e.g., land loss rate of 35 square miles/year). Consequently, there are no unimpacted wetland areas to serve as reference sites for comparison. Thus, for all five subareas, we are establishing protocols to identify and account for non-OCS-related habitat changes (e.g., marinas, onshore oil and gas activity) and to determine background (i.e., non-OCS) rates of habitat change.

INTERACTIONS BETWEEN MIGRATING BIRDS AND OFFSHORE PLATFORMS: CONCLUSIONS AND SYNTHESIS

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The Gulf of Mexico (GOM) is a major ecological barrier confronted by hundreds of millions of migrating birds each spring and fall. Trans-Gulf migrations (TGMs) evolved in the absence of natural islands that could serve as stopover sites; thus, the installation of an artificial archipelago of nearly 4,000 oil and gas production platforms in the northern GOM over the past five decades has introduced a novel and potentially important component into the en route environment of trans-Gulf bird migrants. Since spring 1998, my research group at Louisiana State University (LSU) has been studying the ecology of trans-Gulf migration and the influence of platforms on migrants. The study was funded by two contracts with the Minerals Management Service through a cooperative agreement with the LSU Coastal Marine Institute, and was supported by six cooperating petroleum companies (BP, ExxonMobil, Phillips, Newfield Exploration, Texaco, and Shell). This extensive support permitted us to conduct full-time monitoring operations on up to 10 platforms across the northern GOM during the spring and fall migrations. Our work during this study (hereafter referred to as the "Migration Over the Gulf Project": MOGP) has confirmed that platforms constitute a significant component of the en route environment of trans-Gulf migrants. Although a small proportion of the total numbers of birds migrating over the GOM stops on platforms, platform use varies dramatically among species, and in some cases is of great ecological significance.

Over the course of the study, 315 bird species were recorded on or in the vicinity of offshore platforms. This total included 47 species of marine birds that are resident in the GOM for part of the year. The remaining species that occurred only as migrants comprised 73 trans-Gulf migrant aquatic species, of which 31 (42%) used platforms; 109 trans-Gulf migrant landbirds, of which 106 (97%) used platforms; and 86 "overshoot" migrants (short-distance migrants that spend the winter along the Gulf Coast but inadvertently overshoot the coastline during fall nocturnal migratory flights and end up over GOM waters), of which 83 (97%) used platforms.

Large-scale spatiotemporal patterns of migration were deduced both from direct observations on platforms and from simultaneous remote radar monitoring of the airspace over platforms. During the spring, most migration occurred over the western GOM. Several lines of evidence suggest that many birds departed the Yucatan Peninsula and adjacent portions of the southern GOM coast shortly after nightfall with initial headings toward the northwest, taking advantage of the strong prevailing southeasterly winds. The general stream of migration recurved to the northeast over the northern GOM, such that the largest numbers of migrants made landfall on the Upper Texas Coast and the southwest coast of Louisiana beginning the morning after departure and peaking throughout the afternoon. Arrivals of significant numbers of migrants on platforms occurred from early March through late May, with large spikes possible anytime during the season in association with adverse weather events. The abundance of migrants using platforms exhibited a cyclic pattern throughout the spring, with successive peaks and troughs corresponding to the eastward movement of synoptic weather systems across the continent. A stable high pressure system over the southeastern U.S. or adjacent Atlantic Ocean resulted in favorable tail winds for crossing the GOM and consequently induced large departures of migrants from Mexico. Favorable winds and significant trans-Gulf migration traffic continued during the subsequent movement of a low-pressure system toward the south-central U.S. Following passage of the low and the associated cold front, and during the movement of a new high across the Great Plains, northerly flow inhibited migration across the GOM. This cycle repeated itself throughout the spring, periodically interrupted by fronts that stalled over the northern or western GOM coast, creating foul weather and grounding many migrants on platforms. Preliminary analyses of radar data suggest that approximately 1.6 billion birds undertake trans-Gulf migrations in spring; extrapolation from our study to the ~4,000 platforms in the GOM suggests that about 0.2% of spring trans-Gulf migrants use platforms.

The use of radar to monitor bird migration during the fall is problematic because of extensive insect contamination of nocturnal radar imagery, so we supplemented fall operations by moonwatching. With the moonwatching technique, an observer monitors the moon telescopically during periods of adequate disk illumination and records information on the trajectories of migrants across the moon face; knowledge of the moon's trajectory together with spherical geometry can then be used to calculate the migrants' true trajectories and traffic rates. Moonwatching showed that the orientation of nocturnal fall migration over the western GOM had a westerly component. Very heavy migration traffic was often evident along the coasts of Alabama and the Florida Panhandle, and was generally headed due south or slightly east of south. The largest numbers of migrants landed on platforms during the night and may have been attracted to platform lights. Southbound fall migrants arrived on platforms over an extensive period from July through December, with a gradual increase to a peak in mid-October and a rapid decline thereafter. As was the case during the spring, arrivals on platforms showed a cyclic pattern, with average period of 7-10 days, associated predictably with synoptic weather patterns. Heavy southbound departures from the northern GOM coast occurred following cold frontal passage and during the subsequent movement of an incoming high pressure system across the Great Plains; migration was suppressed as the high moved into the eastern U.S. and a new low moved across the Great Plains.

Our findings indicate that platforms have both beneficial and adverse proximate impacts on migrant birds. When migrants unexpectedly encounter poor weather en route across the GOM, many individuals are forced down and perish in the GOM. During severe weather events, we frequently observed migrants taking shelter on platforms; in extreme instances, several thousand birds crowded together onto a single platform to wait out a storm. Although it is impossible to know the fate of individual migrants after they depart a platform, it is likely that the refuge provided by platforms can ameliorate high weather-induced mortality, and can theoretically have important population-level impacts on species with small continental populations or very compressed migration periods.

Platforms offer a second major benefit by presenting foraging opportunities. During our first two field seasons, we discovered an unexpected abundance of terrestrial insects offshore and expanded our focus to include insect monitoring via both visual censuses and quantitative sampling with ultraviolet light traps. During both spring and fall, a large blanket of terrestrial insects—the "aerial plankton"—is transported offshore by north winds. This aerial plankton represents a significant food resource for birds that stop to rest on platforms. During the spring, 10% of birds on platforms were observed to forage actively, and 44% of the foragers were successful in obtaining food. During the fall, 16% of birds on platforms foraged actively, and 46% of the foragers were successful. Estimated energy intake rates of birds on platforms were sometimes higher than generally observed in "natural" habitats onshore. The frequent abundance of migratory moths and other insects on platforms was especially important to fuel-depleted migrant birds forced down by foul weather during the spring, and to the overshoot migrants during the fall.

Platforms also have adverse impacts on some migrants. During the fall, when migrants are aloft over the northern GOM at night, birds occasionally die in collisions with platforms. The extent of collision mortality varied greatly among platforms; the reason for the variation is unknown, but may be related to differences in platform lighting. The overall probability of a migrant dying in a collision with a platform is very small; we estimate that total mortality over the GOM is <0.01%. A second adverse impact involved the influence of platform lighting on the flight behavior of nocturnal migrants. On some occasions, large numbers of birds from a wide range of species appeared at nightfall and circulated around a platform in a continuous stream—sometimes all night long. These sudden appearances and subsequent circulation events occurred even in the absence of any trans-Gulf migration evident on radar, suggesting that the events involved migrants drawn from a large area. The frequency of this phenomenon also varied greatly among platforms, and circulations were never observed at some platforms. Again, we do not know the exact reason for the variation but suspect that differences in platform lighting are implicated. Circular flight around a platform for long periods of time represents a significant energy drain on a migrant and may reduce the likelihood of completing the trans-Gulf flight successfully. Based on the platforms we studied, we estimate that <0.5% of all trans-Gulf migrants become involved in these circulation events.

In addition to the proximate impacts described above, MOGP observations and other anecdotal evidence also suggest that the archipelago of offshore oil platforms may be facilitating the natural selection of trans-Gulf migration strategies in several species. For example, one of the most common species on platforms is the Cattle Egret (*Bubulcus ibis*), which colonized eastern North America in the last half-century. A rapid evolution of TGM may be implicated in what appears to be a population explosion and major range expansion of White-winged Doves (*Zenaida asiatica*) into the southeastern United States. The Eurasian Collared-Dove (*Streptopelia decaocto*) has recently colonized North America, and began showing up on platforms in fall 1999. Platforms may facilitate the evolution of TGM strategies in these and other species by providing "steppingstones" that allow incipient migrants to cross the GOM successfully via a series of shorter flights.

The platform archipelago may also have evolutionary implications for population shifts in overshooting migrants. During the fall, many short-distance migrants that spend the winter along the Gulf Coast (such as wrens and sparrows) inadvertently overshoot the coastline during nocturnal migratory flights and end up over GOM waters. These overshoot migrants, which are evolutionarily ill-equipped to deal with the rigors of overwater migration, are among the heaviest users of platforms during the fall, and the availability of platform rest stops probably enables many individuals to return to land successfully. This alleviation of selection pressure may in turn be implicated in large-scale southward shifts in the wintering distributions of some of these species. Evaluation of hypotheses concerning the influence of platforms on life-history evolution will, of course, require longer-term data than are currently available.

One of the most important products of this study will be a comprehensive natural history account for each of the 315 species recorded on or near platforms. These species accounts will contain detailed information on migration phenology, flight routes, population structure, and other aspects of migration strategies of interest to ornithologists and conservation biologists. A brief overview of one species will serve to illustrate the depth of basic natural history information provided by this study. Peregrine Falcons (*Falco peregrinus*) – which until recently were listed as federally endangered – have proved to be among the most obvious and interesting beneficiaries of the platform archipelago. Among 44 individuals observed in high-altitude, direct migratory flight, vanishing bearings were significantly oriented toward the southwest, suggesting that many or most of the birds we saw were destined for the western shore of the GOM (as opposed to Cuba or the Yucatan Peninsula). The seasonal timing of Peregrine trans-Gulf migration was highly compressed into the period from late September to mid-October; 60% of all recorded individuals were initially detected in the two-week period from 29 September -12 October. Analysis of population structure was possible because Peregrines are sexually dimorphic in size and exhibit age-related plumage variation. Among 284 individuals that could be identified to age and sex, 61% were male and 60% were juveniles. There were significant seasonal and geographical differences among the age-sex classes in patterns of occurrence: adults arrived earlier than juveniles, and females migrated earlier than males. However, the absolute differences in seasonal timing were minor: there was only a week's difference between peak arrival of the earliest (adult female = 2 October) and latest (juvenile male = 9 October) age-sex classes. Interestingly, there was a significant longitudinal gradient in sex ratio, with a female bias toward the east and a male bias toward the west. Most Peregrines arrived on platforms or were observed flying by platforms after early morning. This pattern differed dramatically from the daily pattern of arrival of most trans-Gulf migrant passerines, indicating that Peregrines usually departed the northern GOM coast during hours of daylight. Peregrines typically arrived on platforms in the afternoon and stayed up to several days, hunting primarily at night when most migrant landbirds were aloft. Peregrines took avian prey of a wide variety (63+ species) and of all sizes, but relied almost entirely on migrants (as opposed to local marine birds, which composed <2% of all prey items) and favored larger species. One of the biggest surprises from the study was the abundance of Peregrines using platforms. For example, we documented 273 Peregrines using our 10 study platforms in fall 1999. A simple extrapolation of our results to the entire GOM yields a population estimate of just over 100,000 Peregrines using platforms during the fall migration, with an extreme lower bound of about 17,000. Thus, it appears that the majority of the eastern North American population of Peregrines now undertakes stopovers on GOM platforms for resting and hunting during fall migration.

THE IMPORTANCE OF MULTIDISCIPLINARY CROSSTALK OR SOME OPERATIONAL ASPECTS OF MARINE 3D SEISMIC SURVEYS

Dr. Jack Caldwell
WesternGeco

Click here to see Dr. Caldwell's slide show.

MIGRATION AND DISPERSAL OF TERRESTRIAL INSECTS OVER THE GULF OF MEXICO

Dr. Robert W. Russell
School of the Coast and Environment
Louisiana State University

Little is known about overwater movements of insects. At the beginning of the MMS-sponsored study of trans-Gulf migration (for details see "Interactions between migrating birds and offshore platforms: conclusions and synthesis" elsewhere in this volume), we were surprised to discover large numbers and many species of insects on platforms in the northern Gulf of Mexico (GOM). As a result of this unexpected abundance of terrestrial insects offshore, we expanded our focus to include insect monitoring. The goals of the expanded work were (1) to quantify the availability of insects as food for migrant birds on platforms, and (2) to learn as much as possible about the flight behavior, dispersal strategies, and biogeography of the insect species and phenomena involved.

Techniques of study included both visual censuses and quantitative sampling methods. Dragonflies, butterflies, and sphinx moths were easy to detect and were counted during regular bird censuses. The abundance and biodiversity of smaller species was sampled quantitatively using 22-watt universal black light traps (Bioquip®) on each platform that would permit the device. Traps were deployed each day at sunset, and samples were collected and frozen the following morning. Enumeration and identification of the insect samples is ongoing in collaboration with the Louisiana State Arthropod Museum.

Concurrent remote radar studies showed that large numbers of insects ascend rapidly into the atmospheric boundary layer shortly after nightfall along the northern Gulf coast. Radar images suggest—and our direct observations confirm—that when winds have a northerly component, a large blanket of small terrestrial insects is transported passively offshore. This aerial plankton represents a significant food resource for migrant birds that stop to rest on platforms. During the spring, 10% of birds on platforms were observed to forage actively, and 44% of the foragers were successful in obtaining food. During the fall, 16% of birds on platforms foraged actively, and 46% of the foragers were successful. Estimated energy intake rates of birds on platforms were sometimes higher than generally observed in "natural" habitats onshore.

A more speculative but potentially important implication of the aerial plankton is the possibility that allocthonous input of carbon via fallout and mortality of drifting insects could be ecologically significant in food webs of the more depauperate waters of the GOM. Preliminary estimates suggest that more than 30 million kilograms of carbon per year enter Gulf marine ecosystems via this mechanism. The impact of this carbon source could be locally much more important, since insects are positively buoyant and consequently accumulate in zones of the GOM subject to persistent surface convergence.

In addition to the passively transported fauna of smaller insect species, we discovered that several species of dragonflies (notably green darner [*Anax junius*] and spot-winged glider [*Pantala hymenaea*] are probably "intentional" trans-Gulf migrants. We also found that a distinct assemblage of three species of sphinx moths occurs regularly over the GOM, though the reason for their overwater sojourns remains unknown to date. Despite published assertions to the contrary, we found that monarch butterflies (*Danaus plexippus*) are not true trans-Gulf migrants, though small numbers do take a short-cut over the nearshore Gulf off the central Texas coast.

A better understanding of offshore insect biodiversity has implications for a wide variety of environmental issues, including the foraging success of migrant birds on platforms, regional pest management strategies (since many of the common offshore species are known to be important agricultural pests on the GOM coastal plain), and perhaps even carbon fluxes in marine ecosystems of the GOM. Future studies should consider using more expensive suction traps of the Johnson-Taylor design to obtain less biased volumetric samples and to refine quantitative estimates of carbon flux.

SESSION 1D

GULF BIOLOGICAL FEATURES STUDIES

Chair: Ms. Susan Childs, Minerals Management Service
Co-Chair: Mr. Greg Boland, Minerals Management Service

Date: January 9, 2002

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Dr. Q. R. Dokken, Dr. J. W. Tunnell, Dr. C. R. Beaver, Ms. S. A. Childs, Dr. K. Withers, and Mr. T. W. Bates, Center for Coastal Studies, Texas A&M University-Corpus Christi
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CROSS-DE SOTO CANYON COMPARISON OF HARD-BOTTOM COMMUNITIES

Dr. George D. Dennis
Dr. Kenneth J. Sulak
U.S. Geological Survey
Florida Caribbean Science Center

INTRODUCTION

The De Soto Canyon separates the Mississippi-Alabama Shelf from the West Florida Shelf (Figure 1D.1) and marks a major biogeographical division of not only marine faunas but also terrestrial faunas (Briggs 1974). A good example is shown by two species of sea basses (Figure 1D.2). The blackear bass (*Serranus atrobranchus*) is found on muddy bottom throughout the Gulf of Mexico but almost disappears from the shelf east of the De Soto Canyon (Darnell and Kleypas 1987). East of the Canyon the saddle bass (*Serranus notospilus*) comes to dominate the shelf fauna. Part of the reason for the change in marine fauna is the change in bottom type from fine to coarse sediments across the Canyon (Doyle and Sparks 1980).

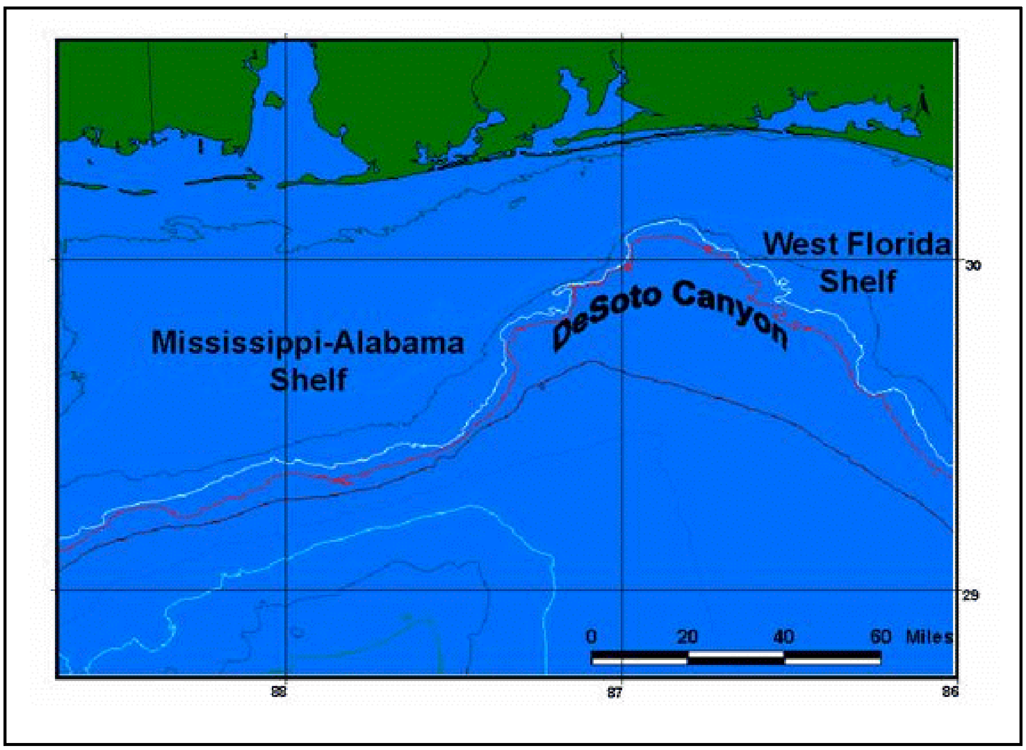

Figure 1D.1. Map of northeastern Gulf of Mexico with major features.

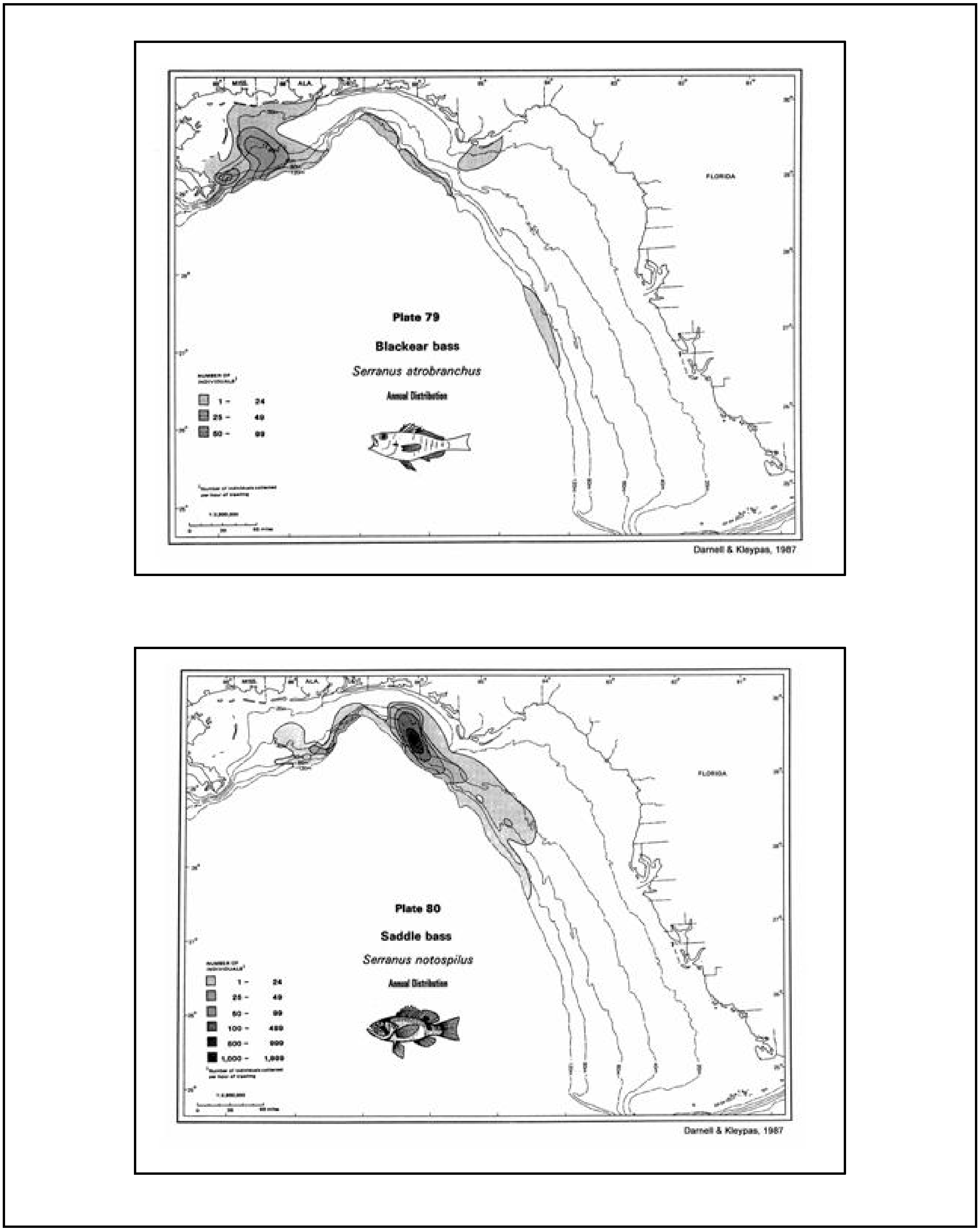

Figure 1D.2. Distribution of blackear and saddle bass in the northeastern Gulf of Mexico illustrating faunal separation across DeSoto Canyon (from Darnell and Kleypas 1987).

In addition, as we move away from the influence of the Mississippi River water column clarity improves because there is less clay input and sedimentation. Previous work on the West Florida Shelf did not indicate a wide range of hard bottom but this might be due to the limited effort there (Ludwick and Walton 1957; Thompson *et al.* 1999). From these observations we might hypothesize that

1. there would be more hard bottom exposed on the West Florida Shelf where there should be less sedimentation,

2. if more hard bottom exists, then greater species richness in hard-bottom communities should exist due to the species-area relationship,

3. limits on the development of the reef fish assemblage noted west of the De Soto Canyon may be relaxed resulting in a greater diversity of fishes, and

4. areas protected from fishing on the West Florida Shelf would exhibit a more “natural” reef fish assemblage when compared to heavily fished areas on the Mississippi-Alabama Shelf.

A joint research effort between the USGS and MMS to better understand the physical-biological coupling of the northeastern Gulf of Mexico (NEGOM) marine system has extended previous research on hard-bottom communities in the Pinnacles area of the Mississippi-Alabama Shelf to the area east of De Soto Canyon, the West Florida Shelf. Our research objectives are to (1) survey hard bottom east of De Soto Canyon, (2) identify areas for further intensive study, and (3) compare and contrast with previously studied hard-bottom assemblages on the Mississippi-Alabama Shelf.

Additional objectives with collaborators include

1. mapping of the West Florida Shelf using high-resolution multi-beam swath (HRMBS) bathymetry (J. Gardner, USGS, Menlo Park, CA),

2. synthesis of ichthyoplankton data for the region (J. Lyczkowski-Shultz, NOAA NMFS Laboratory, Pascagoula, MS), and

3. age and growth of primary hard-bottom fishes of the region (R. McBride, Florida Marine Research Institute, St. Petersburg, FL).

Here we present the preliminary results from the first two cruises of this study.

RESULTS

The initial cruise for this study was made to the Pinnacles area in May 2001 to collect comparative data for the West Florida Shelf. [This work was initiated to better understand the physical causes of reef fish distributions.] Two sites, Roughtongue and Scamp reefs, were selected for long-term study based on previous work (Weaver *et al.* 2001). As part of the USGS Integrated Science Program, fine scale flow over Roughtongue Reef was measured to examine the relationship between reef induced turbulence and reef fish distribution. This was accomplished using ship- and ROV-borne acoustic doppler current profilers (Lacy *et al.* in prep.). Turbulence was observed on the up-current reef edge and reef top (J. Lacy, USGS, Menlo Park, pers. obs.). These observations do not fit well with predicted flow patterns (Kelley and Bender 2001) and may greatly influence reef fish distribution.

Video transects were completed at Roughtongue and Scamp reefs and compared to the West Florida Shelf. In addition, a survey on deeper hard bottom in the Ludwick and Walton Pinnacles was made to further characterize the deep reef tract (85-120 m). This survey resulted in two new records of reef fishes for the Gulf of Mexico.

Our second cruise in August 2001 proceeded to identify hard-bottom areas east of the De Soto Canyon. Due to a delay in deployment of the HRMBS we did not have high-resolution maps to help with identification of hard-bottom areas. Instead we used georeferenced side-scan sonar data in the southern portion of the area (provided by K. Scanlon, USGS, Woods Hole, MA). We first surveyed hard bottom in the Madison Swanson area (Figure 1D.3). This area is a known grouper spawning area (Koening *et al.* 2000) and is now a restricted fishing area (Southeast Fishery Bulletin, 2000). Additionally, three areas were surveyed—a shallow ridge in the north central region, a deep ridge in the south central region, and deep patch reefs in the western region (Figure 1D.3). Fourteen ROV dives were made in these areas, with well-developed hard-bottom communities occurring at all sites.

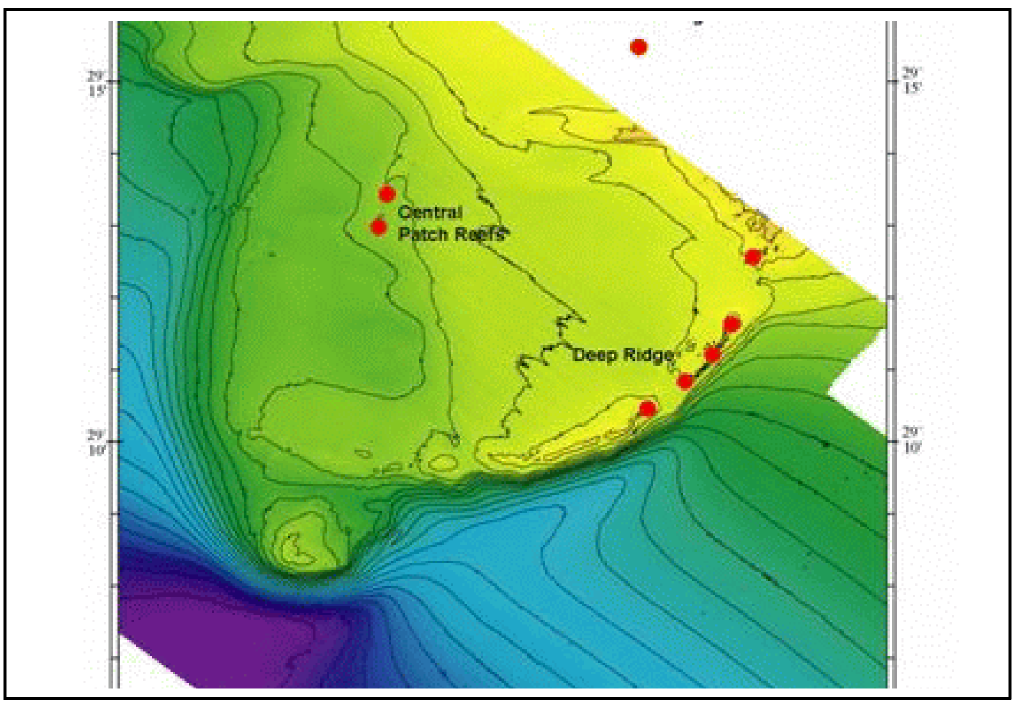

Figure 1D.3. Madison-Swanson fishing reserve area with ROV dive sites indicated by red circles.

After completing work at Madison Swanson we moved north. As no high resolution maps or side-scan data were available for this area we relied on detailed bathymetry charts (NOAA Destin Dome NOS NH 16-8) to identify features to explore for hard bottom. Two deltaic lobes of the outer continental shelf margin, the "Destin Pinnacles" area and the "29°36'N Hump," looked promising (Figure 1D.4). We surveyed the Destin Pinnacles area using a fathometer searching a strong bottom return and sharp rise in profile indicative of hard-bottom features. All steep sloping features in the area were surveyed but none were found to form hard bottom. ROV dives in the area revealed a steep sloping coarse sediment bottom with no exposed hard bottom. Subsequent HRMBS data (Figure 1D.3 insert) revealed that these features are sediment-draped mounds. Two hard-bottom ridges at 30°00' N, 86°30'-86°35' W were not found during our survey and will be explored on future cruises.

We continued south down the 100 m isobath surveying for hard bottom to the next major shelf edge feature, a hump at latitude 29°36'N (Figure 1D.3). Again steep sloping level bottom was indicated by the fathometer. Three ROV dives in the area showed coarse sediment bottom with no exposed hard bottom. Even where ridges were indicated on the HRMBS map no hard bottom was found upon closer examination (Figure 1D.3 insert).

With no success in finding hard bottom thus far, we moved to an area of reported hard bottom called the Coral Trees (D. Devries, NMFS, Panama City, FL, pers. comm.) (Figure 1D.3). Nothing remarkable was noted on the bathymetric chart in this area but the fathometer survey indicated the telltale signs of hard bottom. We made four ROV dives in this area finding high relief (10 m) hard bottom with a well-developed hard-bottom community. Subsequent HRMBS survey revealed a set of four ridges running north and south covering a relatively small area (6.48 ha) (Figure 1D.3 insert).

Preliminary analysis of the hard-bottom community did not indicate any exceptional differences from that observed in the Pinnacles. A similar fish assemblage was observed, though large piscivores (*Mycteroperca* spp.) appeared more abundant on the West Florida Shelf even outside of the fishing reserve.

We carried out extensive Sabiki fishing at all sites visited except within the Madison-Swanson reserve area to collect specimens for life history analysis (see Weaver *et al.* 2000 for description of method). A comparison of Sabiki catch between the Pinnacles and West Florida Shelf shows a striking difference in relative abundance of species captured (Figure 1D.5). The benthic mesoplanktivores, roughtongue bass (*Pronotogrammus martinicensis*) and red barbier (*Hemanthias vivanus*), dominated catch at the Pinnacles, while a benthic generalized carnivore, tattler (*Serranus phoebe*) and a pelagic mesoplanktivore, mackerel scad (*Decapterus macarellus*), were the predominate species caught on the West Florida Shelf. Roughtongue bass and red barbier are dominant components of the hard-bottom fish assemblage at the Pinnacles (Weaver *et al.* 2001). This change in species composition indicated by Sabiki sampling suggests a major change in faunal composition and perhaps trophic function. However, this sampling does not match ROV observations that indicate an abundance of roughtongue bass and red barbier on the West Florida Shelf. At present we have no explanation for this difference in Sabiki catch except that the roughtongue bass and red barbier may be smaller and/or more wary relative to predators on the West Florida Shelf, thus have a lower catchability with this gear than at the Pinnacles. This difference will need to be explored further.

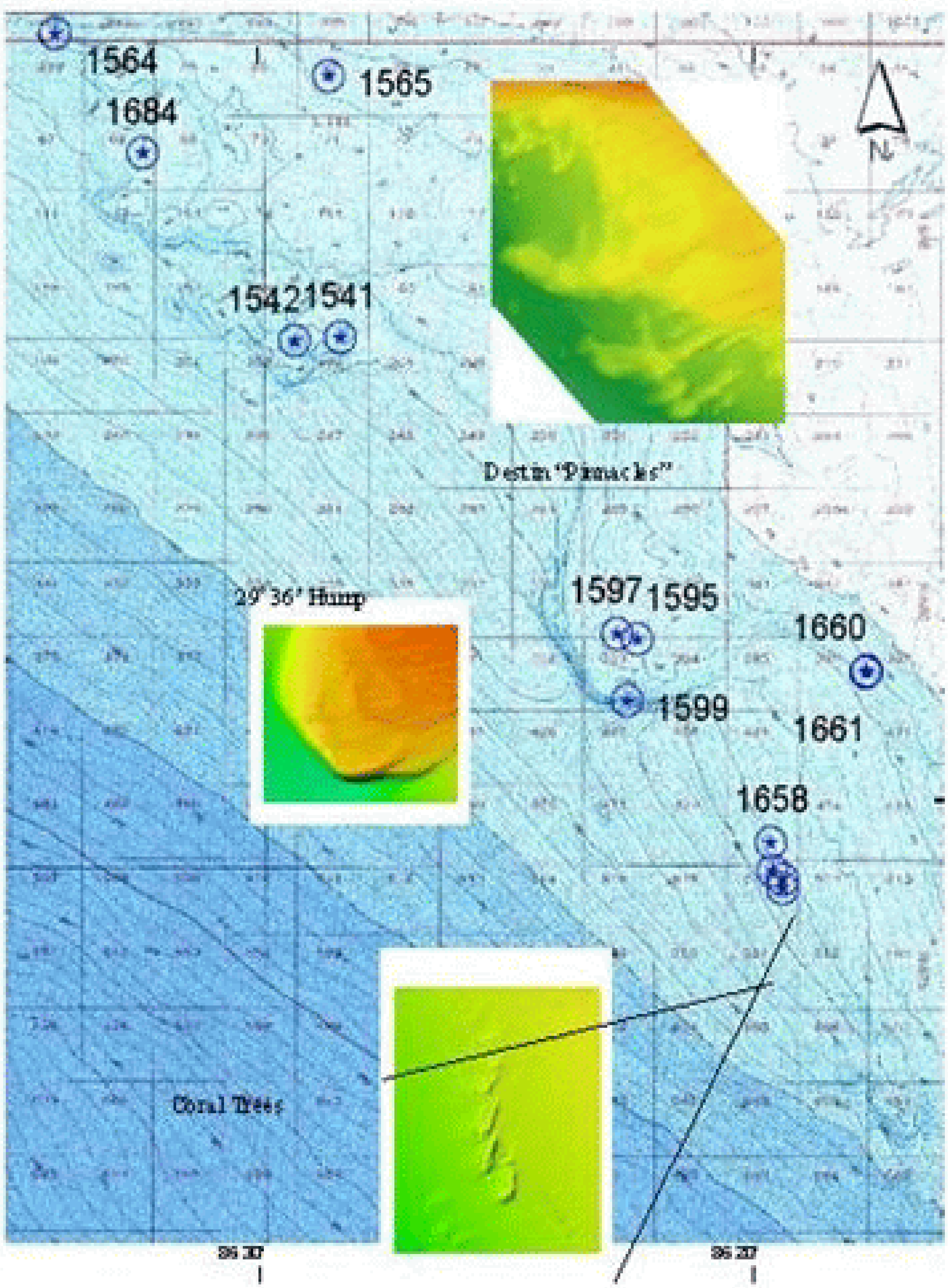

Figure 1D.4. ROV dive sites (circled stars) overlaid on NOAA bathymetry chart with high-resolution bathymetry inserts for northern section of West Florida Shelf outer continental shelf edge.

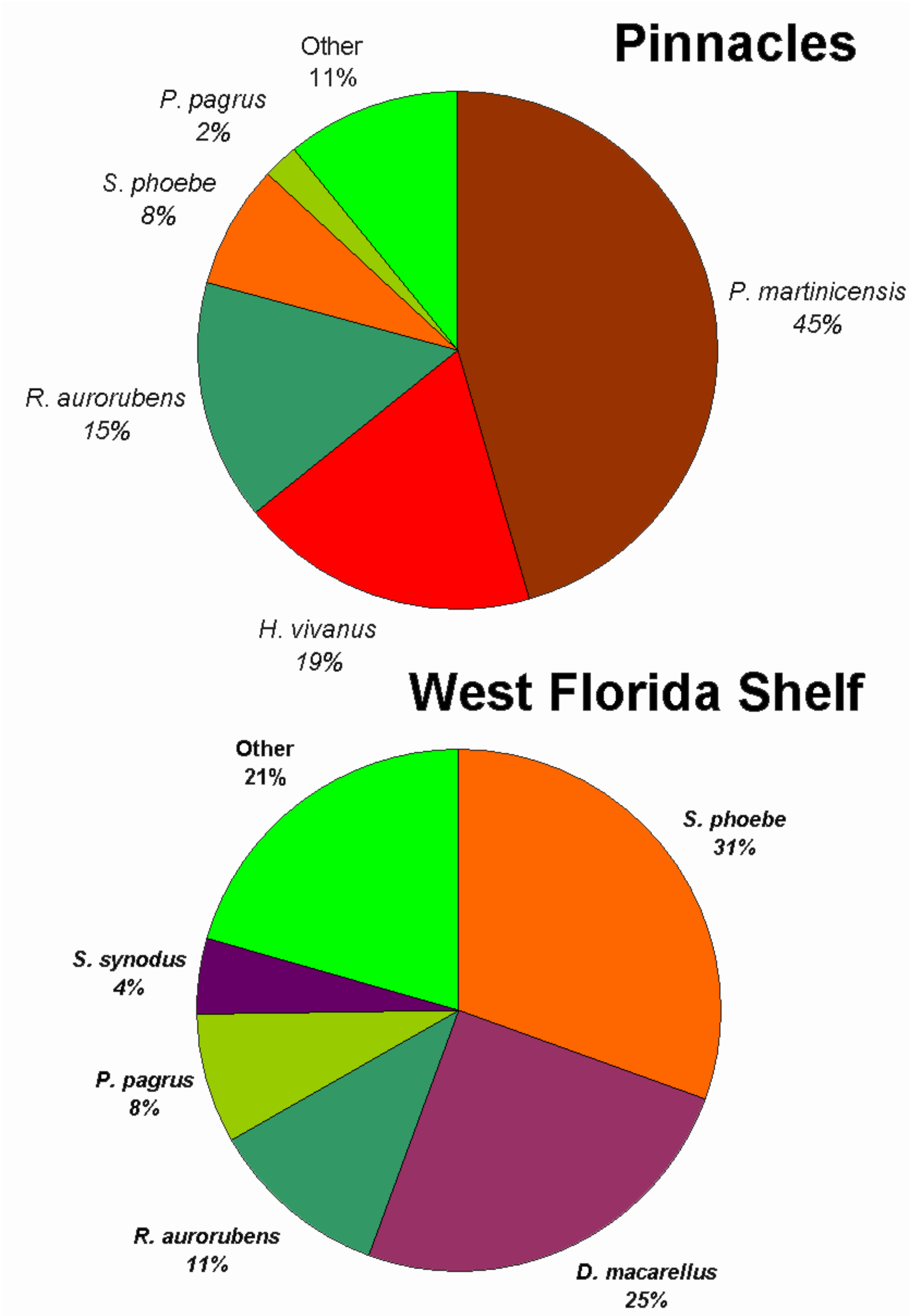

Figure 1D.5. Comparison of Sabiki catch from Pinnacles and West Florida Shelf.

SUMMARY

While considerable work has been completed on the Mississippi-Alabama Shelf in the Pinnacles Reef Tract, we are still increasing our knowledge of the fish assemblage. Comparison with the West Florida Shelf will require high-resolution mapping including the faunal transition area at the head of De Soto Canyon. The difficulty in finding hard bottom in unmapped areas of the West Florida Shelf supports at the critical need for these maps. The HRMBS mapping has been partially completed and will be continued in 2003. Hard bottom revealed by mapping on the West Florida Shelf appears to be of different geological origin (i.e., fossil/barrier reefs) than that in the Pinnacles Reef Tract. Identification of reefs for long-term study will require additional survey effort to identify reef types on the West Florida Shelf. We will survey identified hard-bottom areas and make a comprehensive comparison of hard-bottom communities in the coming year.

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MAPPING DEEPWATER REEFS OF THE NORTHEASTERN GULF OF MEXICO

Dr. James V. Gardner
Mr. Peter Dartnell
Dr. Kenneth J. Sulak
U.S. Geological Survey

INTRODUCTION

A zone of so-called "deepwater" reefs extends from the mid and outer shelf south of Mississippi and Alabama to at least the northwestern Florida shelf off Panama City, Florida (Figure 1D.6). The reefs off Mississippi and Alabama (the Pinnacles area) are found in water depths of 60 to 120 m (Ludwick and Walton, 1957; Gardner *et al*. 2001) and were the focus of a multibeam echosounder (MBES) mapping survey by the U.S. Geological Survey (USGS) in 2000 (Gardner *et al.* 2000). This survey mapped approximately 1,700 km^2 and generated geodetic-quality swath bathymetry and coregistered calibrated acoustic backscatter for the entire Pinnacles area. The deepwater-reef trend along the northwestern Florida shelf was mapped using an identical MBES in 2001 (Gardner *et al.* 2001) and surveyed an area of approximately 3,500 km^2.

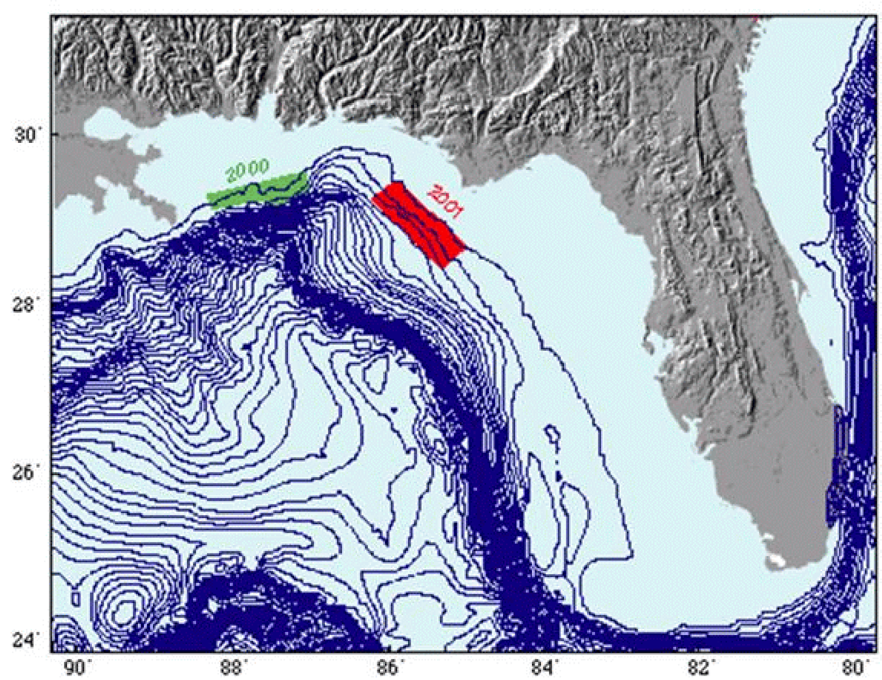

Figure 1D.6. Location map showing northwest Florida shelf area mapped in 2001 (red rectangles; SBL is Steamboat Lumps area) and area mapped in 2000 on Mississippi-Alabama shelf and slope (green).

Precisely georeferenced high-resolution mapping of bathymetry is a fundamental first step in the study of areas suspected to be critical habitats. Morphology is thought to be critical to defining the distribution of dominant demersal plankton/planktivores communities. Fish faunas of shallow hermatypic reefs have been well studied, but those of deep ahermatypic reefs have been relatively ignored. The ecology of deepwater ahermatypic reefs is fundamentally different from hermatypic reefs because autochthonous intracellular symbiotic zooxanthellae (the carbon source for hermatypic corals) do not form the base of the trophic web in ahermatypic reefs. Instead, exogenous plankton, transported to the reef by currents, serves as the primary carbon source. Thus, one of the principle uses of the bathymetric data will be to identify whether the mapped reefs are hermatypic or ahermatypic in origin.

Community structure and trophodynamics of demersal fishes of the outer continental shelf of the northeastern Gulf of Mexico (GOM) presently are the focus of a major USGS research project. A goal of the project is to answer questions concerning the relative roles played by morphology and surficial geology in controlling biological differentiation. Deepwater reefs are important because they are fish havens, key spawning sites, and are critical early larval and juvenile habitats for economically important sport/food fishes. It is known that deepwater reefs function as a key source for re-population (via seasonal and ontogenetic migration) of heavily impacted inshore reefs.

The deepwater reefs south of Mississippi and Alabama support a lush fauna of ahermatypic hard corals, soft corals, black corals, sessile crinoids and sponges, that together form a living habitat for a well-developed fish fauna. The fish fauna comprises typical Caribbean reef fishes and Carolinian shelf fishes, plus epipelagic fishes, and a few deep-sea fishes. The base of the megafaunal invertebrate food web is plankton, borne by essentially continuous semi-laminar currents generated by eddies spawned off the Loop Current that periodically travel across the shelf edge.

The surficial geology and bathymetry of the outer shelf off northwest Florida has been little studied. A few sidescan-sonar surveys have been made of areas locally identified as Destin Pinnacles, Steamboat Lumps Marine Reserve (Koenig *et al.* 2000; Scanlon, *et al.* 2000; 2001), Twin Ridges (Briere, *et al.* 2000; Scanlon, *et al.* 2000), and Madison-Swanson Marine Reserve (Koenig *et al.* 2000; Scanlon, *et al.* 2000; 2001). However, no quantitative and little qualitative information about the geomorphology and surficial geology can be gained from these data. Existing bathymetry along the northwestern Florida shelf suggests the existence of areas of possible isolated deepwater reefs. NOAA bathymetric maps NOS NH16-9 and NG16-12 show geomorphic expressions that hint of the presence of reefs in isolated areas rather than in a continuous zone. There has been no systematic, high-resolution bathymetry collected in this area, prior to this cruise.

After the successful mapping of the deepwater reefs on the Mississippi and Alabama shelf (Gardner *et al.* 2000), a partnership composed of the USGS, Minerals Management Service, and NOAA was formed to continue the deep-reef mapping of the northwest Florida mid shelf to upper slope.

Our objective was to map the region between the 50 to 150-m isobaths south from the eastern end of the Mississippi delta to the western edge of De Soto Canyon (2000) and from the eastern edge of De Soto Canyon as far as Steamboat Lumps (2001) using a state-of-the-art multibeam mapping system (MBES). Both cruises used a Kongsberg Simrad EM1002 MBES, the latest generation of high-resolution mapping systems. The EM1002 produces both geodetically accurate georeferenced bathymetry and coregistered, calibrated, acoustic backscatter. These data should prove extremely useful in relating dominant species groups (which display highly specific biotope affinities) to the geomorphology (*e.g.*, reef flattop, fore reef crest, reef wall, reef base, circum-reef talus zone, circum-reef, high-reflectivity sediment apron, etc.).

THE DIGITAL DATA

The data in various formats as well as additional images from both cruises are posted on the World Wide Web at *http://walrus.wr.usgs.gov/pacmaps*. This website also has both cruise reports (USGS Open-File Repts. 00-350 and 01-448) that describes the multibeam echosounders used, the processing steps, and the problems encountered during these surveys. The cruise reports can also be accessed at *http://geopubs.wr.usgs.gov/open-file/of00-350* and *http://geopubs.wr.usgs.gov/open-file/of01-448*. In addition, two USGS Open-File Reports on CD-ROMs (USGS Open-File Rept. 02-5 and 02-6) contain the northwest Florida and Pinnacles data respectively), in various formats and FGDC-compliant metadata are available at no cost from the first author. The data formats on the CD-ROM include a free GIS viewing program ArcExplorer, ArcExplorer projects, ESRI grids, and ASCII xyz point data.

OVERVIEW OF AREAS MAPPED

Figures 1D.7 through 1D.18 are map overviews of the mapping accomplished on these two cruises. The bathymetry and acoustic backscatter for each area is shown. The acoustic-backscatter maps for the Pinnacles and Steamboat Lumps Reserve areas are shown in greyscale whereas the acoustic-backscatter maps for the northwest Florida areas are shown in color. Because the northwest Florida region is so large (i.e., the file sizes are huge), the region was subdivided into North, Central, and South areas.

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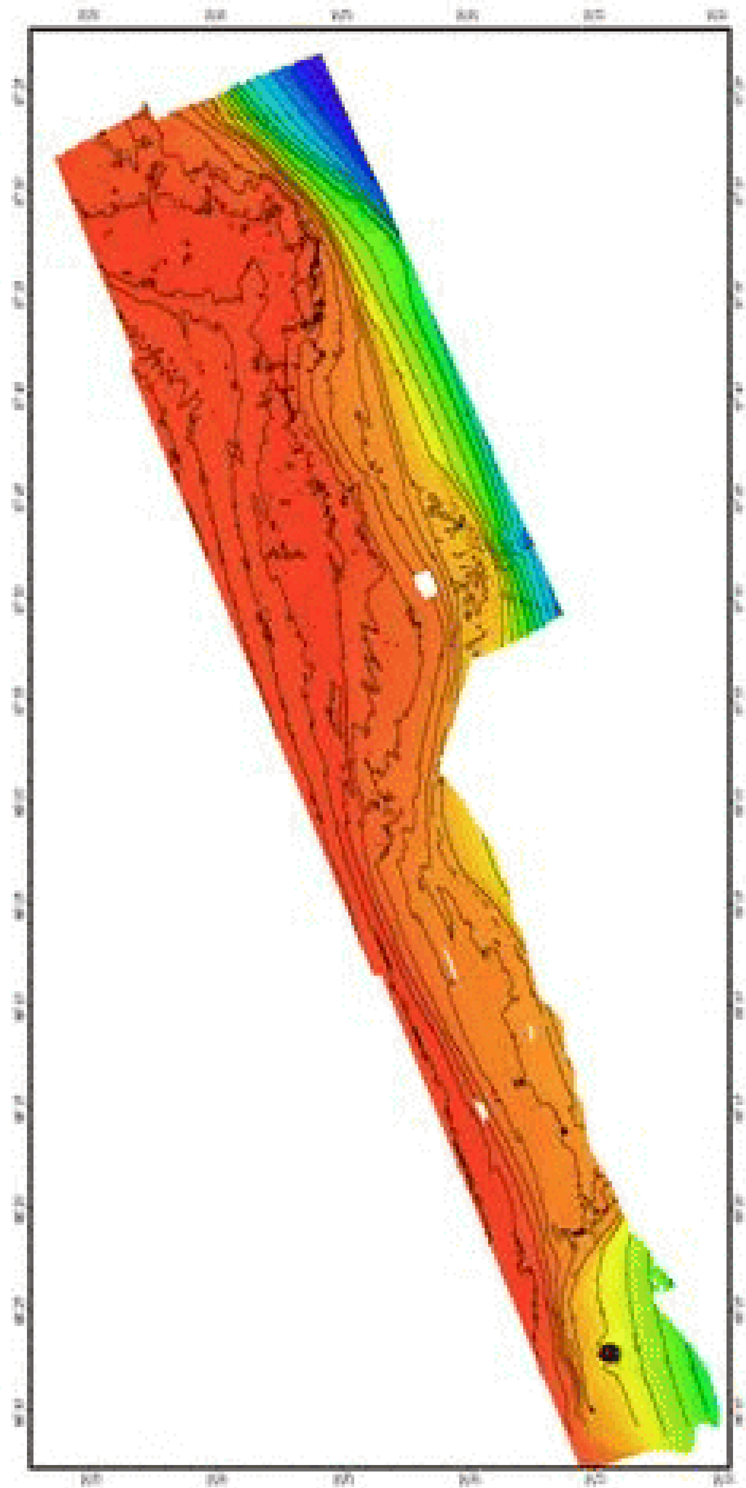

Figure 1D.7. Bathymetry of the Pinnacles area. Note that map is rotated 90˚ counter clockwise.

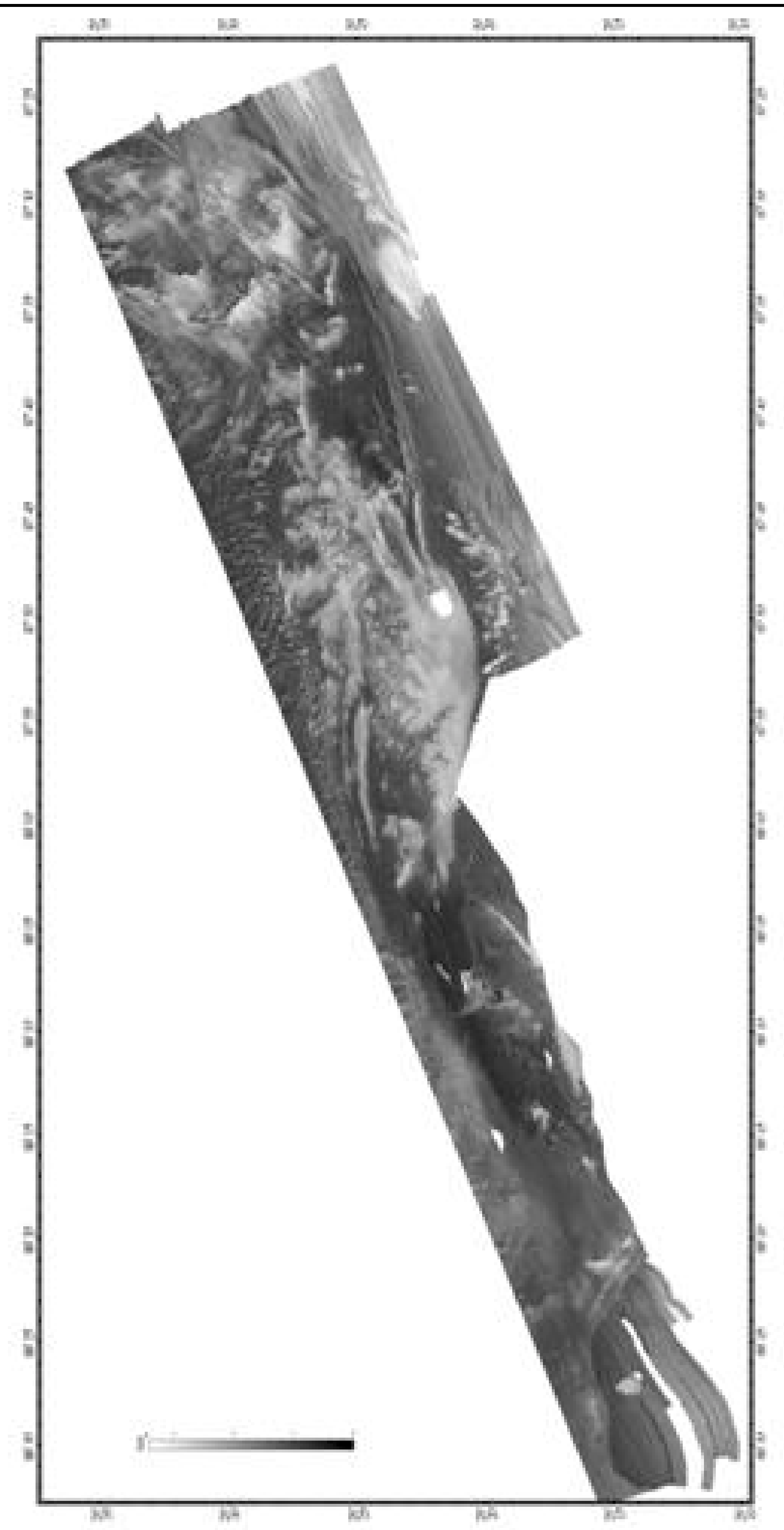

Figure 1D.8. Acoustic backscatter of the Pinnacles area. Note that map is rotated 90˚ counter clockwise.

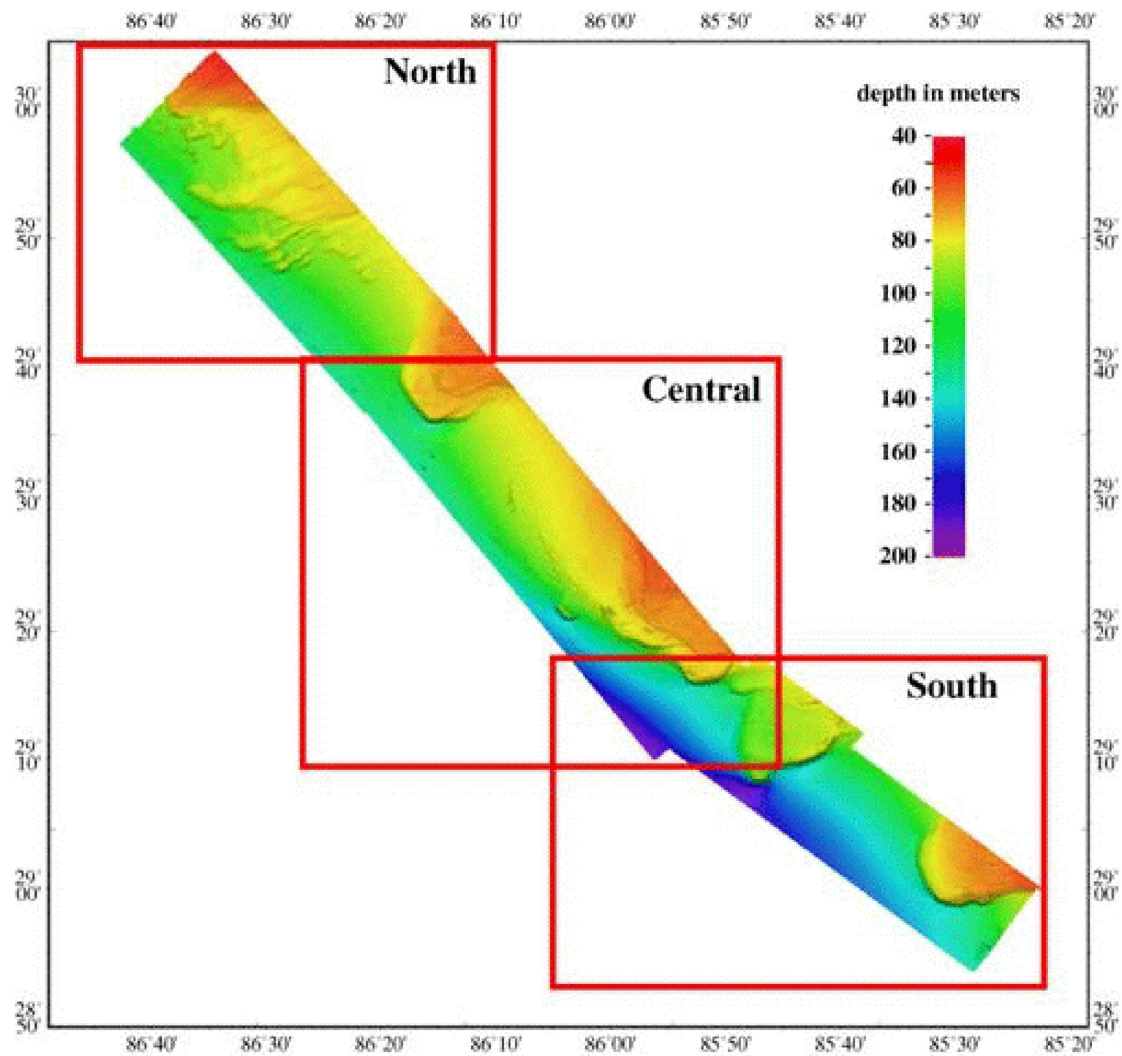

Figure 1D.9. Overview colored shaded-relief map of entire mapped area. Red labeled boxes outline sections gridded at 8-m resolution.

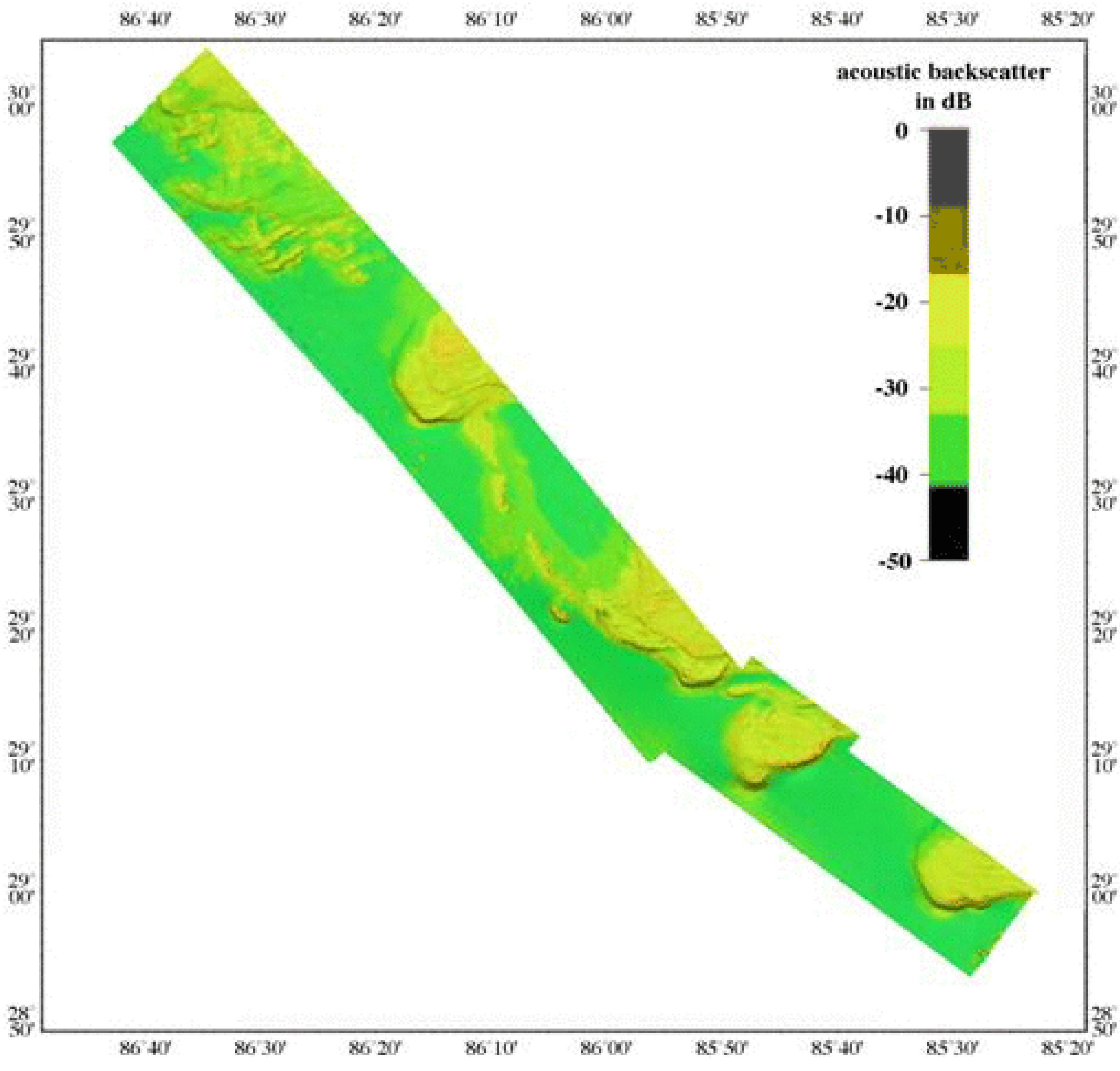

Figure 1D.10. Overview colored acoustic-backscatter map of entire area mapped.

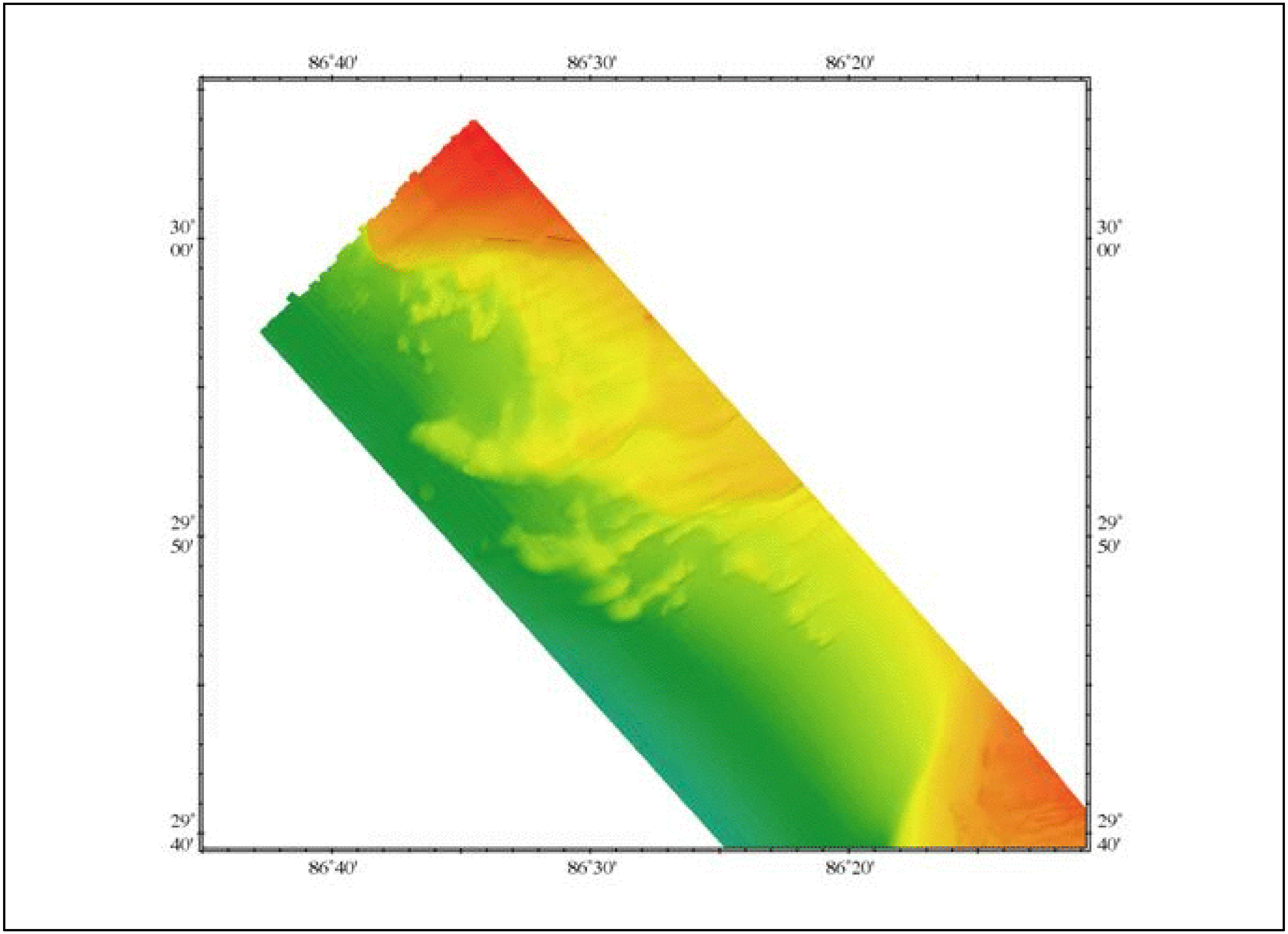

Figure 1D.11. Colored shaded-relief map of North section. Note that map is rotated 90˚ counter clockwise.

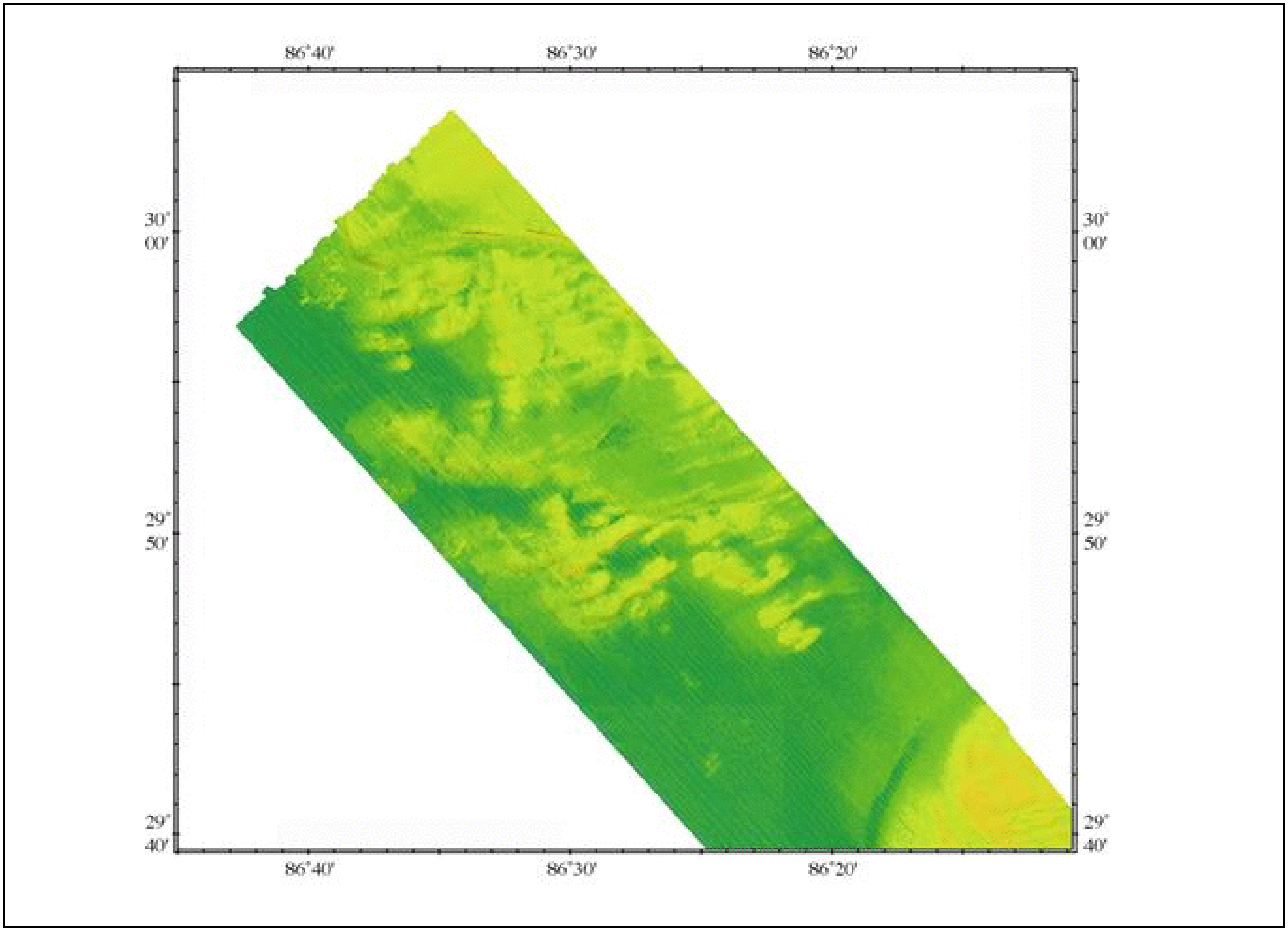

Figure 1D.12. Colored acoustic-backscatter map of North region. Note that map is rotated 90˚ counter clockwise.

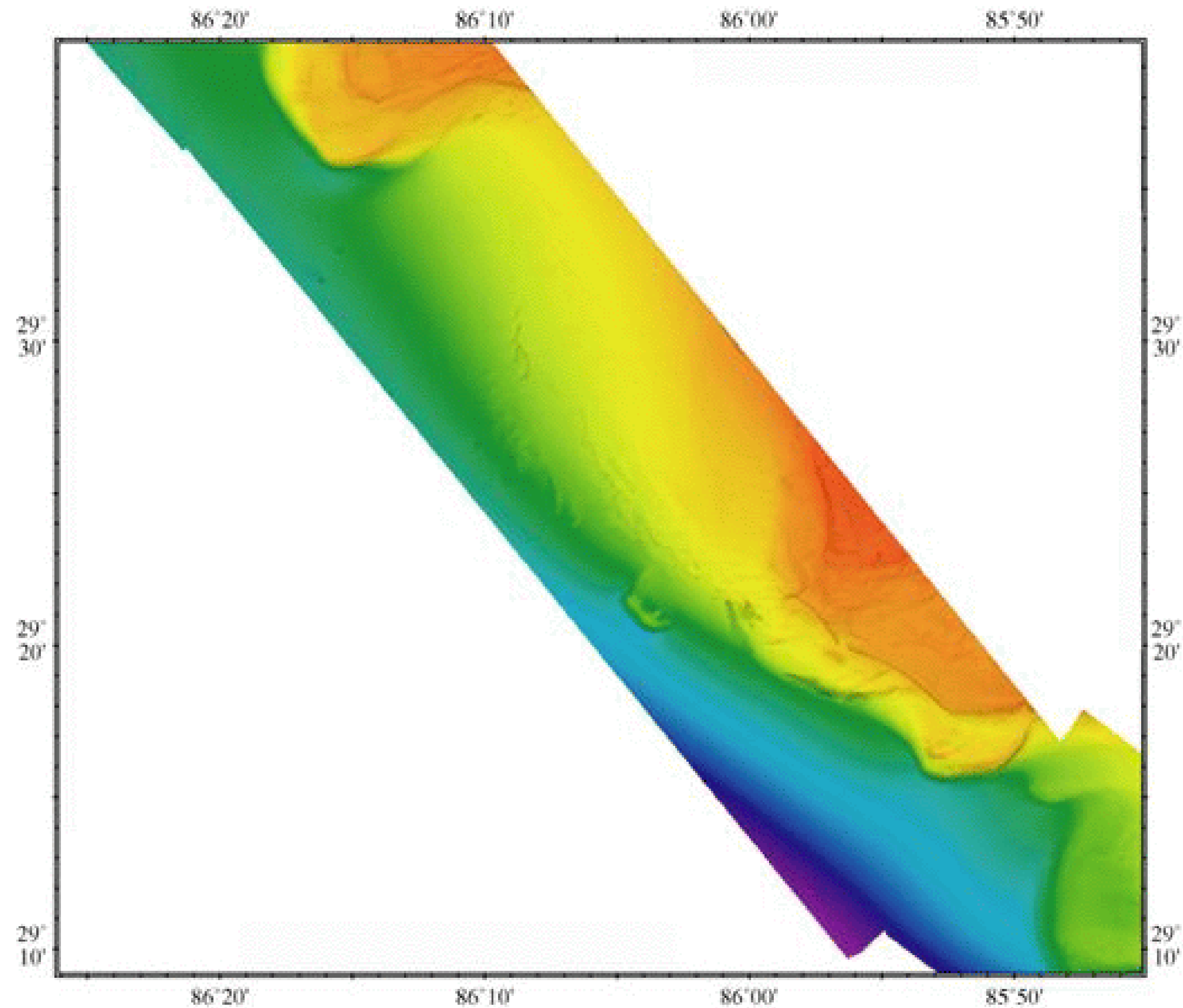

Figure 1D.13. Colored shaded-relief map of Central region. Note that map is rotated 90˚ counter clockwise.

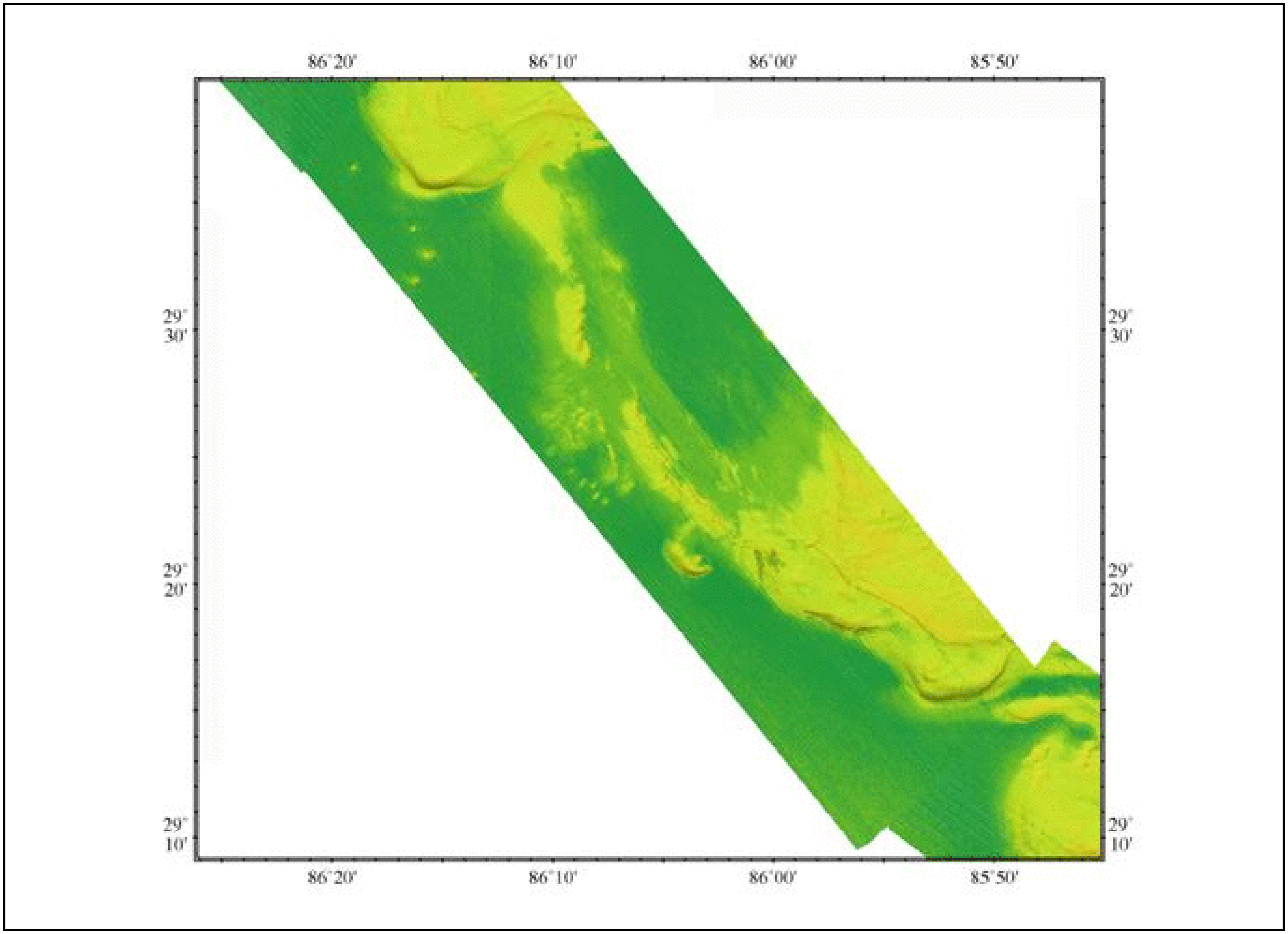

Figure 1D.14. Colored acoustic-backscatter map of Central region. Note that map is rotated 90˚ counter clockwise.

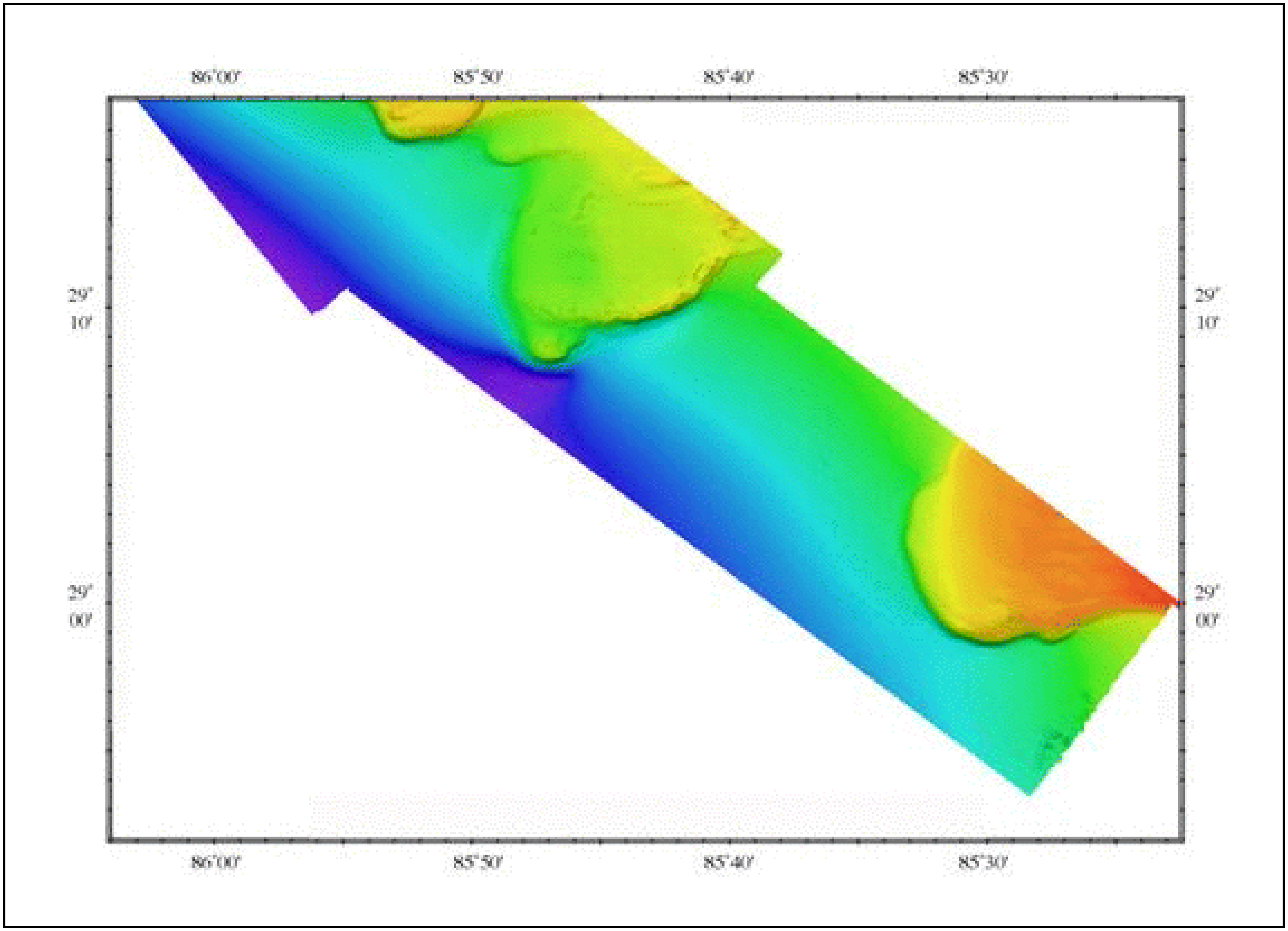

Figure 1D.15. Colored shaded-relief map of South region. Note that map is rotated 90˚ counter clockwise.

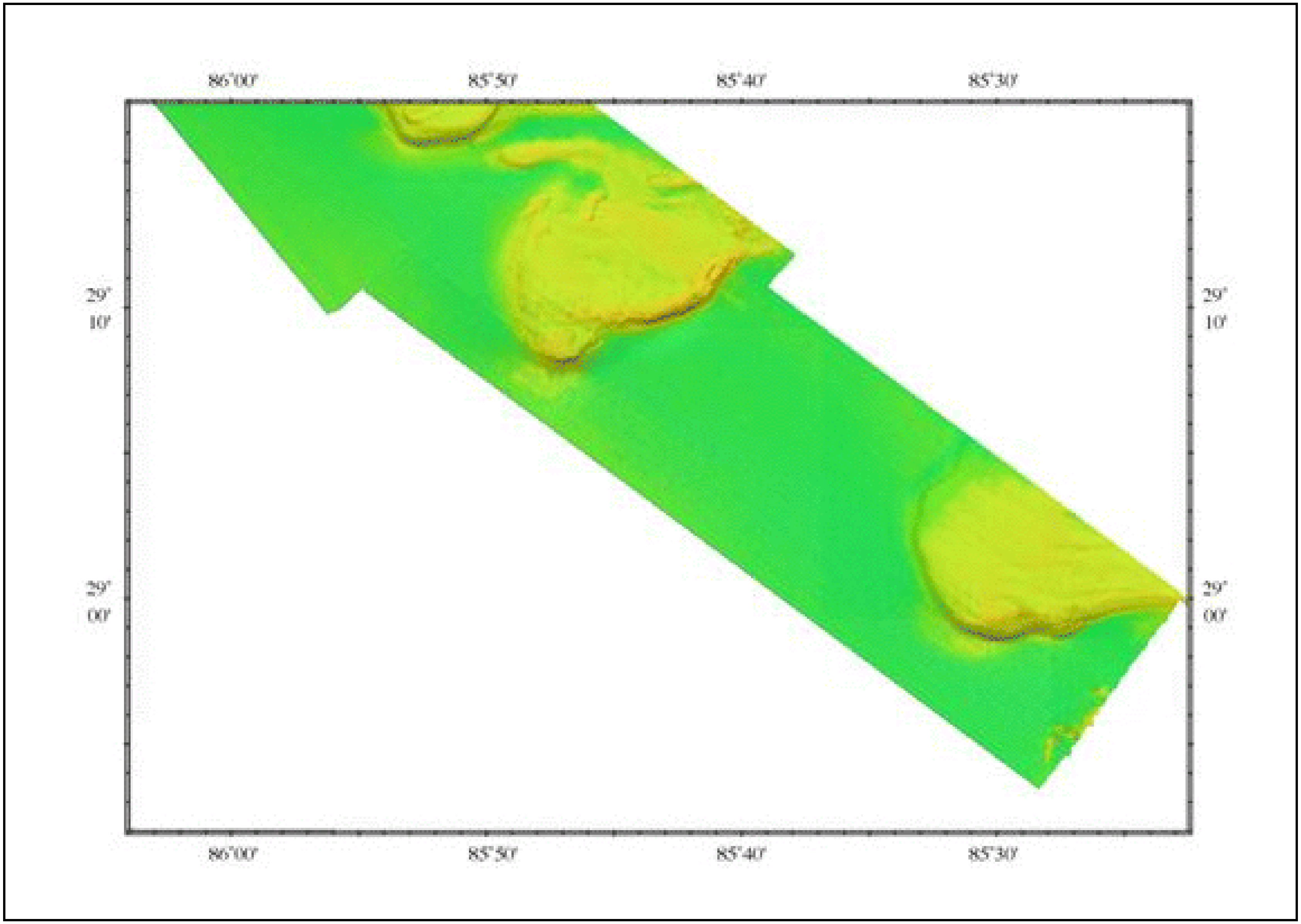

Figure 1D.16. Colored acoustic-backscatter map of South region. Note that map is rotated 90˚ counter clockwise.

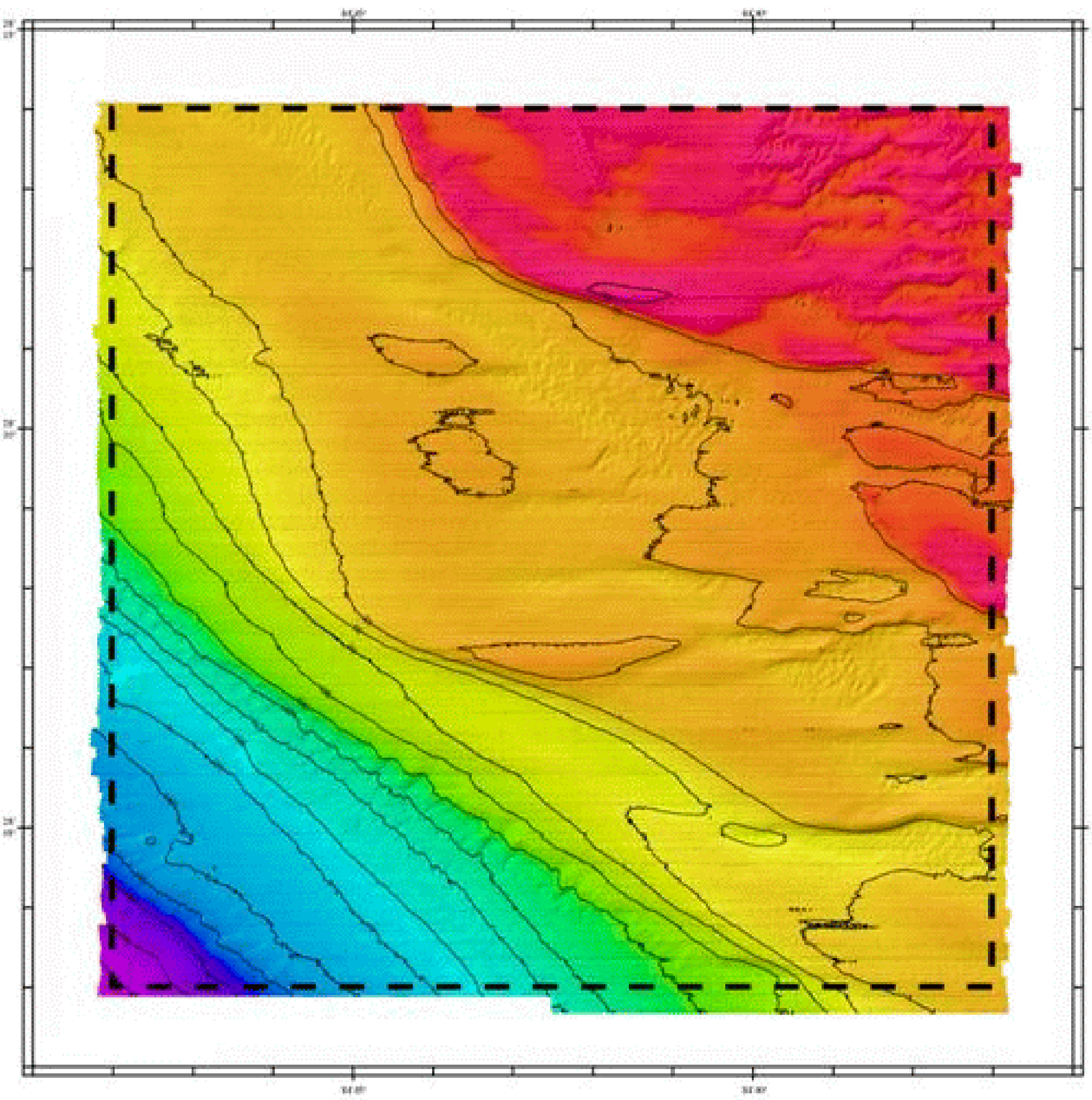

Figure 1D.17. Colored shaded-relief map of Steamboat Lumps Reserve.

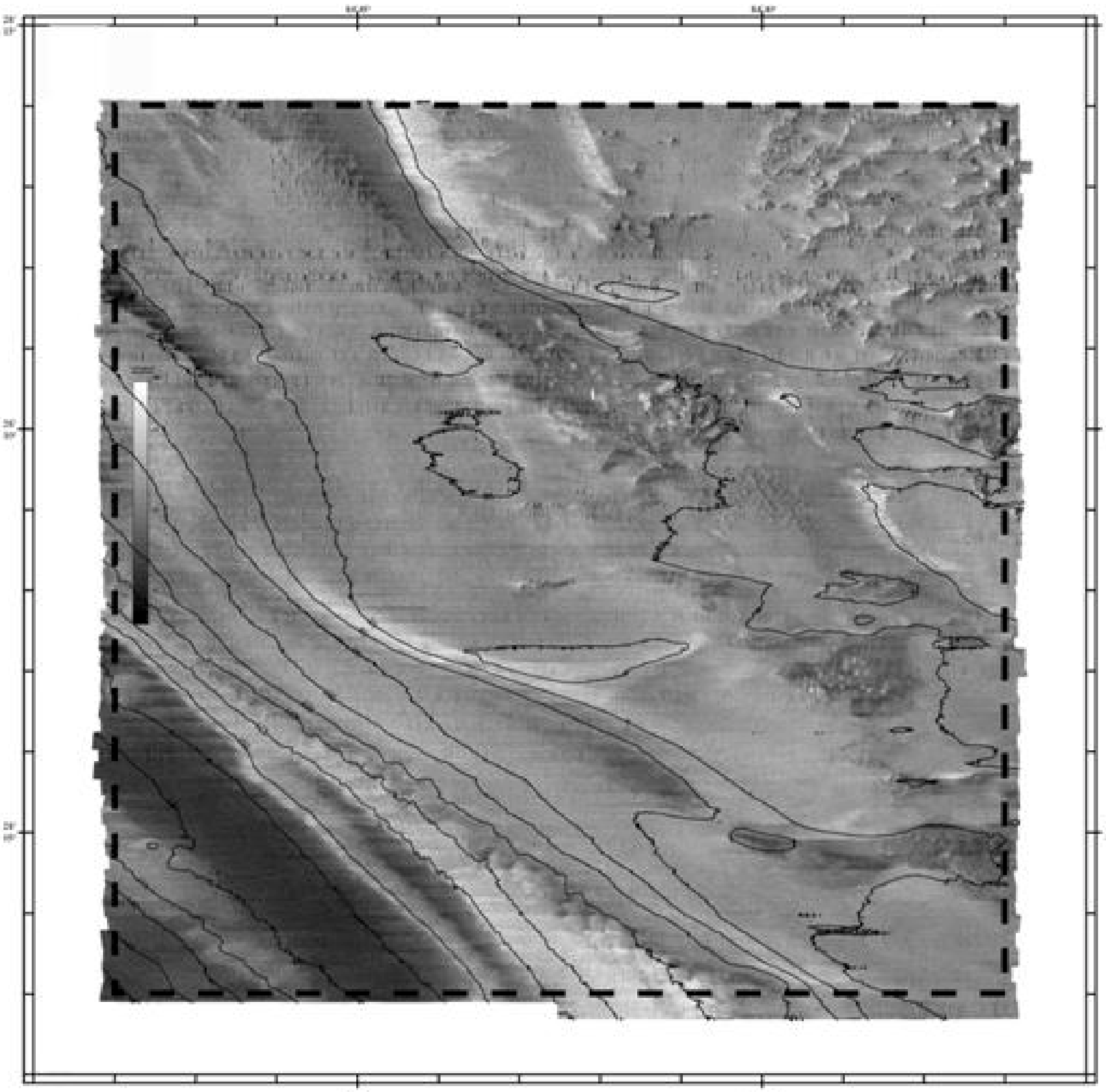

Figure 1D.18. Greyscale acoustic backscatter map of Steamboat Lumps Reserve. Darker tones are lower backscatter, lighter tones are higher backscatter.

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LONG-TERM MONITORING AT THE EAST AND WEST FLOWER GARDEN BANKS NATIONAL MARINE SANCTUARY 1998-1999

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INTRODUCTION

Monitoring of the coral reef habitats of the Flower Garden Banks National Marine Sanctuary (East Flower Garden Bank 27°54.5′ N X 93°36.0′ W and West Flower Garden Bank 27°52.4′ N X 93°48.8′ W) continued in 1998 and 1999 currently funded by MMS and NOAA. The methodology of assessment was consistent with that of Gittings et al. 1992 and Dokken et al. 1999 for the purpose describing changes in the conditions of hermatypic corals of the Flower Garden Banks (FGBs). In addition, guest scientists were invited to conduct ancillary investigations during the time of monitoring cruises. Ancillary studies included investigations of the algal community (Fredericq et al. University of Louisiana at Lafayette; Lehman and Albert, Texas A&M University-Corpus Christi), micromolluscs (Barrera and Tunnell, Texas A&M University-Corpus Christi), food web structure and primary productivity (Dunton and Miller, University of Texas Marine Science Institute), and pore water toxicity (Nipper and Carr, U.S. Geological Survey Marine Ecotoxicology Research Station). Study of the occurrence of disease at the FGBs was also initiated as a thesis project of T. Oberding (TAMUCC Center for Coastal Studies). An upgrade of the instrumentation recording water quality parameters was also initiated following the 1999 monitoring cruise.

RESULTS AND DISCUSSION

The *Montastraea annularis* complex (*M. annularis, M. Faveolatis, M. franksii*) was the dominant coral taxon in both percent cover and relative dominance. During the 1998 cruise to the East Flower Garden Bank, the *M. annularis* complex had a mean percent cover and relative dominance of 34.35% and 55.43%, respectively, while on the West Flower Garden Bank the *M. annularis* complex displayed a mean 39.64% cover and relative dominance of 59.25%. *Diploria strigosa* was second in percent cover at both study sites comprising 8.65% and 13.38% mean cover on the East and West banks, respectively. Mean relative dominance for *D. strigosa* was 13.97% for the East Bank site and 20.01% for the West Bank site.

The *Montastraea annularis* complex continued to be dominant during the 1999 cruise. Percent cover for this species was determined to be 31.43% and 33.29% for the East and West Banks respectively. Relative dominance was 53.26% for the East Bank and 60.96% for the West Bank. None of these figures was determined to be significantly different from the previous year.

The percent of leafy algae observed at both banks was significantly (0.05) greater during 1999 than 1998. This increase came at the expense of bare reef rock, which showed a significant decrease at both banks for the same period. The percent cover of leafy algae at the East Bank increased from 3.30% in 1998 to 27.57% in 1999. Concurrently, the percent of reef rock on the East Bank decreased from 31.44% in 1998 to 10.60% in 1999. The West Bank displayed an increase in leafy algae from 3.2% in 1998 to 20.72% in 1999 and a decrease in bare reef rock (28.99% in 1998) to 22.50% in 1999.

Coral growth was measured as both accretionary growth (*Montastraea faveolata*) and encrusting (*Diploria strigosa*). Based on radiographs of cores taken from *M. faveolata*, accretionary growth from 1985 through 1999 varied significantly within each bank and between banks during some but not all years. Between banks, 10 of the 15 years (1985-99) had significant differences in growth rates. Mean accretionary growth at the East Bank was greater than at the West Bank every year during the period 1985-99.

Encrusting growth data suggested that conditions at the East and West Flower Garden Banks were less than optimum for growth of *D. strigosa* in 1998 and 1999. Measurement of encrusting growth is a year-to-year direct comparison of square centimeters of living coral tissue in a demarcated photographic area. Of the 46 stations deemed suitable for comparison on the East Bank in 1998, 45.6% showed a net tissue gain and 30 % displayed a net tissue loss. The cumulative tissue loss was greater than cumulative tissue gained (mean net loss = 0.14 cm^2/station). In 6 of the 14 stations lost, a red turf algal mat replaced virtually all coral tissue. West Bank stations had a mean net gain of 0.54 cm^2/station in 1998. Of the 50 West Bank stations analyzed, 54% (27) had a net gain of tissue, 24% had a net loss, and 22% remained unchanged.

Diploria strigosa colonies fared better in 1999 at the East Bank despite the significant increase in the red turf algal biomass with a positive net growth rate (0.16 cm^2/station). West Bank colonies exhibited a negative mean net growth of 0.05 m^2/station, which was a reduction from the 1998 net loss of 0.54 cm^2/station. Direct competition between the red turf algal mat and coral polyps was less in 1999, but not totally absent.

At the Flower Garden Banks (FGB), bleaching was observed, but not as a “mass” event. Bleaching at the FGB to date has been short term, unevenly distributed throughout the reef and of short duration. As in 1998 (Dokken et al. 1999), in 1999 the hydrocoral, *Millepora alcicornis*, seemed to be particularly susceptible to bleaching. Bleaching observed in 1998 followed by mortality was observed 26 times at the West Bank in 1999. In the 1996-97 monitoring study, bleaching correlated with a rise in water temperatures above 30^{o}C, which typically occurs in the latter part of August.

Where direct comparisons were possible, there were distinct short- and long-term differences in the PAR (photosynthetically active radiation) doses recorded at the East and West Bank monitoring sites. However, increased variability in PAR doses during summer months is not surprising considering higher overall levels during this season and the heightened effect of overcast days.

Analysis of water quality using Semi-Permeable Membrane Devices to sample for polycyclic aromatic hydrocarbons, pesticides and other potential contaminants indicated very minute trace levels (i.e. ng/l). Water quality was judged to be a non-factor.

CONCLUSION

The Flower Garden Banks coral reef habitats remain healthy and productive, particularly in comparison to other reefs of the Mexican Gulf of Mexico, the Florida Keys, and the Caribbean Sea. However, some negative shifts in the monitoring parameters were recorded (i.e. encrusting growth, algal biomass, and disease occurrence). It is not known what the impact of these shifts will be or whether they are short-term anomalies or the first steps of a long-term trend. Subsequently, continued close scrutiny is crucial. The 2000 - 2001 monitoring data will be critical in assessing the true meaning of the 1998 and 1999 results. Of particular interest will be the status of algal biomass/coverage and incidence of disease.

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A PRELIMINARY SURVEY OF CORAL DISEASES IN THE FLOWER GARDEN BANKS NATIONAL MARINE SANCTUARY (GULF OF MEXICO)

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INTRODUCTION

A major worldwide factor affecting the survival of coral reefs is disease. The study of coral disease is a relatively new science. Black Band Disease (BBD) was the first reported disease of scleractinians in the Caribbean (Antonius 1973). A study conducted by Mitchell and Chet (1975) demonstrated increasing bacterial growth rates on coral as a result of pollution. This research was followed by that of Dustan (1977) and Gladfelter (1977) on white band disease (WBD) of branching coral and plaque of plate corals, respectively.

Most studies of coral disease during the late 1970s consisted of microscopic observation of diseased coralline tissue (Richardson 1998). These studies showed the presence of bacteria in the tissue of diseased corals; however, no attempts were made to apply strict microbiological techniques (Koch's postulates) to bacterial speciation (Richardson 1998).

By the early 1980s, quantitative studies were being widely conducted. White Band disease continued to spread rapidly throughout the Caribbean and had been identified as a major threat worldwide to coral populations (Gladfelter 1982). By 1984, four different diseases had been differentiated: Black Band Disease, White Band Disease, plaque, and "shut-down." A potential pathogen was identified for Black Band Disease (Richardson 1998).

By the 1990s, many characteristics of various coral-related diseases had been described, and new diseases had been identified (Richardson 1998). A persistent problem with these new diseases has been the potential for confusion associated with misdiagnosis. The primary reason for this misdiagnosis is the numerous gross signs exhibited by the same disease. Coral diseases for which known pathogens (or associated vectors) exists are: Black Band Disease, White Band Disease type II, and plaque type I. White Band Disease type I has not been subjected to conclusive microbial testing to demonstrate that the bacteria associated with the disease are the actual causes of the death of the coral tissue. However, WBD type I has been the only one shown to significantly change the structure of the reefs where it occurs (Richardson 1998).

Though much of the research on coral diseases was initially conducted in the western Atlantic and the Caribbean, diseases of reef coral are a worldwide problem, having been observed in the Great Barrier Reef and the South Pacific as early as 1992 (Miller 1996). Most of the Black Band Disease has been observed in previously uninfected reefs after heavy rains. The increased turbidity of the waters from terrestrial runoff raises the stress level on corals (Littler and Littler 1996). Studies in the Gulf of Kutch and the Indian Ocean have found that up to 90% of the corals present had some form of necrosis (Ravindran *et al.* 1999).

Previous disease free areas appear to be becoming infected as well. Bruckner and Bruckner (1997) observed Black Band Disease, White Band Disease and white plaque in Puerto Rico (previously unknown in the area) after Hurricane Hortense (September 1996). Not only are new areas of diseased coral being discovered, but also new diseases are being identified. In the Indo-Pacific region, *Halofolliculina corallasia* (a colonial heterotrich ciliate) has been observed and is manifested as Skeleton Eroding Band (Antonius 1999). The red alga, *Metapeyssonnelia corallepida* (Rhodophyta), previously found only in the Mediterranean Sea, has also now been found in the Caribbean Sea. This algal infection, termed PEY, destroys coral on reef crests and forms a tightly attached skin: Under this skin, there is no trace of coral tissue (Antonius 1999).

Much research still needs to be completed to understand the nature of the multitude of diseases appearing on the coral reefs of the world. Recent press coverage has illuminated the trend towards massive extinctions currently occurring among coral. With 27% of the world’s corals already destroyed, the trend for mass coral extinction increases each year. A controversial report has postulated the worldwide death of all corals 20 years in the future (Wilkinson 2000). There is still much debate on this topic and though the exact amount of damage being caused by disease has yet to be quantified, it is nevertheless a sobering postulate.

OBJECTIVES

Objective 1: To evaluate levels of coral degradation due to disease at the Flower Garden Banks National Marine Sanctuary.

Objective 2: To describe, identify, and evaluate the bacteria collected and isolated from above the infected corals at this same study site.

MATERIALS AND METHODS

Study Site

The study site for this research was the Flower Garden Banks National Marine Sanctuary’s (FGBNMS). East and West Banks are the northernmost coral reef system located in the Gulf of Mexico and on the North American Atlantic Shelf. The FGBNMS consists of three reefs. Two are located on top of diapirismically formed Jurassic salt banks 190 km south-southeast of Galveston, TX (Hagman 1998, Minnery 1990). The third component of the FGBNMS is Stetson Bank, a system 12 miles west of the previously mentioned bank.

Quantification of Coral Disease

Data collection occurred during two cruises. The first cruise was 18-20 July 2001, the next cruise was 17-19 September 2001. On each cruise three transects were established at each bank. This was performed by tying one end of the transect tape to the common mooring block and unwinding to a distance of 50 meters (Vogt 1995, Ohlhorst *et al.* 1988). The transect lines were 120 degrees apart with the primary line at each site being run due north (0 degrees) at the West bank and due south (180 degrees) at the East bank. Digital video filming over the length of the transect was then undertaken using a Sony TVR900™ camera, in an Amphibico™ housing.

Collection of Samples

During the cruise, physical microbial samples were gathered from suspected representative diseased corals along the transect bearings. Due to logistical constraints, samples were limited to seawater from the water column directly above the infected areas. Control samples were taken from directly above the coral in non-infected areas within the same transect. Samples were collected on the last day at each site using 50 mL sterile syringes (Richardson 1997).

Bacterial Isolation and Enumeration

Bacterial isolation was conducted via standard dilution and isolation-streak procedures (Jensen 1995). In-lab isolation was continued initially on glycerol artificial seawater and Zobell's 2216E. Bacteria were described utilizing standard oxidase and Gram tests. Enumeration of bacteria was accomplished using standard epifluorecent microscopy (Chrost *et al.* 1999) using Acridine Orange stain. A Zeiss Hg microscope was also used. Fourteen samples from eighth generation isolates were subjected to identification using Biolog™ species determination kits.

RESULTS

Bacterial Enumeration

A total of 44 preserved samples were analyzed for cell density counts. Suspected White and Black Band Diseases had the highest cell density counts based upon diseases (110, and 101 cells/ml respectively). Bleaching had the next highest cells counts at 34 cells/ml.(Figure 1D.19).

Eleven of the thirty-six plated samples were identified. This identification was based upon eighth generation isolation streaks of the original on-ship plated samples. Two marine pathogens were identified: *Vibrio alginolyticus* and *V. proteolyticus* (Table 1D.1).

Transect Results

The total area surveyed was 741109.42 cm^2. Of that, 532015.98 cm^2 (71.79%) were covered by coral. *Montastrea annularis* complex was the most prevalent coral species present, accounting for 31.04% of the total area observed.

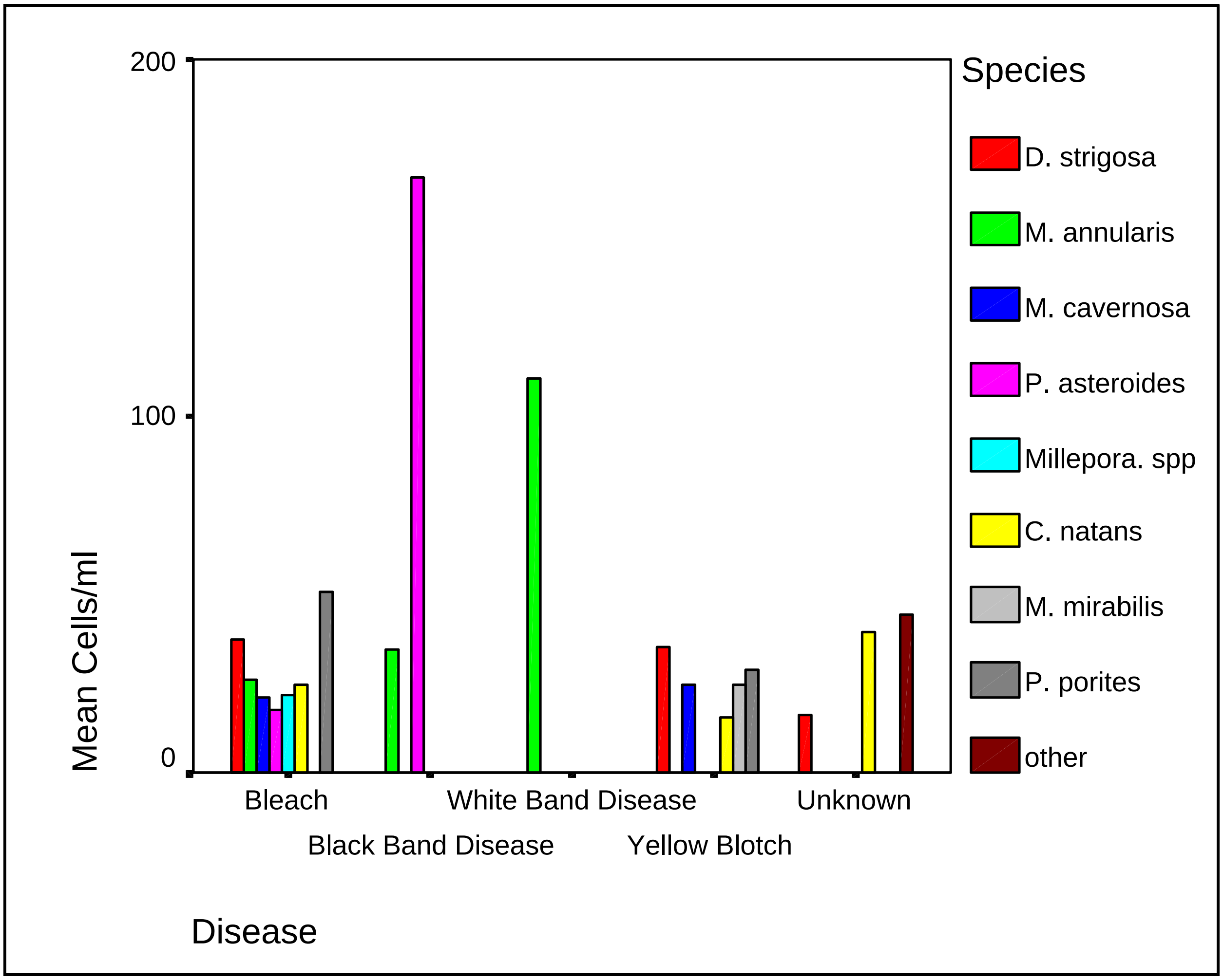

Figure 1D.19. Cell density.

Bleached areas of corals accounted for 125054.78 cm^2, and were the most prevalent sign of unhealthy coral. 78.64% of all *Millepora* spp. (3.00% of the total area) observed were bleached. 38.51% of all *M. annularis* complex were bleached (11.95% of the total area). The second most prevalent species at the FGBNMS (*D. strigosa*), showed 4.71% bleaching (0.96% of the total area).

Black Band Disease was the second most prevalent disease present at the FGBNMS. The total area impacted by BBD was 24039.81 cm^2, which represents 3.25% of the total area surveyed. *D. strigosa, M. annularis, and M. cavernosa* were the three species which had the highest area represented by BBD (1.51%, 0.91%, 0.45% of the total area surveyed).

The unknown or unclassified disease was the third most observed state of disease present at the FGBNMS. Overall, 18464.89 cm^2 were experiencing an unknown disease state. This number represents 2.49% of the total area surveyed. Of the total area surveyed *M. annularis, D. strigosa,* and *M. cavernosa* were the species that experienced the highest levels of unknown disease (1.28%, 0.54%, 0.37% respectively).

Table 1D.1. Bacterial species identified and most common environment.

Species	Common Environment
Staphylococcus aureus	skin, mucous , found in dust, water
Arthrobacter cumminsii	soil
Micrococcus luteus	mammalian skin, soil, found in air
Brevibacterium mcbrellneri	human skin, dairy products
Corynebacterium auris	mucous membranes
Streptococcus spp.	mouth, upper respiratory
Vibrio alginolyticus	marine, vert and invert pathogen
Vibrio proteolyticus	marine
Aeromonas veronii	sewage
Bacillus halodurans	varied
Kytococcus sedentarius	not listed in Bergey's

CONCLUSIONS

Overall, the FGBNMS is a moderately healthy site. The primary threat to the site comes from bleaching, BBD and, diseases of unknown origin. The values presented in this study should be considered to be towards the high end of the spectrum. Additional studies must be conducted during the cold spring months to quantify the lower extreme of the states of disease, and to validate that bleaching experienced by corals at the banks is temperature-related and thus a form of recoverable disease.

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LUMINESCENT BANDS IN STAR CORALS AT THE FLOWER GARDEN BANKS NW GULF OF MEXICO

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RESEARCH HYPOTHESIS

Luminescence in corals at the FGB is linked with regional runoff (Mississippi and Atchafalaya Rivers).

SPECULATIVE CLUES

- Barnes and Taylor (2001): New findings explaining luminescence in corals as increased holes in coral skeleton slice
- Dodge and Lang (1983): Correlation of Atchafalaya River runoff and FGB coral growth
- Observations of recurrent green, “snotty” waters at the FGB

DATA SOURCES

- Slice of Montastraea annularis collected at the FGB in 1994
- NWGOM and FGB temperature, salinity, solar radiation, chlorophyll-a, and nutrient data
- Shelf circulation studies
    - McGrail (1983); SAIC (1989); CSA (1996); Nowlin *et al*. (1998); Dokken *et al*. (1999); Rezak *et al*. (1985).
    - Nowlin *et al*. (1998) (data from 1992-1994 at “Mooring 8" 30-48 km west of FGB and hydrographic stations near the FGB

RESULTS

X-radiography and Luminescence of Montastraea Annularis

Luminescent bands preceded high-density (summer) skeletal growth bands (1983-1994) (Figure 1D.20). A stress band occurred between high-density bands, possibly coinciding with annual water temperature minima.

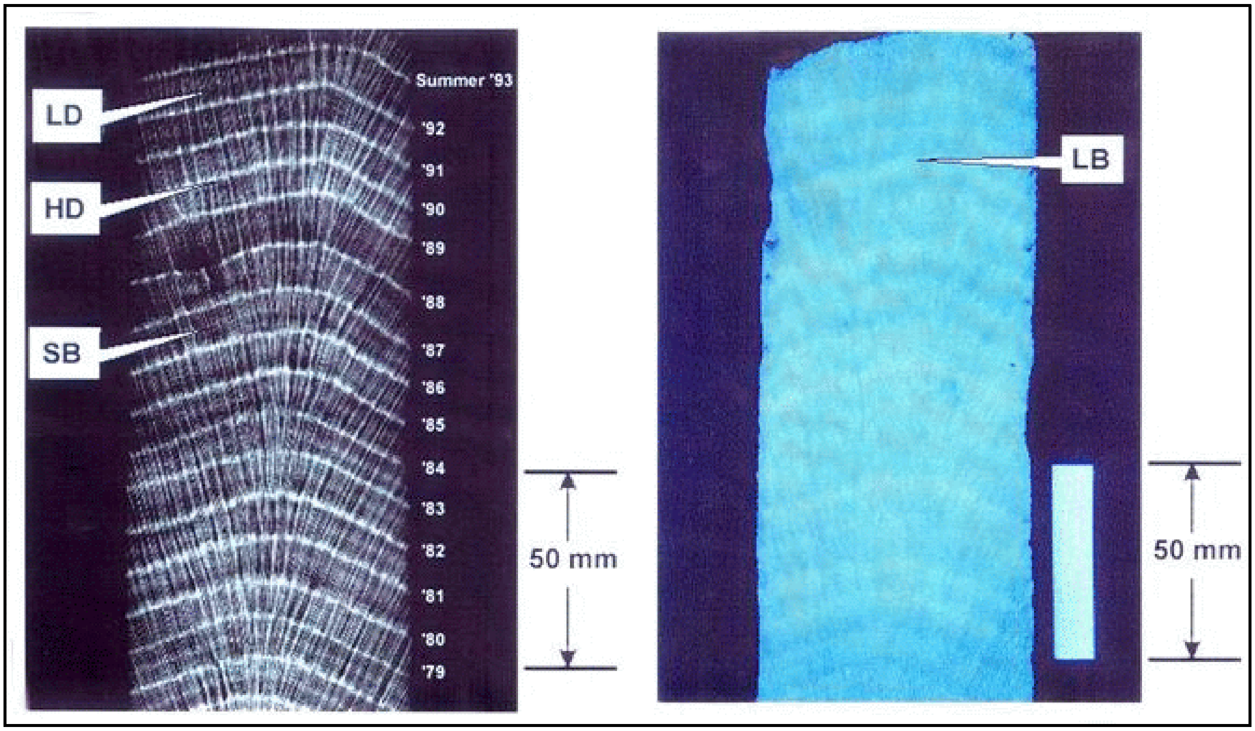

Figure 1D.20. Slice of star coral: x-ray positive and photograph under UV light. LD = low density; HD = high density; SB = stress band; LB = luminescent band.

Temperature

The temperature sensor on Mooring 8 recorded temperature profiles at 13 m, 100 m, and 190 m from 1992 through 1994. Temperature was the least variable at 190 m oscillating between 14 and 17°C. At 100 m, temperature varied between 16 and 22°C. At the 13 m depth, the temperature profile was comparable to know profiles at the FGB: December-April temperature ranged from 17-23°C, and 23-30°C the rest of the year. Annual temperature maxima occurred in July and August.

Salinity

Salinity profiles at Mooring 8 at 100 m and 190 m showed little variation (approx. 36.5 psu). At 13 m, however, salinity dropped annually to almost 30 psu (1994) in April-July. The salinity variations were significantly correlated with same and previous year Mississippi-Atchafalaya River runoff. The mid-shelf mix of the same and previous year runoff appeared to reach the FGB.

Light Attenuation

In May, June, July, and October we witnessed recurrent murky, green surface waters at the FGB. Dokken *et al*. (1999) and FGB dive charter logs contain similar observations. Further, dive charter logs recorded discolored waters in May-August, some in December, February, and March.

In situ measurements of light attenuation showed high attenuation from January to March, June through August, and October through December.

Season and salinity are significantly correlated with light attenuation (k). In summer, high values of k were clustered around low salinity values (<34.8 psu). In winter, k was more homogeneously distributed and clustered with higher salinity values.

An analysis of cross-shelf of PAR near 92° W revealed that water parcels bearing yellow substances that reach the FGB probably originated from nearshore and were transported to the FGB by the northern Gulf of Mexico shelf circulation.

Chlorophyll-a

Shipboard profiles of chl-a near the FGB peaked at 40 m. Values of chl-a were variable in the upper 30 m. Time series data are needed to further study the potential correlation of seasonal chl-a variations associated with regional river runoff.

Nutrients

Shipboard vertical profiles of nutrients (nitrate, nitrite, phosphate, silicate) consistently showed low values in the upper 50 m inferring depletion, and maximum values at 100 m. The profiles did not contain seasonal trends. Rezak *et al*. (1985) found similar nutrient concentrations at the FGB.

DISCUSSION

Mix of river water and seawater (river-seawater mix + yellow substances + suspended particulate matter) came in contact seasonally with the FGB reef crest as shown by decreased salinity and increased light attenuation. Nutrient and chl-a data did not show obvious seasonal variations.

Low salinity correlated with same year and previous year Mississippi and Atchafalaya River runoff. SCULP drifters showed that the river-seawater mix is delivered seasonally onto the shelf edge (Niiler *et al*. 1997) inferring that nearshore river-seawater mix water was transported through the FGB. The April to July shelf edge low salinity events and associated increased light attenuation were potential sources for skeletal changes (increased number of holes) in M. annularis visualized as luminescent bands under UV light.

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FISH COMPOSITION AND BIOMASS ASSOCIATED WITH THE WEST FLOWER GARDEN BANK

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INTRODUCTION

The use of platforms for artificial reefs has been well established. The basis for this practice is the common user group knowledge that platforms support superior recreational fishing. This public perception has been supported through various and numerous scientific investigations. However, there is little data to suggest that the reef configurations employed to date are as productive as natural reefs. The reef value of toppled and partially removed platforms cmpared to standing platforms and natural reef systems is not known. The advantages of the various artificial reef configurations of retired platforms needs further investigation.

The largest natural reef in the northern Gulf of Mexico (GOM) is the Flower Garden Banks. This complex is composed of natural geological formations known as salt domes. Although fishermen have known about the Flower Garden Banks since the late 1800s, it was not until 1936 that the banks were officially discovered and mapped by the U.S. Coast and Geodetic Survey during surveys in the GOM to map pinnacles. In 1961 Dr. Thomas E. Pulley documented that the Flower Gardens were viable coral communities (Elvers and Hill 1985). After nearly two decades of effort the Flower Garden Banks were designated a marine sanctuary in 1992 (Gittings and Hickerson 1998). Although several fisheries surveys have been conducted around these geological features, few scientific investigations have considered a holistic account of the fish population and fish density beyond the cryptic reef fishes.

To date the most extensive survey of fish assemblages on the Flower Garden Banks was conducted by LGL Ecological Research Associates (Boland *et al.* 1983).The investigators reported characteristic fish assemblages zoned primarily by depth and/or habitat types delineated as upper coral reef, algal-nodule sponge zone, shallow drowned reef, deep drowned reef, and soft bottom. The investigators also estimated species abundance. For example, they estimated that the population size for creole-fish *Paranthias furcifer* ranged from 400,000 to 993,948, red snapper *Lutjanus campechanus* from 4,000 to 20,000, and groupers *Mycteroperca spp.* from 20,000 to 47,000 at the Flower Garden Banks.

Other investigators have described biotic zonation (Bright et. al. 1974), fauna (Bright and C.W. Cashman 1974), fish communities (Dennis and Bright 1988), and fish species richness (Rooker *et al.* 1997). Rooker *et al.* (1997) compared fish communties between the West Flower Garden Bank (WFGB) and a nearby oil platform (High Island A389A); these showed a marked difference. They reported 54 species and 39 species, respectively, at the WFGB and HI A389A. They also reported that midwater pelagics such as carangids and scombrids accounted for over 50% of all taxa enumerated at the platform; 50% of the observed total fish population at the WFGB was composed of species in the family Pomacentridae.

The proximity of the several artificial reef projects to the natural coral formations of the Flower Gardens afforded us the opportunity to compare these fish communities to that of a neighboring natural system. Therefore the purpose of this study was to describe the fish communities, species composition, and to estimate the fish density/biomass at the WFGB.

MATERIALS AND METHODS

The WFGB is located approximately 172 km southeast of Galveston, Texas, on the edge of the outer continental shelf at 27˚ 52.4' north latitude and 93˚ 48.8' west longitude. It represents the largest charted calcareous bank in the northwestern GOM and (Bright *et al*. 1985 as in Dokken *et al*. 1999) and the northernmost coral reef on the continental shelf of North America (Bright *et al*. 1984 as in Dokken *et al*. 1999). The coral cap varies in depth from approximately 18 to 36 meters. (Rezak *et al*. 1985 as in Dokken *et al*. 1999).

A120 kHz downward oriented dual beam transducer coupled with a Biosonics DT 5000 Echosounder was towed from the starboard hip of the research vessel R/V Pelican (June 1999) or the M/V Epic Mariner (June 2000). This hydroacoustic system allowed us to estimate the density and size frequency distribution of fishes associated with the WFGB and two artificial reef sites in the near vicinity. Navigational data were collected with a Garmin GPS III global positioning system (GPS) in conjunction with a Garmin GB 21 differential beacon receiver.

The mobile survey of WFGB consisted of twenty-six transects spaced 300 meters apart running along the long axis of the WFGB, from northeast to southwest. The lines varied in length from 2.5 kilometers to 13.5 kilometers. Data were collected along these transects continuously over a 29-hour period 22-24 June 2000. For analysis purposes, the WFGB was separated into three biological community "terraces" based on water depth and specified as upper (20-50 meters), middle (50- 80 meters), and lower (80- 100 meters) (Bright and Boland 1985). Depths deeper than 100 meters were treated as openwater. A high resolution multi-beam side scan survey assisted the determination of the terraces (Gardner *et al*. 1998). These geological terraces have been related to distinct biological zonations (Dennis and Bright 1998).

Acoustic data were collected with a Biosonics model DT5000 scientific echosounder/multiplexer. Digitized hydroacoustic data were processed with a Biosonics' Visual Analyzer 4.02. Recent advances in the software allowed simultaneous estimates of sigma (target strength) and mean volume backscatter (reflected acoustic energy) for each depth strata. These parameters are used to estimate fish density/m^3 and fish size. Processing of acoustic data yields several parameters of interest. Fish density is calculated based on the volume backscatter (reflected acoustic energy) of a known volume (cubic meter) of water divided by the average target strength (reported as sigma) from that same volume of water. Density is reported as density/m^3 in this study.

Statistical analysis of these data included the reported reflected acoustic energy as volume backscatter (SV), a proxy for fish biomass, as a dependent variable in our analysis. The use of volume backscattering avoided the uncertainty of Target Strength (TS) error in density calculations. "Fish Energy" should be considered to be an acoustic measurement of fish biomass as it is based on the average acoustic reflectance/m^3. The second dependent variable in our analysis was density/m^3. A randomized block analysis of variance was used to examine the main effects of TS as described by Stanley and Wilson (1997). Due to the larger number of zero values in the mobile survey, logistic regression (Trexler and Travis 2001) was used to analyze the mobile data. Class variables included depth or terrace, stratum, time of day (TOD), transect number, and all two-way interactions. Tukey's standardized range tests (Ott 1982) were used to compare the means of significant variables. Statistical tests were reported as significant at the alpha < 0.01 level.

Fish abundance estimates of the WFGB were based on the average density by stratum, within each terrace multiplied by the area of each terrace and summed over all strata. Visual surveys were conducted with a Deep Ocean Engineering Phantom HD2 ROV with standard visual census techniques and recording video on S-VHF tape. (Bohnsack and Bannerot 1986). During mobile surveys the ROV was deployed from the M/V Epic Mariner. Video data from the WFGB were collected along random transects designed to represent the three major terrace regions and geologic features located throughout the WFGB. The ROV was flown down to the bottom where it traveled at a speed of 1 knot for 45 minutes along a transect through each of the three major terraces.

RESULTS

The acoustic survey of the West Flower Garden Bank provided valuable insight into the fish community associated with this unique natural bottom habitat. Twenty-six survey lines covering a linear distance ranging from 2.5 to13.5 km were sufficient to cover the WFGB at 300 m intervals. The survey took 29 hours to cover approximately 160 km of survey lines. Survey lines were generally parallel; however, periods of high sea state contributed to some deveance in the intended tracks. A break in the transducer cable prevented data collection over a portion of one transect over the upper terrace.

Analysis of the acoustic data produced some very interesting results reflecting topography, fish community composition, and general geology. The acoustic system not only provided quantification of the fish community, but also provided insight about geological properties of the bottom and location natural gas seeps. For the purpose of this analysis we divided WFGB into three terraces; upper = 20 – 50 m, middle = 51 – 80 m, lower = 81 – 100 m based on description by *Balard et al.* (1981). Depths greater than 100 m were considered to be open water in our analysis.

A binomial logistic regression with the presence/absence of SV as the dependent variable was used to model the relationship between fish presence and class variables: Terrace, time of day, and stratum. All class variables were significant. Using logistic procedures without an intercept provided insight into the relative differences within the class variables. The chance of encountering a fish was highest over the upper terrace and lowest over open water. Stratum and TOD were not significantly different in the variables, but were significant in the model. Based on logistic regression (without intercept), there was a 35 to 100 times greater chance of finding fish over the upper terrace than over the middle or lower terraces. Mean fish energy was an order of magnitude higher over the upper terrace compared to the middle and lower terrace and over open water (Figure 1D.21). Fish energy also varied with TOD as energy over the WFGB was an order of magnitude lower at noon that at other times of day.

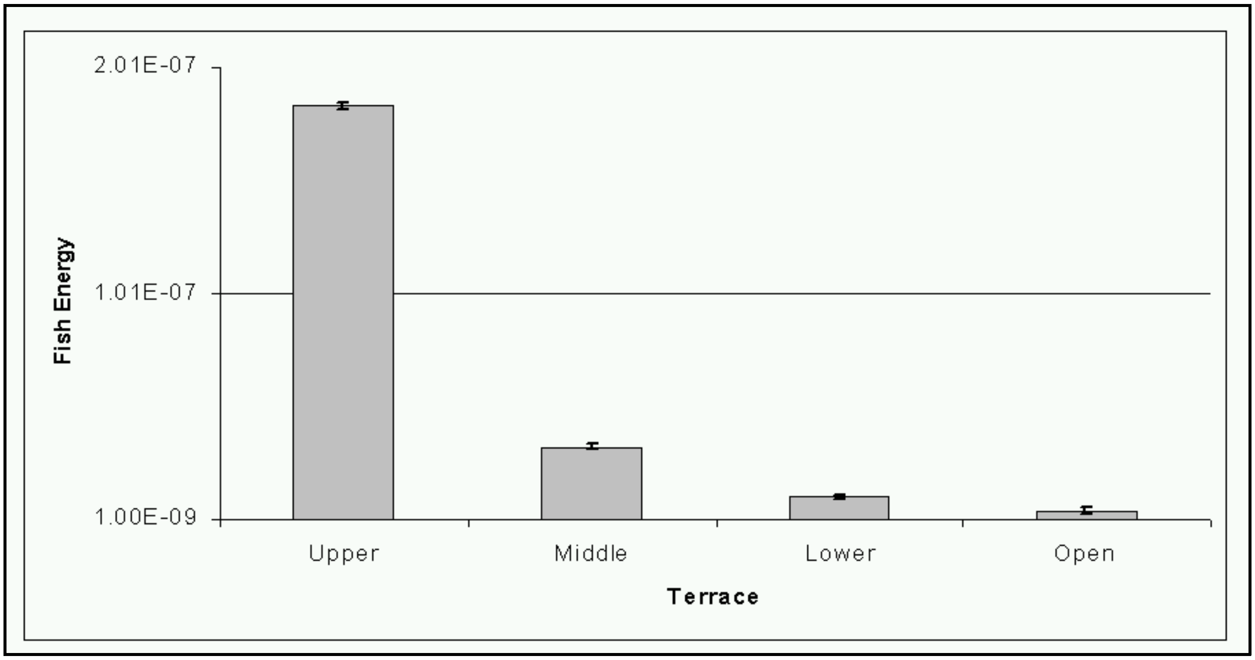

Figure 1D.21. Mean fish energy (from volume backscatter) by Terrace over the West Flower Garden Bank based on a dual beam hydroacoustic survey conducted in June 2000.

Using RBD ANOVA to model the effect of class variables on fish size, fish size varied with terrace and depth and their interactions. Fish were significantly larger over the upper terrace and near the surface. Mean fish size over the WFGB was - 47dB (6.7 cm), and ranged from -65 to -25 dB (1 to 108 cm) (Love 1971).

Estimated mean fish density ranged from 0 to 0 .009 fish/m^3 over the WFGB. When broken down by terrace, fish densities were highest over the upper terrace just above the bottom at about 30 meters and just above the bottom of the middle terrace at about 70 meters (Figure 1D.22). Similarly, densities on the lower terrace peaked just above the bottom at 90 meters but were almost an order of magnitude less than the highest densities observed on the upper terrace.

The fish community at the WFGB was very diverse and reflected that of a typical coral reef community. Creole-fish and Bermuda chub were the most abundant species present followed by great barracuda and black durgon. The ROV survey results likely represent only a small cross-section of the total species present as we did not include cryptic species in the visual survey.

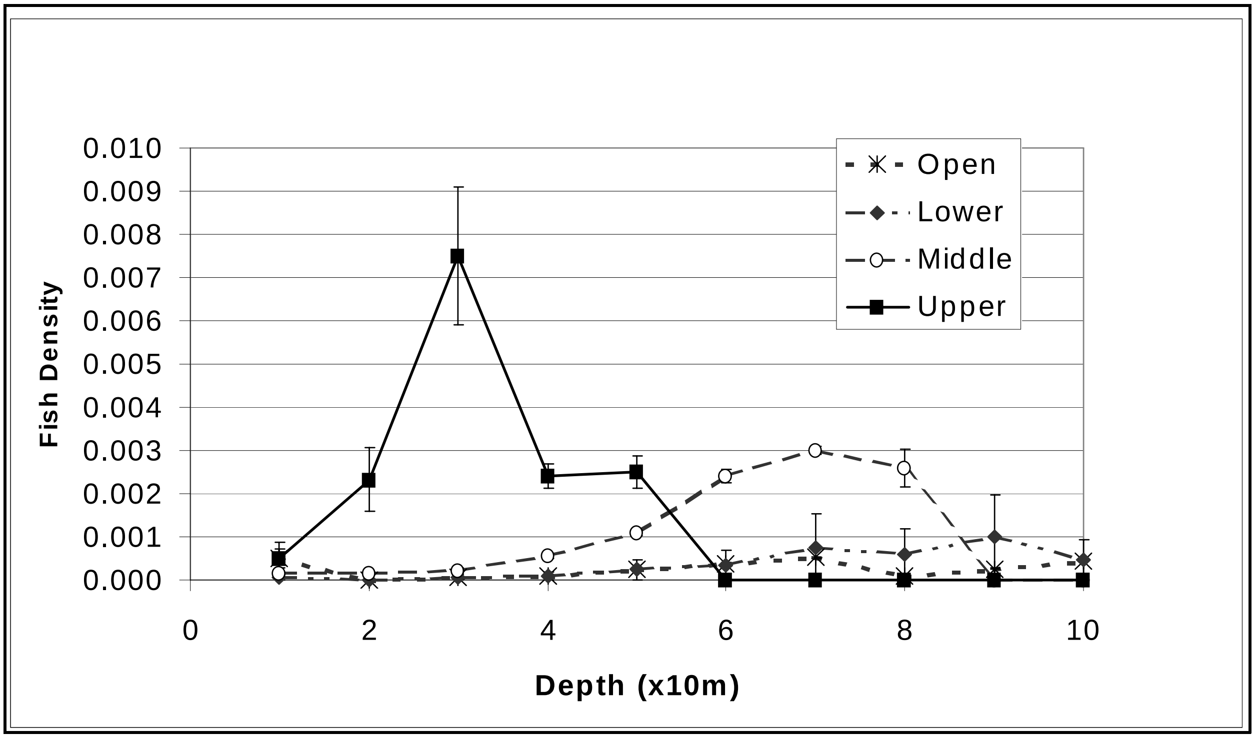

Figure 1D.22. Estimated density of fish (fish/m^3) over the West Flower Garden Bank based on a dual beam hydroacoustic survey conducted in June 2000. Error bars are 95 % confidence intervals.

Fish abundance at the WFGB was estimate around 2,500,000 (Table 1D.12). The most abundant fishes at the WFGB were Bermuda chub and creole-fish. There were roughly 630,000 bermuda chub and 485,000 creole-fish followed by 261,000 great barracuda 130,000 and black durgon.
Discussion

The close geographical proximity of several previously studied platforms, provided us an opportunity to use stationary and mobile acoustic survey methods to compare species composition, fish biomass, and fish densities within and between platforms and a natural reef. Dual beam hydroacoustics coupled with video surveys afforded the best combined method for assessing fish resources at these sites.

These results combined with our earlier studies provide evidence that fish densities and biomass around standing oil and gas platforms are higher than those found at the WFGB. Fish were not only more abundant around platforms, but also they were larger than those found in the open water habitats or over the WFGB. Densities and species composition at the artificial reef sites were similar to the middle and upper terraces of the nearby natural reef.

The mobile acoustic survey at the WFGB were conducted around the same time as our survey of a toppled platform (WC617A) and a partially removed platform (HIA355). The two reef sites were both surveyed in 1999 and all three sites were surveyed in 2000. By using the same collection technique at all three sites we are better able to compare the results.

Table 1D.2. Estimated numbers of fish over the West Flower Garden Bank based on a Dual Bean Hydroacoustics survey conducted in June 2000. Depth refers to a 10 m depth stratum and Area is the spatial extent of the WFGB that falls within that depth range . Total is the number of fish estimated to be within each depth range summed across all 10m stratum. Upper Terrace = 10-50m, Middle Terrace = 50-80m, and Lower Terrace = 80-100m. Population size is the sum of the total number of fish by Terrace.

Depth	Area (m^2)	Stratum 1	Stratum 2	Stratum 3	Stratum 4	Stratum 5	Stratum 6	Stratum 7	Stratum 8	Stratum 9	Stratum 10	Totals
10-20	144800	724	3910									4634
20-30	200000	1000	5400	15200								21600
30-40	195800	979	5287	14881	4699							25846
40-50	1668700	8344	45055	126821	40049	41718						261986
50-60	1752200	4030	2804	4030	9988	19274	42438					82564
60-70	2215800	5096	3545	5096	12630	24374	53667	67139				171547
70-80	8290900	19069	13265	19069	47258	91200	200806	251214	215563			857445
80-90	16403700	10466	2264	9662	18700	39369	57413	124668	96782	162397		521720
90-100	15653200	9987	2160	9220	17845	37568	54786	118964	92354	154967	73570	571420

	Population Size
Upper	314,065
Middle	1,111,556
Lower	1,093,140
TOTAL	2,518,761

This study was the first direct acoustic comparison of fish communities between natural reefs and artificial reefs in the same geographic region. We recognize that the absolute estimates of fish numbers are likely skewed due to the uncertainty of target strength estimates. However, these data do provide a basis for comparisons between the two types of habitats. It is now clear that the fish densities around a standing platform and the resultant artificial reef configurations of toppled in place or partially removed are greater than that of nearby WFGB habitat on a per-unit area basis. The highest densities at WFGB were found over the upper terrace where they were two to three orders of magnitude greater than the middle or lower terraces. The fish size was also larger over the upper terrace and smallest over the open water areas of the WFGB. The WFGB supports well over 2 million fish that can be detected by acoustics. This fish biomass appears to be rivaled by the fish populations of some 150 platforms in water depths ranging from 100 to 500 m water depth based on our survey of HI 350 and the previous surveys mentioned above.

Not only are we interested in comparing the natural reef to an artificial reef but also we wished to compare our results to previous studies of the WFGB. The most extensive study of the fish community and WFGB was conducted by Boland *et al*. (1983). Of great interest is that our estimates of the fish populations at WFGB are along the same order of magnitude as those reported in Boland *et al*. (1983). For example, Boland et. al. (1983) reported from 400,000 - 900,000 creole-fish on the WFGB. We estimate that there was 23% of 2,500,000, or 575,000 creole-fish at the time of our survey. Note that these studies were nearly 20 years apart. Given the techniques used by Boland *et al*. (1983), they identified more than twice the number of species that we found as they included the numerous cryptic reef species. We found 8 of the 16 primary species reported by Boland *et al*. (1983) from the WFGB of these 16, seven were cryptic and not targeted in our study.

Fish populations near reefs, both natural and artificial, are highly variable over time and space. Variations in abundance are the result of many factors which include, but are not limited to, competition, seasonality, physical perturbation, ontogenetic changes, predation, recruitment, emigration and immigration (Sale 1990; Bohnsak *et al*. 1991; Sale; 1991). Reefs are thought to be nonequilibrial systems with their occupants constantly changing (Sale 1991). Population estimates often vary by an order of magnitude over monthly surveys (Sale 1990; Bohnsak *et al*. 1991; Sale1991; Stanley 1994) and are equally divergent over spacial scales. A reef's size, layout, depth, and location all play an important role in the heavily disputed attraction verses production issue and are also important in determining fish densities at artificial reef sites and natural reefs.

This research continues to support the working hypothesis that platforms do make useful artificial reefs since they tend to support a population of fish that can be 10 to over 1,000 times greater in density than the adjacent sand and mud bottom habitats and are equal to or even exceed that of coral reef habitat. Densities of fishes away from platforms, the lower terrace of the WFGB, and open water range from 0 to 0.0001 FPCM and adjacent to standing platforms and over reef sites range from 0 to 10 FPCM depending upon site.

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SESSION 1E

OUTER CONTINENTAL SHELF SAND AND GRAVEL: ATLANTIC AND GULF OF MEXICO ENVIRONMENTAL STUDIES

Chair: Mr. Barry Drucker, Minerals Management Service
Co-Chair: Ms. Sarah Tsoflias, Minerals Management Service

Date: January 9, 2002

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OVERVIEW OF MMS SAND AND GRAVEL ACTIVITIES, ISSUES, AND STUDIES

Mr. Barry S. Drucker
Minerals Management Service

INTRODUCTION

Many of the submerged shoals and surficial sand sheets located on the Federal Outer Continental Shelf (OCS) under the jurisdiction of the Minerals Management Service (MMS), a bureau within the U.S. Department of the Interior, represent viable sources of sand borrow material for coastal erosion management because of

- the general diminishing supply of onshore and nearshore sand,
- the renourishment cycles for beaches or coastal areas requiring quantities of sand not currently available from State sources,
- immediate/emergency repair of beach and coastal damage from severe coastal storms.

These resources must be wisely managed to ensure that environmental damage to the marine and coastal environments will not occur. Some of these areas may represent long-term sources of material which may be used on a continual, prolonged basis. Thus, long-term, cumulative effects become an issue and it is imperative that management be accomplished on a long-term, system-wide basis to ensure that environmental damage will not occur. Sand sources that are to be used repeatedly may require additional biological and physical monitoring to avoid or alleviate adverse impacts to the marine and coastal environment.

MMS, through its International Activities and Marine Minerals Division (INTERMAR), has been focusing on integrating both geologic and environmental information, which has been developed through partnerships with coastal states and contracted studies, to identify suitable OCS sand deposits and to provide needed environmental information for the environmental management of these resources. This comprehensive analysis provides the basis for decisions regarding the use of Federal sand for future beach nourishment activities. Public Law 103-426, enacted 31 October 1994, allows the MMS to convey, on a noncompetitive basis, the rights to OCS sand, gravel, or shell resources for shore protection, beach or wetlands restoration projects, or for use in construction projects funded in whole or part or authorized by the federal government. Since the law was enacted, MMS has conveyed over 13 million cubic yards of sand to state, local, and federal entities (Table 1E.1).

STATE/FEDERAL COOPERATIVE SAND INVESTIGATIONS

A key strategy to ensure environmental protection, safe operations, and issue resolution for decisions on access to OCS marine mineral activities is the closely coordinated partnerships between the federal government, coastal states and local communities. The MMS presently has, or in the past

Table 1E.1 Cubic yards of OCS sand conveyed as of 6 December 2001.

STATE	LOCALITY	CUBIC YARDS CONVEYED
FLORIDA	Jacksonville (Duval County)	1,240,000
SOUTH CAROLINA	Myrtle Beach (Surfside)	150,000
VIRGINIA	Dam Neck Naval Facility	808,600
VIRGINIA	Sandbridge Beach	1,098,191
MARYLAND	Assateague National Seashore	134,000
FLORIDA	Brevard County	7,300,000
FLORIDA	Patrick Air Force Base	600,000
MARYLAND	Assateague Island	1,800,000

has had, cooperative projects with Alabama, Delaware, Florida, Maryland, New Jersey, North Carolina, South Carolina, Texas, Virginia, and Louisiana to identify OCS sources of beach nourishment sand for potential use in shore protection projects. These partnerships rely primarily on state geological surveys-in cooperation with other state and federal agencies-to identify the state's needs and propose suitable offshore areas for study. Figure 1E.1 shows the location of state/federal sand investigations to date.

To ensure that proposed offshore sand and gravel operations are undertaken in an environmentally sound manner, INTERMAR has, since 1992, diligently pursued the collection of environmental information. This has included the collection of information and participation in studies dealing with the harvesting of offshore sand and gravel as construction aggregate. As of mid-December 2001, total MMS Environmental Studies Program (ESP) dollars appropriated for marine mineral studies was approximately $6.6 million.

Two general categories of studies have been developed by INTERMAR and supported by MMS ESP funds:

- Generic studies to provide information relevant to all OCS sand and gravel operations and management. These studies examine the effects of particular types of dredging operations (beach nourishment and construction aggregate activities) on various aspects of the physical, chemical, and biological environments, and/or develop/recommend appropriate mitigation, laboratory modeling, or monitoring techniques to alleviate or prevent adverse environmental impacts in areas where limited biological/physical information is available prior to initiation of a lease or negotiated agreement.
- Site-specific biological/physical environmental studies in areas which the State/MMS Task Forces have identified as potential offshore sand borrow areas for beach and coastal restoration.

Figure 1E.1. Location of state/federal cooperative sand investigations environmental studies.

Taken together, the generic and site-specific studies provide a foundation on which the MMS can make sound environmental decisions relative to marine mineral development. The information is used to prepare environmental analyses to meet the requirements of current environmental laws and legislation and incorporate results, as appropriate in lease requirements for the dredging of OCS sand.

OBJECTIVES OF THE SITE-SPECIFIC BIOLOGICAL/PHYSICAL STUDIES

The individual ITM papers describe the conduct and results of several MMS-funded site-specific marine mineral studies conducted to-date. The following lists the general objectives of each of these efforts:

Biological Objectives

- Compile and synthesize existing oceanographic literature and data sets to develop an understanding of the baseline benthic ecological conditions within the identified offshore borrow areas.

- Conduct biological field data collection efforts to supplement those existing resources.
- Analyze the biological field data in conjunction with existing literature to characterize and evaluate the present infauna, epifauna, demersal fishes and sediment grain size in proposed borrow areas.
- Address the potential effects of offshore sand dredging on benthic communities including an analysis of the potential rate and success of recolonization following cessation of dredging.
- Develop a time schedule of environmental windows that best protects benthic and pelagic species from adverse environmental effects.
- Develop a document summarizing the above information to assist decision-makers in preparing an environmental analysis that meets the requirements of the National Environmental Policy Act.

Physical Objectives

- Examine the potential for alteration in the local wave field following dredging and the excavation of sand within the identified borrow sites.
- Explore the potential for increased wave action after dredging within the identified borrow sites and any resultant adverse localized changes in erosional patterns and longshore coastal transport which could result in significant losses of beach sand after renourishment.
- Examine the potential for changes in local sediment transport rates as a result of any offshore dredging.
- Examine the cumulative physical effects of multiple dredging events within the identified borrow sites.

GENERIC STUDIES AND ISSUES

In recent years, several important generic issues have come to the forefront that have prompted the MMS to conduct environmental studies. This includes the evaluation of the cumulative, long-term effects of offshore dredging, as well as the concept of regional management in areas where the long-term use of borrow sites is anticipated.

Effects of Multiple Extractions Within the Same Borrow Site

Multiple excavations of sand within an offshore borrow site can affect both wave heights and the direction of wave propagation. The existence of an offshore borrow site can cause waves to refract toward the shallower edges of the dredged area. This alteration to the wave field by a borrow area may change local sediment transport rates, where some areas may experience a reduction in longshore transport, while other areas may show an increase. Therefore, MMS funded a study to determine the potential physical impacts associated with multiple dredging events at several borrow sites located offshore the east coast of the U. S. The study was completed in November 2001.

Development of Biological and Physical Monitoring Protocols

In April 2000, the MMS awarded a contract to design/develop biological/physical monitoring templates to provide a mechanism which could be implemented to ensure that adverse impacts do not occur in areas where the long-term use of sand from offshore borrow sites is anticipated. The effort was completed in October 2001. A study, initiated in Fiscal Year 2002, will test out several of the protocols at Sandbridge Shoal, offshore Sandbridge Beach, Virginia.

Examination of Regional Management Strategies for Federal Offshore Borrow Areas Along the United States East and Gulf of Mexico Coasts

Now, in the early stages of resource utilization, is the time to establish the mechanisms for long-term management of federal OCS resources. MMS identified the need to formulate options and recommendations for including federal, state, and local governments and other stakeholders in an overall planning process to manage the federal offshore borrow sites in an environmentally responsible and cost-effective manner over the long term and initiated a study in fiscal year 2001 to examine the feasibility of a regional sand management approach to improve coordination among the relevant regional parties, organizations, and agencies with interest in the use of OCS sand resources for beach and coastal restoration. Objectives of any regional management scheme include demonstrated cost savings and value added benefits.

CONCLUSION

The MMS continues to work with coastal states in the Atlantic and Gulf of Mexico regions to identify potential sources of offshore sand for beach and coastal restoration efforts. The individual ITM papers describe in more detail the site-specific and generic studies which the agency has funded to provide information which can be used for lease decisions, as well as providing mechanisms to help protect the marine and coastal environments as offshore dredging activities take place in U.S. federal waters. Completed study reports, as well as progress reports for ongoing MMS studies, can be accessed on the web at: *http://www.mms.gov/intermar/environmentalstudiespage. htm.*

Mr. Drucker has served as a physical scientist/physical oceanographer since 1988 in MMS' International Activities and Marine Minerals Division (INTERMAR). His duties are to recommend and develop environmental studies in support of MMS's marine minerals program. As INTERMAR's environmental coordinator, Mr. Drucker develops statements of work for funded studies, oversees those studies as MMS Contracting Officer's Technical Representative, and ensures that all provisions of NEPA are carried out during the evaluation of prospective offshore dredging operations on the Federal OCS. He has a B.A. in geology and oceanography from the City University of New York and an M.S. in marine geology and physical oceanography from C. W. Post College of Long Island University.

SHIP SHOAL PHYSICAL DREDGING IMPACT STUDIES, OFFSHORE LOUISIANA

Dr. Gregory Stone
Louisiana State University

BACKGROUND

In an earlier MMS-funded project conducted by the PI, three numerical modeling objectives were undertaken: (1) to develop a numerical model of wave energy transformation and decay across the inner shelf encompassing Ship Shoal and the nearshore adjacent to the Isles Dernieres; (2) to develop a nearshore sediment transport model along the Isles Dernieres; and, (3) to quantify changes in (1) and (2) due to removal of various sediment quantities based on likely scenarios provided by MMS.

OBJECTIVES

The current project included three additional field measurement objectives: (1) to procure and fabricate an additional bottom-boundary layer instrumentation system; (2) to obtain direct field measurements of temporally- and spatially-varying directional wave spectra at two locations; and, (3) to obtain direct field measurements of bottom-boundary layer hydrodynamic processes and suspended sediment transport. All experiments were conducted at Ship Shoal.

DESCRIPTION

Instrumentation was deployed on the Louisiana inner shelf during two winter periods, between 24 November 1998 and 2 February 1999, and 9 February and 25 March 2000. The three instrumentation packages consisted of two types of frame-mounted systems, both of which included a self-contained data recorder module. System 1 was a unique multi-sensor package nicknamed WADMAS, which consisted of a Paroscientific pressure sensor, a sonar altimeter, and a vertical array of three co-located Marsh-McBirney electromagnetic current meters and Seapoint optical backscatter sensors (OBS's). This instrumentation enabled WADMAS to measure water level, directional wave parameters, and seabed elevation, as well as current velocity and suspended sediment concentration at heights of 20, 60, and 100 cm above the seabed. Systems 2 and 3 each consisted of a pressure sensor and a SonTek$_{TM}$ downward-looking Acoustic Doppler Velocimeter (ADV) that measured seabed elevation, relative particulate concentration and three-dimensional currents at an elevation of approximately 20 cm above the bed. During the first deployment, Systems 1 and 2 were deployed in approximately 8.5 m of water on the seaward side of Ship Shoal, while System 3 was deployed in about 7 m of water on the landward side. During the second deployment, Systems 1 and 3 were deployed in the same locations as previously, while System 2 was placed at a 3.5 m water depth in the middle of the Shoal. During each deployment and retrieval, divers collected sediment from the bed, and water samples from the water column, and observed and measured any visible bed forms. Data were then processed and analyzed using conventional methods found in the literature.

STUDY RESULTS AND SIGNIFICANT CONCLUSIONS

1. Hydrodynamic, bottom-boundary layer, and sedimentary processes on the Louisiana inner shelf during the winter are characterized by episodic variability, largely as a result of the quasi-periodic cycle of recurring extratropical storm passages in the region.

2. Extratropical storms are generally characterized by increases in wave height, near-bed orbital, and mean current speed, shear velocity, suspended sediment concentration, and sediment transport. Decreases in wave period and apparent bottom roughness are also apparent.

3. Despite these regularities, considerable variability between storms, as well as during storms themselves, is reflected in hydrodynamic, bottom-boundary layer, and sedimentary processes. During strong storms, some indices were several orders of magnitude greater than during fair weather, while during weak storms they were lower.

4. The following extratropical storm classification, consisting of two storm types, is proposed on the basis of their influence on the Louisiana inner shelf. Type 1 storms are characterized by weak southerly pre-frontal and strong northeasterly post-frontal winds that cause strong post-frontal responses including high, short-period, southerly waves, strong, southwesterly currents, and moderately high southwesterly sediment transport. Type 2 storms include periods of both strong southerly pre-frontal winds, which generate high, long-period northerly swell waves, and strong northerly post-frontal winds, which cause energetic southerly storm waves. Rotational, net southeasterly currents and high shear velocity occurs during both the pre- and post-frontal phases, while sediment transport occurs predominantly during the post-frontal phase, when it is southeasterly.

5. Local extratropical storms are apparently not the only cause of high-energy responses on the Louisiana inner shelf. Distant storms apparently cause high, long-period waves, accompanied by moderate rotational currents that can create high sediment transport.

6. Results suggest that resuspension and transport of bottom sediment may sometimes occur during winter fair weather conditions, although it has previously been considered unlikely.

7. Differences between the seaward and landward sides of Ship Shoal are apparent. Waves tend to be higher and longer in period on the seaward side, while mean currents are generally higher landward, where they are directed onshore, unlike the offshore site, where seaward currents predominated. It is apparent, therefore, that Ship Shoal exerts a significant influence on regional hydrodynamics, reducing wave energy and modulating current velocity.

8. The short-term evolution of Ship Shoal appears to be the result of a balance between fair weather influences, which cause erosion and landward migration, and winter storm influences (particularly Type 2 storms), which cause accretion and seaward migration.

Dr. Gregory W. Stone is a professor in the Coastal Studies Institute and Department of Oceanography and Coastal Sciences at Louisiana State University. He earned his doctorate at the University of Maryland where his doctoral research concentrated on the late Holocene evolution and morphosedimentarty dynamics of the northeast Gulf of Mexico coast. His current research interests are nearshore and inner shelf coastal processes and sediment transport during fair weather and severe storms conditions. He also directs a large coastal ocean observations system (Wave Current Surge Information System) off the Louisiana coast in which he and colleagues are further developing a computer and physical measurements workbench for numerical model skill assessment and development. Dr. Stone was named the ExxonMobil endowed Professor of Marine Geology at LSU in 1997. In 2002 he was awarded the James P. Morgan Distinguished Professor of Coastal Geology at LSU. He serves as scientific advisor to the National Park Service (Gulf Islands National Seashore) and as Deputy Editor-in-Chief of the Journal of Coastal Research. He has worked extensively on the impacts of large sand bodies of the Louisiana coast, a multi year program funded by MMS.

ENVIRONMENTAL SURVEY OF IDENTIFIED SAND RESOURCE AREAS OFFSHORE ALABAMA

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In recent years, there has been increasing interest in sand and gravel mining on the Outer Continental Shelf (OCS). Under the OCS Lands Act, the U.S. Minerals Management Service (MMS) is required to conduct studies to obtain information useful for environmental decisions regarding physical and biological effects of offshore sand mining. The inshore portion of the Alabama continental shelf, seaward of the federal-state OCS boundary and within the Exclusive Economic Zone (EEZ), encompasses the project study area (Figure 1E.2). The purpose of this study was to assist the MMS in assessing the potential impacts of dredging sand from the OCS offshore Alabama for beach replenishment. To this end, seven study objectives were identified:

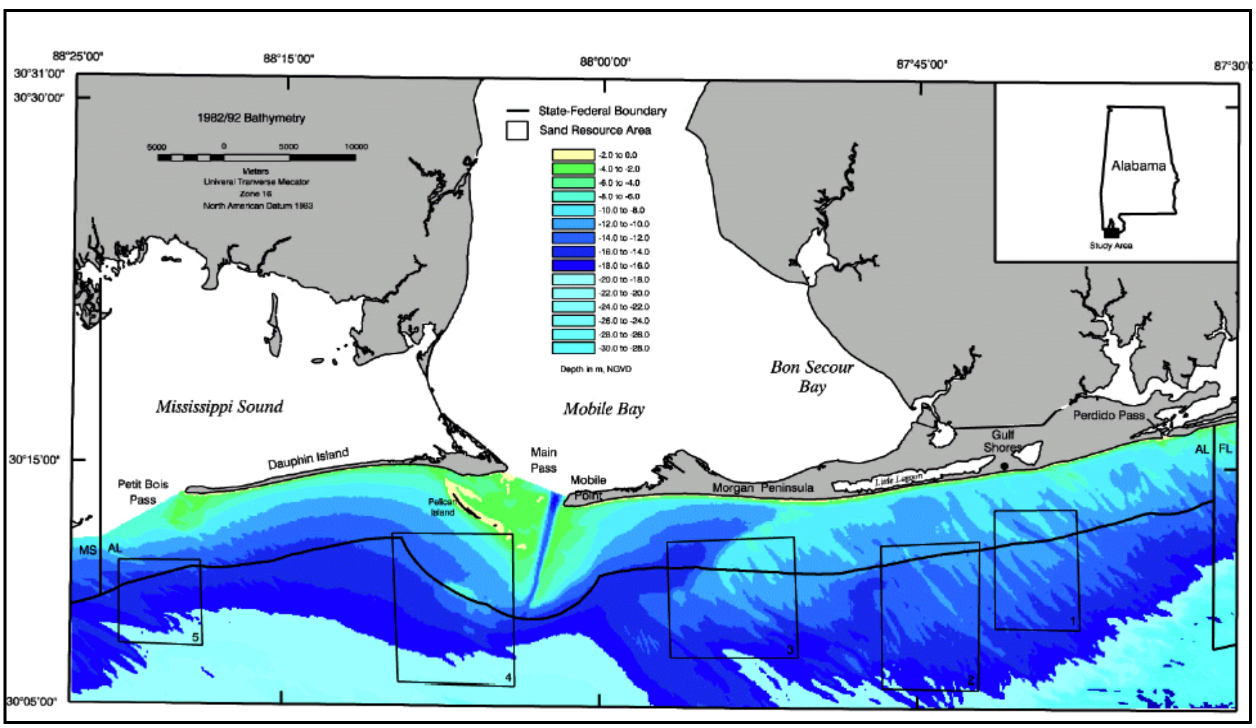

Figure 1E.2. Location of Alabama study area and potential sand resource areas.

- Compile and analyze existing oceanographic literature and data sets to develop an understanding of existing environmental conditions offshore Alabama and the ramifications of dredging operations at selected sand borrow sites;
- Design and conduct physical and biological field data collection efforts to characterize existing resources;
- Analyze the physical and biological field data sets to address basic environmental concerns regarding potential sand dredging operations;
- Use physical processes field data sets and wave climate simulations to predict wave transformation under natural conditions and in the presence of proposed dredging activities;
- Determine existing coastal and nearshore sediment transport patterns using historical data sets, and predict future changes resulting from proposed sand dredging operations;
- Evaluate the potential cumulative environmental effects of multiple dredging scenarios; and
- Develop a document summarizing the information generated to assist with decisions concerning preparation of an environmental assessment/impact statement to support a negotiated agreement.

Information presented in the Final Report will enable the MMS to identify ways in which dredging operations can be conducted to minimize or prevent long-term adverse impacts to the marine environment.

PHYSICAL PROCESSES

Potential sand extraction activities on the OCS may impact wave propagation patterns on the continental shelf and at the shoreline. In turn, sediment transport patterns may be altered so as to adversely impact beach erosion. The spectral wave transformation model REF/DIF S was used to evaluate changes in wave approach resulting from potential sand dredging activities. From previously collected data, prevalent seasonal conditions were used to generate representative seasonal wave climates. Seasonal wave conditions were selected to represent the differences in spectral wave approach and to investigate long-term average trends in wave and sediment transport patterns. In addition, a storm event (50-yr storm) was developed to investigate potential impacts during high energy conditions.

Wave modeling results indicate that minor changes will occur to wave fields under typical seasonal waves and sand extraction scenarios representing multiple beach nourishment events. Under existing seafloor conditions seaward of Dauphin Island, wave heights are relatively consistent along the shoreline while the eastern end of the island is protected from significant wave energy by Pelican Island and subaqueous shoals associated with the ebb delta. Several areas of wave energy focusing were identified from the Dauphin Island simulations, including those associated with the Mobile Outer Mound disposal site, which concentrates wave energy near Pelican Island during most seasons. Areas of wave energy concentration along Morgan Peninsula are primarily caused by southwest-oriented shoals on the continental shelf. For the 50-yr storm simulation, wave patterns are similar to normal seasonal results. An increase in wave height is significant in many areas where wave energy concentration occurs. For example, the Mobile Outer Mound disposal site concentrates 4.0- to 4.5-m storm wave heights on Pelican Island.

Similar wave modeling results were illustrated for post-dredging simulations. At Dauphin Island, maximum wave height differences for seasonal simulations were as high as 0.2 m. These maximum changes dissipate relatively rapidly as waves break and advance towards the coast. At Morgan Peninsula, maximum wave height differences were slightly larger due to borrow site sizes and orientations, as well as their proximity to the shoreline. However, wave energy is dissipated as waves propagate toward the shoreline, and increases in wave height of 0.1 m or less are observed at the potential impact areas along the coast. During storm wave conditions, wave heights are modified between 1.5 and 2.0 m, suggesting potentially significant changes. However, for all sand resource sites, a significant amount of storm wave energy dissipates before waves reach the coast. Overall, the physical environmental impact caused by offshore sand extraction during seasonal simulations is minimal.

Throughout the study area, currents were predominantly parallel to shelf depth contours and driven by wind stress. Winds were shown to produce an approximate five-fold increase in current speed, with order 10 cm/sec currents during mild wind conditions to order 50 cm/sec during strong wind conditions. Frictional effects on the continental shelf modified currents as well; currents were strongest in the surface layer and weaker along the bottom and nearshore boundary areas. Major bathymetric and shoreline features, for example, the ebb-tidal shoals encompassing Pelican Island and vicinity at the western margin of Main Pass, were shown to modify predominant flow directions, and provide turning points that signaled major shifts in large-scale circulation patterns. Less significant bathymetric features, such as the dredged material disposal mound located at Sand Resource Area 4 or shore-oblique shoals prevalent in Areas 1 and 2, were found to have little effect on large-scale circulation. No direct observations of currents were obtained near Sand Resource Area 3 immediately east of Mobile Bay.

Current measurements and analyses and wave modeling provided baseline information on coastal processes impacting beach environments under existing conditions and with respect to proposed sand mining activities for beach nourishment. Ultimately, the most important data set for understanding physical processes impacts from offshore sand extraction is changes in sediment transport dynamics resulting from potential sand extraction scenarios relative to existing conditions.

Three independent sediment transport analyses were completed to evaluate impacts due to offshore sand dredging. First, historical sediment transport trends were quantified to document regional, long-term sediment movement throughout the study area using historical bathymetry.data sets. Second, sediment transport patterns at proposed offshore borrow sites were evaluated using wave modeling results and current measurements. Third, nearshore currents and sediment transport were modeled using wave modeling output to document potential impacts to beach erosion and accretion. All three methods were compared for evaluating consistency of measurements relative to predictions, and potential impacts were identified.

Historical Sediment Transport Patterns

Regional geomorphic changes between 1917/20 and 1982/91 were documented for assessing long-term, coastal sediment transport dynamics. Although these data do not provide information on the potential impacts of sand dredging from proposed borrow sites, they do provide a means of calibrating predictive sediment transport models relative to infilling rates at borrow sites and longshore sand transport.

A comparison of erosion and deposition volumes at proposed borrow sites provided a method for quantifying sediment transport rates (or borrow site infilling rates). For borrow sites in Sand Resource Areas 1, 2, and 3, infilling rates ranged from about 9,000 to 34,000 m^3/yr. This compared well with sediment transport predictions made near borrow sites using wave model output and currents measurements (13,000 to 43,000 m^3/yr). For Sand Resource Area 4, net deposition at a rate of about 65,000 m^3/yr recorded the influence of sediment input from Mobile Bay and local transport processes.

The longshore sand transport rate for Morgan Peninsula was determined by comparing cells of erosion and accretion in the littoral zone between Perdido Pass and Main Pass (Mobile Bay entrance) in a sediment budget formulation. The transport rate for that portion of the study area was determined to be approximately 106,000 m^3/yr to the west. Net transport rates determined via sediment transport modeling ranged from about 50,000 to 150,000 m^3/yr. These rates compare well and provide a measured level of confidence in wave and sediment transport modeling predictions relative to impacts associated with dredging from proposed borrow sites.

Sediment Transport at Potential Borrow Sites

In addition to predicted modifications to waves, potential sand dredging at offshore borrow sites results in minor changes to sediment transport in and around the sites. Modification to bathymetry caused by sand dredging influences local hydrodynamic and sediment transport processes, but areas adjacent to the borrow site do not experience dramatic changes in wave and transport characteristics.

Initially, sediment transport at borrow sites will experience mild changes after sand dredging activities. After several years of seasonal and storm activity, sediment will be deposited at the borrow sites, eventually re-establishing pre-dredging conditions. Given the water depths at the proposed borrow sites, it is expected that minimal impacts will occur during sediment infilling of the borrow site. The pre- and post-dredging differences will be reduced as sediment infills the borrow site, and wave and resulting sediment transport will steadily return to pre-dredging conditions.

Sediment that replaces the dredged material will fluctuate based on location, time of dredging, and storm characteristics following dredging episodes. Borrow sites at Sand Resource Areas 1, 2, and 3 are expected to fill with the same material that was excavated. The sediment type in this region is consistent, high-quality, and compatible for beach nourishment. The potential borrow site at Sand Resource Area 4, however, will likely be filled with fine sediment (i.e., fine sand to clay) exiting Mobile Bay by natural processes or human activities (maintenance channel dredging and disposal). Because the potential transport rate plus sediment flux from Mobile Bay is substantially greater than shelf transport rates alone, the borrow site in Sand Resource Area 4 will fill faster than other borrow sites, limiting the likelihood for multiple dredging events from the same area.

Nearshore Sediment Transport Modeling

The potential effects of offshore sand dredging on nearshore sediment transport are of interest because dredged holes can intensify wave heights at the shoreline and create zones of erosion. Therefore, numerical techniques were developed to use nearshore wave modeling results to evaluate beach erosion and accretion.

Sand dredging in Resource Areas 1, 2, and 3 potentially causes a slight change in sand transport along the beach. Due to naturally higher sand transport rates at the eastern end of coastal Alabama, the magnitude of impacts associated with Sand Resource Areas 1 and 2 appear to be higher than those associated with Sand Resource Area 3. For all three sand resource sites, the maximum variation in annual transport rate along the beach landward of the site is approximately 8 to 10% of the existing value. However, the increase or decrease in longshore sand transport rates associated with each potential resource area amounts to approximately 1 to 2% of the longshore sand movement distributed over a 10 km stretch of shoreline.

The potential impacts of dredging Sand Resource Area 4 on beach sand transport rates are insignificant in relation to Sand Resource Areas 1, 2, and 3. Average annual conditions indicate a relatively high percentage change in transport rates along the eastern portion of Dauphin Island; however, the existing alongshore transport is almost non-existent at this location. The net effect of dredging Sand Resource Area 4 would direct a greater percentage of beach sand transport to the east, with a maximum increase of approximately 8,000 m 3 /yr.

Overall, the potential impacts of offshore sand dredging throughout coastal Alabama appear to be minimal relative to offshore and beach sand transport patterns. However, for specific project requirements, additional data should be collected to determine the nature and extent of potential impacts.

BENTHIC ENVIRONMENT

Results of the biological field surveys in the five sand resource areas agreed well with previous descriptions of bottom-dwelling organisms residing in shallow waters off the Alabama coast. Seafloor communities surveyed in the five sand resource areas consisted of members of the major invertebrate (for example, worms, crabs, and clams) and vertebrate (for example, fishes associated with the seafloor) groups that are commonly found in the study region. Temporal differences were apparent from the biological field surveys. The abundance of organisms living in the seafloor was substantially higher during the May survey than was observed in December. Potential effects to bottom-dwelling organisms from dredging will result from sediment removal, suspension/dispersion, and deposition. Potential effects are expected to be short-term and localized. Temporal and recruitment patterns indicate that removal of sand between late fall and early spring would result in less stress on benthic populations. Early-stage succession will begin within days of sand removal through settlement of young recruits, primarily worms and clams.

Recolonization of Areas 1, 2, and 3 east of Mobile Bay should occur in a timely manner and without persistence of transitional assemblages. Infaunal assemblages that typically inhabit the eastern portion of the study area should become reestablished within 2 years. Area 4 infaunal assemblages can be expected to recover more quickly than those in the eastern areas. Because of the physical environmental characteristics of Area 4, especially outflow of fine sediment (silts and organics) from Mobile Bay, existing assemblages are comprised of species that colonize disturbed habitats. Infaunal assemblages that inhabit the western study areas.would therefore become reestablished relatively rapidly, probably within 12 to 18 months. Given that the expected beach replenishment interval is on the order of ten years, and that the expected recovery time of the affected benthic community after sand removal is anticipated to be much less than that, the potential for significant cumulative benthic impacts is remote.

PELAGIC ENVIRONMENT

Based on existing information, potential effects from offshore dredging could occur to migrating fish populations. Dredging effects on most zooplankton (microscopic aquatic animals) from entrainment and turbidity should be minimal due to the high variability of populations in space and time. If Area 4 is used as a sand source, summer and fall months could be considered to avoid dredging when shrimp and blue crab larvae are most prevalent, but only if additional data become available to determine the extent of impacts and justify the restriction. Dredging is unlikely to significantly affect squid populations in the vicinity of the sand resource areas. Although entrainment, attraction, and turbidity could occur from dredging, quantitative data are lacking to support the use of an environmental window for pelagic fishes.

The main potential effect of dredging on sea turtles is physical injury or death caused by the suction and/or cutting action of the dredge head. No significant effects on turtles are expected from turbidity, low oxygen levels, or noise. Loggerheads are expected to be the most abundant turtle in the project area. Increased numbers of loggerhead turtles may be expected during the nesting season, which extends from 1 May through 30 November. A schedule that avoids the loggerhead nesting season also would avoid potential impacts to occasional nesting green and leatherback turtles. Hawksbill and Kemp’s Ridley turtles do not nest anywhere near the project area. It is not known whether sea turtles are likely to be resting in bottom sediments of the project area during winter. Consequently, there is insufficient information to determine whether seasonal restrictions on dredging during winter months would be appropriate.

The two marine mammals most likely to be found in and near the project area are the Atlantic spotted dolphin and the bottlenose dolphin. There is no strong seasonal pattern in abundance for either species that would provide an appropriate basis for seasonal restrictions on the project. In addition, the likelihood of significant impact from physical injury, turbidity, or noise is low even if these animals are present.

CONCLUSIONS

Minimal physical environmental impacts due to potential sand dredging operations have been identified through wave and sediment transport simulations. Under normal wave conditions, the maximum change in sand transport dynamics is about 5% of existing conditions. Because wave and sediment transport predictions are only reliable to within about ±35% (Rosati and Kraus 1991), predicted changes are not deemed significant. Although changes during storm conditions illustrate greater variation, the ability of models to predict storm wave transformation and resultant sediment transport is less certain. Because minimal impacts were documented to wave and sediment transport dynamics, additional data may be required for a specific sand dredging scenario to determine the extent of impacts.

The data collected, analyses performed, and simulations conducted for this study indicate that proposed sand dredging at sites evaluated on the OCS should have minimal environmental impact on water and sediment dynamics and biological communities. Short-term impacts to benthic communities are expected due to the physical removal of borrow material, but the potential for significant long-term and additive benthic impacts is remote. Additionally, no cumulative effects to any of the pelagic groups are expected from potential sand dredging operations.

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Rosati, J.D. and N.C. Kraus. 1991. Practical Considerations in Longshore Transport Calculations. CETN II-24, U.S. Army Engineer Waterways Experiment Station, Coastal and Hydraulics Laboratory, Vicksburg, MS. 6 pp.

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Dr. Mark Byrnes is a senior coastal scientist and principal at Applied Coastal Research and Engineering, Inc. (Applied Coastal). He received a Ph.D. in oceanography from Old Dominion University in 1988. For the past 16 years, he has been a principal investigator/program manager on more than 50 coastal and nearshore process studies as a Research Scientist at the U.S. Army Corps Coastal and Hydraulics Laboratory (formerly the Coastal Engineering Research Center), a research professor in the Coastal Studies Institute at Louisiana State University, and a senior coastal scientist at Applied Coastal. Dr. Byrnes' expertise includes coastal processes analyses, sediment transport dynamics, coastal erosion analyses (shoreline and bathymetry change), offshore sand resource assessments, sediment budget evaluations, shoreline restoration strategies, wetland loss delineation and classification, and geologic framework. He has also been responsible for managing and conducting numerous projects focused on coastal sedimentation processes and regional response of beaches, inlets, and estuaries to incident wave and current processes. He currently is conducting studies of wave and sediment transport processes, historical sediment transport pathways, and regional-scale sediment budgets along the East Florida coast between Cape Canaveral and Jupiter Inlet and at the Columbia River Littoral Cell, WA/OR.

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OFFSHORE MARYLAND/DELAWARE PHYSICAL/BIOLOGICAL IMPACTS STUDY

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BIOLOGICAL IMPACTS STUDY

The study area included the prominent shoal features on the inner continental shelf generally at approximately the 20 m isobath between Cape Henlopen, Delaware and Ocean City Inlet, Maryland. Most of the work was concentrated on Fenwick Shoal (Figure 1E.3). To assess benthic resources and to predict recolinization rates, we relied on data collected with a benthic grab, sediment profile camera, towed video sled, and metered beam trawl.

Benthic Habitats

Four basic types of benthic habitat were documented around Fenwick Shoal. Along the southwest region of the shoal finer sediments predominated with a diverse and numerous epifauna assemblage. Infauna which build tubes from fines, such as *Asabellide*s, were common. Along the southeast side of the shoal, coarser sediments predominated with large tubes of the polychaete *Diopatra cuprea* common in the shelly rippled sands. Along the northeast and northwest sides of the shoal coarser sediments were predomiant, but surface-oriented infauna and epifauna was sparse. On the crest of the shoal coarsest sediments were found with surface oriented biology and biological features absent. The crest was also a unique habitat for burrowing fish *Ammodytes* spp.

In summary, benthic habitat quality followed the topographic features associated with the shoal system and was divided into two general areas. The deeper regions surrounding the shoals and especially the valley between Fenwick and Weaver Shoals were more biologically active and productive than shoal crests and northwest faces. The shoal flanks were where fishes, filter feeding epibenthos, and sand dollars were more prevalent. There was a functional community shift between the subenvironments defined by depth and proximity to shoal crest.

Assessing Potential Sandmining Impacts on Biological Resources

Given a scenario that would have the surface sediments on top of Fenwick Shoal completely mined to a depth greater than 0.5m, the first order prediction for benthic community recolonization is based upon the neighboring community groups, species compositions, and proportional abundances. We would expect the nearby (within 1 km of the dredging boundary) communities to provide recruits. Review of within-group abundances the initital recolonizers should be from eight identifiable cluster subgroups. Table 1E.2 provides a summary of the recolonization potential of the dominant infaunal species. The full project report provides more specific information. The effect of seasonal sandmining, either spring/summer or fall/winter, on recolonization potential would be seen in

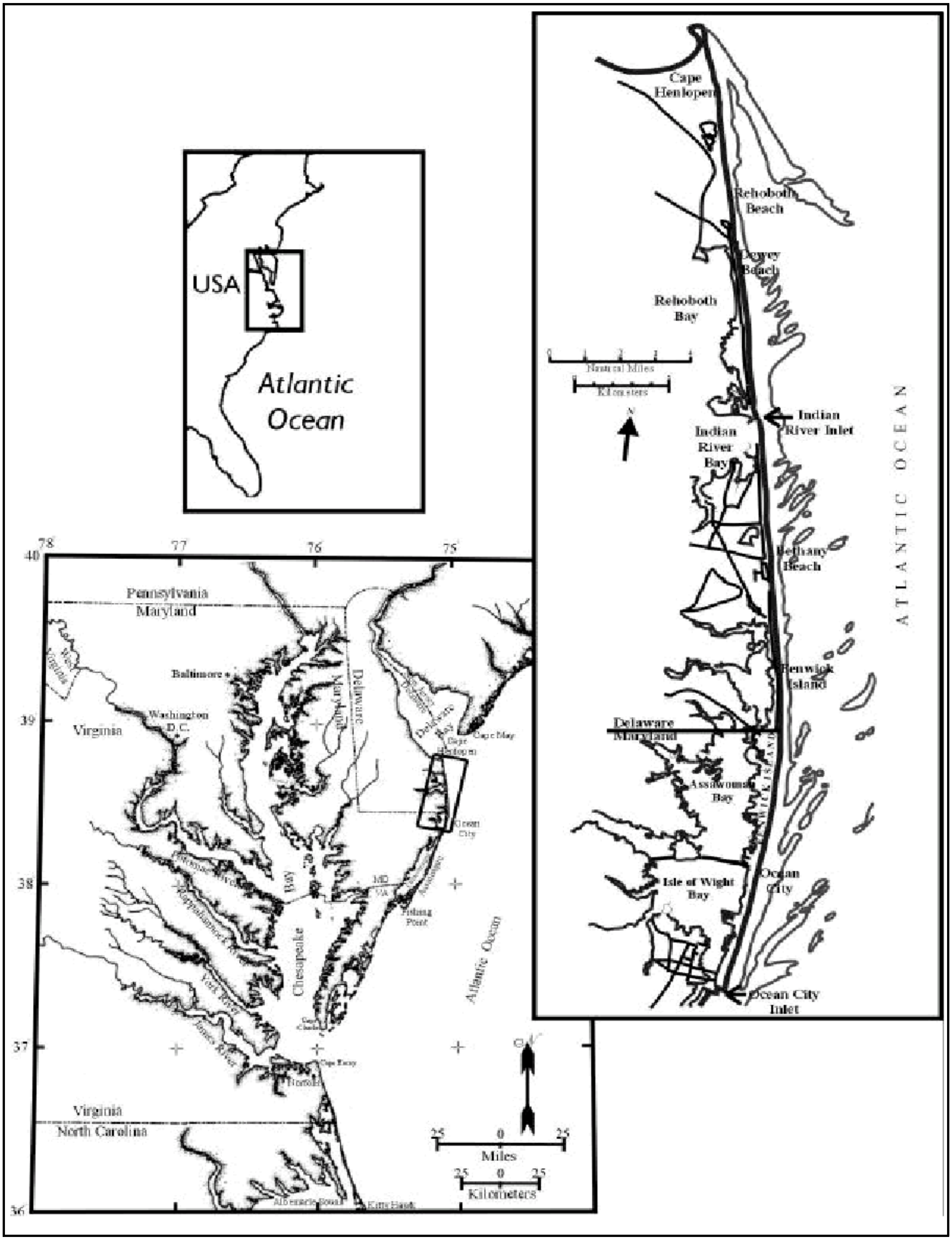

Figure 1E.3. Location map of the Maryland-Delaware study area.

Table 1E.2. Summary of life history attributes for dominant taxa from the inner continental shelf off Maryland and Delaware.

		Recruitment Potential		
Major Group	**Species Name**	**Year Round**	**Spring/ Summer**	**Fall/ Winter**
Cnidaria	**Anthozoa**	Poor	Poor	Poor
Nemertinea	**Nemertinea**	Good	Good	Good
Oligochaeta	**Oligochaeta**	Good	Good	Good
Polychaeta	**Aricidea spp.**	Poor	?	?
	Hemipodus roseus	Poor	?	?
	Hesionura elongata	Poor	?	?
	Brania wellfleetensis	Poor	Poor	Good
	Mediomastus ambiseta	Poor	Poor	Good
	Parapionosyllis longicirrata	Poor	Poor	Good
	Aphelochaeta sp.	Poor	Good	Poor
	Spiophanes bombyx	Poor	Good	Poor
	Streptosyllis pettiboneae	Poor	Good	Poor
	Asabellides oculata	Good	Good	Good
	Nephtys spp.	Good	Good	Good
	Protodorvillea kefersteini	Good	Good	Good
	Spio Setosa	Good	Good	Good
Gastropoda	**Busycon canaliculata**	Good	Good	Good
	Nassarius trivittatus	Good	Good	Good
Bivalvia	**Astarte spp.**	Poor	Poor	Good
	Mytilus edulis	Poor	Poor	Good
	Nucula proxima	Poor	Poor	Good
	Ensis directus	Good	Good	Good
	Spisula solidissima	Good	Good	Good
	Tellina agilis	Good	Good	Good
Cumacean	**Oxyurostylis smithi**	Good	Good	Good
	Pseudoleptocuma minor	Good	Good	Good
Isopoda	**Politolana concharum**	Good	Good	Good
Amphipoda	**Ampelisca spp.**	Poor	Good	Poor
	Byblis serrata	Poor	Good	Poor
	Protohaustorius wigleyi	Poor	Good	Poor
	Pseudounciola obliquua	Poor	Good	Poor
	Unciola irrorata	Poor	Good	Poor
Cephalochordata	**Branchiostoma caribaeum**	Good	Good	Good

species that have life history characteristics that would preclude their availability as recruits (Table 1E.2). Recolonization potential for the dominant.infauna was based on substrate preference, feeding mode, mobility, individual size, spawns/year, larval recruitment mode, spawning times, and life span. Overall, there would likely be slightly better larval and juvenile recruitment after spring/summer than after fall/winter sandmining activities. Recruitment by adults during any season would likely be regulated by factors, such as storms, that affect passive transport. Active transport of mobile species, such as epifaunal mysids or the decapod *Crangon septemspinosa*, may proceed more rapidly during warmer seasons but would also occur in winter.

The disturbance-recolonization scenario would be removal of the top meter of sand from Fenwick Shoal. An area approximately 7.7 km^2 would be mined. We assume that grain-size of the sediment surface in the mined area remains unchanged. Benthic infaunal community characterized by a specific cluster subgroups describes the existing communities on the shoal, which have infaunal densities of about 1,900 individuals/m^2 and a biomass of about 3.8 g wet weight/m^2. The acute impacts would be the loss of about 150 x 10^6 infaunal individuals and 300 kg of biomass. Recolonization would proceed after the project and would follow two trajectories depending on the season in which the mining operation ended. A spring/summer project end would favor crustaceans. After a single spring/summer recruitment season, some level of benthic resource value for demersal fishes would return. This assumes no change in surface sediment type, and resources could possibly be enhanced by any factors favorable to conditions for crustacean recruitment. A fall/winter project end would favor annelids. After a fall/winter recruitment event, benthic resource value would likely not be as high because annelids are not utilized by demersal feeders to the extent that crustaceans are. Should fining of surface sediments occur, annelids and bivalves would be favored, which in the long-term might reduce resource value for demersal fishes.

Minimizing Impacts to Biological Resources

To minimize impacts from sand mining activities, the project design and timing should ensure that biological assemblage that recolonizes a mined area resembles that present prior to mining. Total area removal of surficial substrates should be avoided by retaining small refuge patches (RP) to minimize alteration of community structure and function and to reduce potential effects upon trophically dependent fishes. Retaining RP's is analogous to the silvicultural practice of retaining seed trees for natural regeneration of harvested forests.

Impacts of sandmining on mobile fisheries resources also will be connected to the rate and success of benthic recolonization. Many fishes utilize the shallow continental shelf as a nursery ground. Juvenile demersal fishes overwhelmingly feed on epifaunal and infaunal crustaceans. Any aspect of sandmining that would enhance the production of crustaceans would likely also improve habitat quality for demersal fishes.

Although there are potentially adverse consequences to sand mining in the offshore regions of Delaware and Maryland, they likely are not substantial, and actions can be taken to eliminate or minimize them. Obviously, dredging the bottom destroys all the organisms that had lived within the dredged area, but the best sands for beach nourishment have a comparatively low resource value. The benthic fauna of those areas are likely to recolonize fairly rapidly especially if refuge patches

(RP) are left untouched within the otherwise dredged area. Care.should be taken to minimize disturbance of the substrate between the shoals that will be the targets for dredging because this is where the highest benthic productivity resides.

PHYSICAL IMPACTS STUDY

This report summarizes the possible impact on the oceanographic parameters of wave transformation, tidal currents, storm surge, and the associated bed shear stress that might be caused by the dredging at Fenwick Shoal and Isle of Wight on the continental shelf of Maryland and Delaware.

Using high quality, raw bathymetric data, we developed a computing domain of 44.970 km x 67.560 km for studying the possible changes on wave transformation and tidal currents. This grid is large enough to use wave data measured at a NOAA offshore wave station and the grid cell size (30 m x 60 m) is small enough to show the effect of wave diffraction. We considered two possible scenarios for dredging. The first scenario is dredging 2 x 10^6 m^3 of sand from each shoal. The second scenario is removing a total of 2.4 x 10^7 m^3 of sand from the two shoals.

A total of 13 years' wave measurements from NDBC buoy station 44009, about 45 km offshore at the Ocean City, were used to analyze the possible choices of wave heights, periods, and directions for analysis of possible alteration due to the modeled dredging. Two near shore wave stations, MD001 and MD002, provided about four years' measurements. The measured waves at these two near-shore stations are almost identical. Using data from the offshore and nearshore stations allows verification of the wave transformation model.

Sixty wave conditions are selected for analysis. These wave conditions include four wave heights (2 m, 4 m, 6 m, and 8 m), five wave periods (10 s, 12 s, 14 s, 16 s, and 20 s), and four wave directions (ENE, E, ESE, SE). Wave energy loss caused by bottom friction is not a linear process, and thus, all four wave heights have to be included in the calculations. REF/DIF-1 was selected from the suite of wave models because of the excellent accuracy, computing efficiency, and the selection of checking each wave component. REF/DIF-1 was calibrated using one-month wave measurements (1 to 30 November 1997) from stations 44009 and MD001.

The calculated wave height distributions for the original bathymetry indicate that waves coming from the east have a tendency to converge near the southern limit of Ocean City. The high wave energy (for all waves that come from the east) may be responsible for the shore line retreat along the southern portion of Ocean City. Near the Maryland-Delaware border, there is an area of extensive wave height attenuation because of wave shoaling and breaking after the waves pass the Fenwick Shoal. The relatively small breaking wave heights along this section of shore may explain the relatively stable shoreline.

This study indicates that the possible impact from the one-time dredging of a total of 4 x 10^6 m^3 of sand from Fenwick and Isle of Wight Shoals is negligibly small in terms of potential modification to wave transformation. For the cumulative dredging at Fenwick Shoal and Isle of Wight Shoal of a total of 2.4 x 10^7 m^3 of sand, this study suggests that the major change of wave height is between the dredging site and the shore line. Local wave height can increase by as.much as a factor of two. The change in breaking wave height, however, is not so obvious except for the clear reduction of breaking wave height modulation (BHM) at the Maryland- Delaware border. The reduction of BHM at this location, however, is not necessarily a positive impact because it increases the breaking wave height at that location. As a consequence, more erosion and shoreline recession might occur. Otherwise, the probable impact is not significant.

The SLOSH model developed by NOAA (the standard model used by FEMA) was used to analyze the possible change of storm surge resulting from the modeled dredging. Tropical storms with an 86 mbar central pressure drop and 15-mile maximum wind radius (category 4 storm) were used to simulate the coastal storm surges. Two orthogonal tracks, one across- and one along-shore were modeled. The maximum change in storm surges are about 0.1 cm which is negligible compared to the maximum surge (around 3 m).

The maximum near-bed tidal current is weak, on the order of 5 cm/s except at the shoals, where current velocity increases to around 8 cm/s. The postulated cumulative dredging at the shoals would reduce the maximum near-bed tidal current velocity (around 10%, *i*.e., 1 cm/s). Immediately on the leeward side of the shoal, dredging would increase the tidal velocity by as much as 10%. These results indicate a negligible impact and suggest that in future studies the impact on current and storm surge can be excluded.

The Grant-Madsen-Glenn (GMG) model was used to study the possible change of bed shear stress caused by dredging. The results indicate that the change of bottom stress distribution is not substantial.

Additional Studies

The study of the potential biological and physical impacts of mining sand offshore of Maryland and Delaware is part of a larger survey. In addition to the two facets discussed above, the more inclusive project included parts on the transitory species of vertebrate nekton, the reproductive finfish and icthyoplankton, and shoreline change. The reference for the full project report, which contains substantially more specific information and references, is listed below.

REFERENCE

Environmental Survey of Potential Sand Resource Sites Offshore Maryland and Delaware. OCS Study 2000-055. Virginia Institute of Marine Science, Gloucester Point, VA 23062.

Dr. Jerome Peng-Yea Maa is an associate professor in the Department of Physical Sciences, School of Marine Science at Virginia Institute of Marine Science, College of William and Mary in Gloucester Point, Virginia. He received his B.S. and M.S. from National Cheng-Kung University and his Ph.D. the University of Florida.

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ENVIRONMENTAL SURVEY OF POTENTIAL SAND RESOURCE SITES: OFFSHORE NEW JERSEY

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Dr. Richard M. Hammer
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Dr. Tim D. Thibaut
Barry A. Vittor & Associates, Inc.

There has been increasing interest in sand and gravel mining on the Outer Continental Shelf (OCS). Under the OCS Lands Act, the U.S. Minerals Management Service (MMS) is required to conduct studies to obtain information useful for environmental decisions. The primary purpose of this study was to address environmental concerns raised by the potential for dredging sand from the OCS for beach replenishment. Primary concerns focused on physical and biological components of the environment at eight proposed sand resource areas (Figure 1E.4). Physical processes and biological data were analyzed to assess the potential impacts of offshore dredging activities within the study area to minimize or preclude long-term adverse environmental impacts at potential borrow sites and along the coastline landward of borrow sites. Five primary study elements were conducted to 1) evaluate potential modifications to waves due to offshore sand dredging; 2) evaluate the potential impact of offshore dredging on natural sediment transport patterns at borrow sites and along the shoreline; 3) characterize benthic ecological conditions in and around the sand borrow areas by sampling infauna, epifauna, and demersal fishes; 4) assess the potential effects of offshore sand dredging on benthic organisms; and 5) develop a schedule of best and worst times for offshore sand dredging in relation to transitory pelagic species.

PHYSICAL PROCESSES

Potentially rapid and significant changes in bathymetry due to sand extraction on the OCS may have substantial impact on wave propagation patterns on the continental shelf and at the shoreline. In turn, sediment transport patterns may be altered so as to adversely impact beach erosion. The spectral wave transformation model REF/DIF S was used to evaluate changes in wave approach resulting from potential sand dredging activities. The region offshore of Townsends and Corsons Inlets has a relatively consistent longshore wave height distribution. However, several areas of wave convergence and divergence were caused by the shoals surrounding Sand Resource Areas A1 and A2. Offshore Little Egg and Brigantine Inlets (Area G), wave transformation is influenced by numerous linear ridges. Increased wave heights appear most frequently near Brigantine Inlet. The area south of Barnegat Inlet experiences mild shoreline retreat and a consistent wave height distribution along the shoreline. Shoals and depressions south of Area C1, as well as offshore linear ridges to the north, can produce significant wave propagation changes within the modeling domain. The area seaward of northern Barnegat Bay (Area F) also experiences wave height changes produced by offshore shoals and depressions. Consistent wave focusing is observed from the shoal

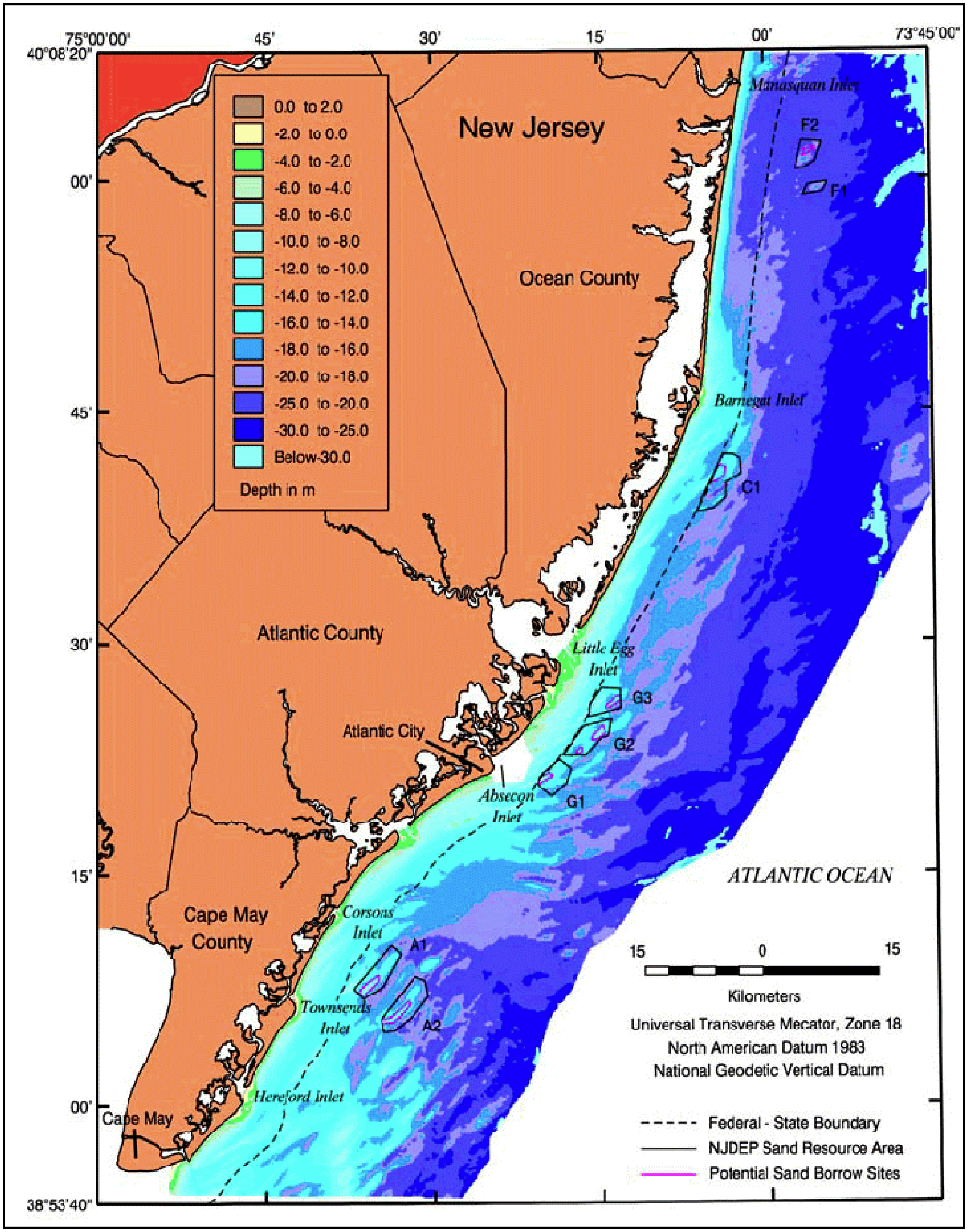

Figure 1E.4. Location diagram illustrating offshore sand resource areas, potential sand borrow sites, and the federal-state boundary relative to the 1934/77 bathymetry.

within Area F2, as well as the shoals to the south and southeast of F2. Wave energy focused by these features may impact regions just south of Manasquan Inlet, depending on approach direction.

Differences in wave height between existing conditions and dredging scenarios offshore New Jersey indicate maximum wave height changes ranging from 0.1 to 0.25 m (7 to 16% of the initial wave height). The magnitude of modifications increases as the magnitude of waves increases or when the orientation of potential borrow sites aligns with waves to produce maximum impact (e.g., southeast approach at Areas A1 and A2). In Areas A and G, maximum wave height changes dissipate relatively quickly as waves advance towards the coast and break. In Areas C and F, maximum changes do not dissipate as readily. At potential impact areas along the coast, wave height changes average ±0.13, ±0.15, ±0.11, and ±0.10 m for Areas A, G, C, and F, respectively. These modifications represent changes of approximately ±3 to 15% when compared with wave heights for existing conditions. Overall, there is minimal to no impact to waves caused by potential offshore dredging during normal conditions..Analysis of current patterns in the study area suggests sand mining will have negligible impact on large-scale shelf circulation. Measurement of bottom currents offshore New Jersey (seaward of Little Egg Inlet) throughout an approximate two-year period (1993 to 1995) revealed considerable variability in flow speed and direction. Mean flow was to the southwest along the inner shelf bathymetric contours. Strongest flow was observed in the along-shelf direction, with peak velocities of nearly 50 cm/sec (1 knot) to the south; maximum northward currents reached 37 cm/sec. Flow reversals were noted frequently. In the cross-shelf direction, mean flow was oriented onshore, consistent with upwelling processes that push bottom waters up onto the shelf. Maximum cross-shelf flow was 31 cm/sec (directed onshore); minimum flow was -13 cm/sec (directed offshore). Cross-shelf bottom currents were affected most significantly by semi-diurnal tides, with a mean onshore flow.

Regional geomorphic changes for the period 1843/91 to 1934/77 were analyzed to assess long-term, net coastal sediment dynamics. These data provide a means of calibrating predictive sediment transport models relative to infilling rates at borrow sites and longshore sand transport. The predominant direction of transport throughout the study area is north to south. Southern Long Beach Island (north of Little Egg Inlet) and southern Island Beach (north of Barnegat Inlet) have migrated to the south at a rate of about 14 m/yr since 1839/42. The ebb-tidal shoals at all inlets in the study area are skewed to the south, and channels are aligned in a northwest-southeast direction. Alternating bands of erosion and accretion on the continental shelf east of the federal-state boundary illustrate relatively slow but steady reworking of the upper shelf surface as sand ridges migrate from north to south. The process by which this is occurring at Areas G1, G2, and G3 suggests that a borrow site in this region would fill with sand transported from an adjacent site at a rate of about 62,000 to 125,000 m^3 /yr. At Areas A1 and A2, the potential offshore sand transport rate increases to 160,000 to 200,000 m^3 /yr. Net longshore transport rates determined from seafloor changes in the littoral zone between Little Egg Inlet and the beach south of Hereford Inlet indicate an increasing transport rate to the south from about 70,000 m^3 /yr south of Little Egg Inlet to 190,000 to 230,000 m^3 /yr at Townsends and Hereford Inlets.

Given the water depths at the borrow sites, it is expected that minimal impacts to waves and regional sediment transport processes will occur during infilling. Based on offshore waves and currents, calculated infilling rates range from a minimum of 28 m^3 /day (about 10,000 m^3 /yr; Area F2) to a high of 450 m^3 /day (about 164,000 m^3 /yr; Area A1). Predicted nearshore sediment transport rates are slightly lower than those determined from historical data sets, but they are within the same order of magnitude. Calculated longshore sand transport rates vary from 60,000 m^3 /yr south of Little Egg Inlet to 300,000 m^3 /yr near Townsends Inlet. Sand dredging impacts for Areas A1 and A2 illustrate relatively minor changes in longshore sand transport (7% relative to existing conditions) associated with proposed offshore dredging. For borrow sites in Areas G2 and G3, the maximum variation in annual longshore sand transport rate is approximately 9% of existing conditions. However, for borrow sites in Areas C1 and F2, maximum variation in annual longshore sand transport rate is approximately 17% of the existing value. Although minimal physical environmental impacts from potential sand dredging operations have been identified through wave and sediment transport simulations, predicted changes are not deemed significant because wave and sediment transport predictions are only reliable to within about ±35% (Rosati and Kraus 1991).

BENTHIC AND PELAGIC ENVIRONMENT

Results of the biological field surveys in the sand resource areas agreed well with previous descriptions of benthic assemblages associated with shallow shelf habitats offshore New Jersey. Benthic assemblages surveyed consisted of members of the major invertebrate groups commonly found in the study area. Numerically dominant infaunal groups included numerous crustaceans, echinoderms, molluscans, and polychaetes, while epifaunal taxa consisted primarily of decapod crustaceans, sand dollars, and moon snails. Potential benthic effects from dredging would result from sediment removal, suspension/ dispersion, and deposition. Primary effects to infaunal populations would be through removal of individuals along with sediments. Effects are expected to be short-term and localized. Temporal and recruitment patterns indicate that removal of sand between late fall and early spring would result in less stress on benthic populations. While community composition may differ for a period of time after the last dredging, the infaunal assemblage type that exists in mined areas should be similar to naturally occurring assemblages in the study area, particularly those assemblages inhabiting inter-ridge troughs. Based on previous observations of infaunal reestablishment in dredged areas, the infaunal community most likely would become reestablished within two years, exhibiting levels of infaunal abundance, diversity, and composition comparable to nearby non-dredged areas.

Dredging should not present a significant problem for pelagic fishes offshore of New Jersey. Potential effects to fishes could occur through entrainment, attraction, and turbidity. Quantitative data are lacking to support use of an environmental window for pelagic fishes. The effect of dredging on Essential Fish Habitat (EFH) for managed species is expected to be minimal. No significant effects on turtles are expected from turbidity, anoxia, or noise. The main potential effect of dredging on sea turtles is physical injury or death caused by the suction and/or cutting action of the dredge head, so seasonal or other restrictions may be necessary. Potential effects to marine mammals could occur through physical injury, noise, and turbidity. Measures to minimize possible vessel interactions with endangered marine mammals may be appropriate. Zooplankton, squids, fishes, sea turtles, and marine mammals were groups in the pelagic environment considered to be potentially affected by offshore dredging. No cumulative effects to any of these groups are expected from multiple sand mining operations.

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http://www.oceanscience.net/mms_nj_ny/related_nj.htm

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COLLECTION OF ENVIRONMENTAL DATA WITHIN SAND RESOURCE AREAS OFFSHORE NORTH CAROLINA AND THE ENVIRONMENTAL IMPLICATIONS OF SAND REMOVAL FOR COASTAL AND BEACH RESTORATION

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Under the OCS Lands Act, the U.S. Minerals Management Service (MMS) is required to conduct studies to obtain information useful for environmental decisions regarding physical and biological effects of offshore sand mining. The inshore portion of the North Carolina continental shelf, seaward of the federal-state OCS boundary offshore Dare County and within the Exclusive Economic Zone (EEZ), encompasses the project study area (Figure 1E.5). The purpose of this study was to assist the MMS in assessing the potential impacts of dredging sand from the OCS offshore North Carolina for beach replenishment. Physical processes and biological data were analyzed to assess the potential impacts of offshore dredging activities within the study area to minimize or preclude long-term adverse environmental impacts at potential borrow sites and along the coastline landward of borrow sites. Five primary study elements were conducted to 1) evaluate potential modifications to waves due to offshore sand dredging; 2) evaluate the potential impact of offshore dredging on natural sediment transport patterns at borrow sites and along the shoreline; 3) characterize benthic ecological conditions in and around the sand borrow areas by sampling infauna, epifauna, and demersal fishes; 4) assess the potential effects of offshore sand dredging on benthic organisms; and 5) develop a schedule of best and worst times for offshore sand dredging in relation to transitory pelagic species.

PHYSICAL PROCESSES

Potentially rapid and significant changes in bathymetry due to sand extraction on the OCS may have substantial impact on wave propagation patterns on the continental shelf and at the shoreline. In turn, sediment transport patterns may be altered so as to adversely impact beach erosion. Four potential sand resource areas were identified offshore North Carolina in Federal waters by the North Carolina Geological Survey and the U.S. Minerals Management Service, INTERMAR. Each site has specific geologic and geographic characteristics that make it more or less viable as a sand resource for specific segments of coast. In all cases, maximum shoal relief is on the order of 5 m, and average shoal relief is about 2 to 3 m. Although modern beach replenishment practice varies depending on geographic location and level of funding for the North Carolina coast, it is reasonable to expect multiple replenishment events over the next 50 years from the designated sand resource areas. As such, one shoal deposit was selected from each resource area based on geological characteristics. A maximum excavation depth was determined for each specific site. In Area 1, bathymetry data and

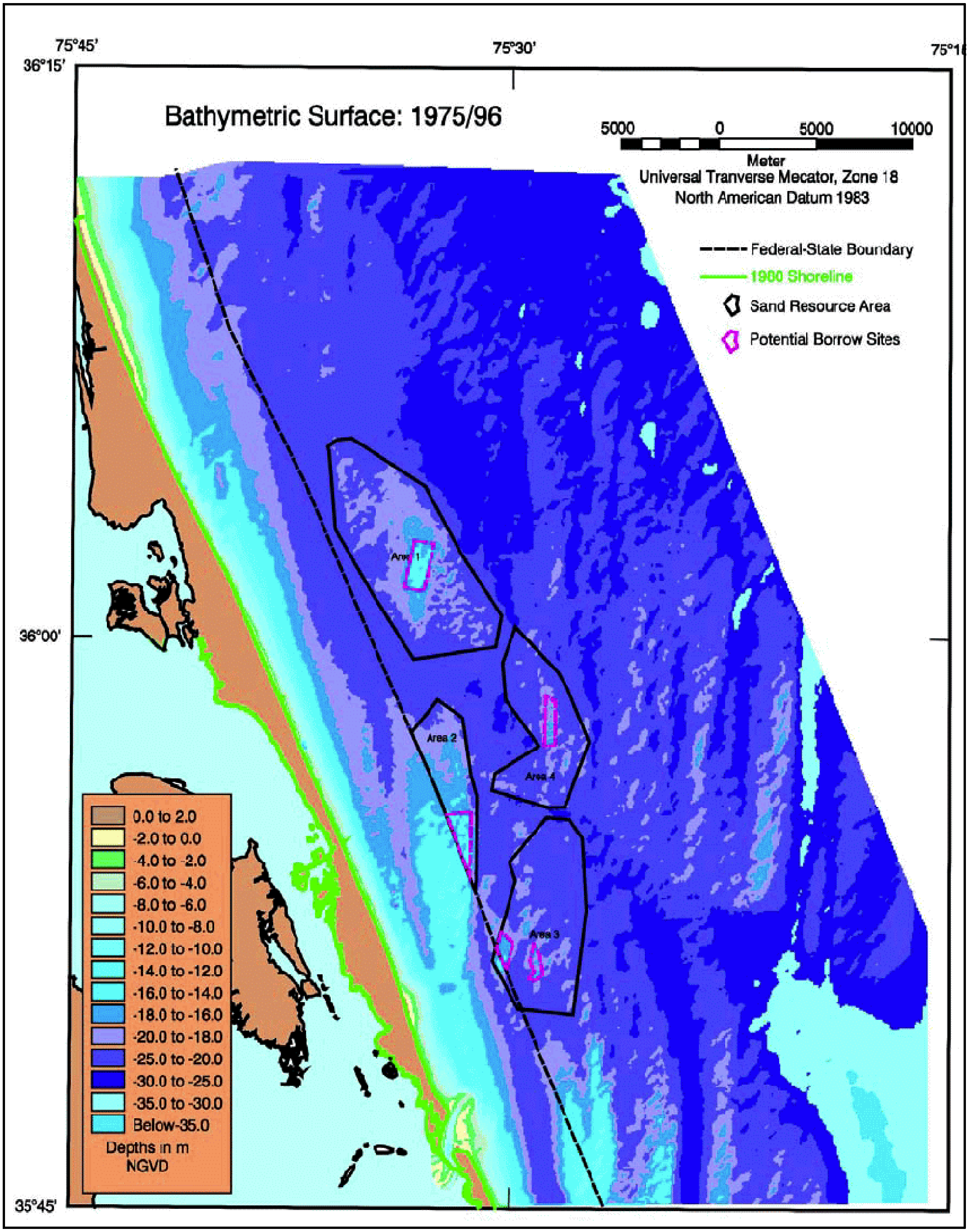

Figure 1E.5. Location diagram illustrating offshore sand resource areas, potential sand borrow sites, and the federal-state boundary relative to the 1975/96 bathymetry.

geological samples indicate a maximum excavation depth of 3 m, resulting in a 7.2 million cubic meter (MCM) extraction scenario; median grain diameter for the deposit is 0.41 mm. The selected borrow site in Area 2 can provide approximately 5.8 MCM of sand when excavated to a depth of 3 m. The borrow site for Area 3-west contains about 2.5 MCM of sand based on maximum excavation depth of 3 m, and the borrow site in Area 3-east contains about 1.4 MCM (2-m excavation depth). Finally, the potential sand borrow site in Area 4 contains 2.3 MCM of sand to a depth of 2 m.

The spectral wave transformation model STWAVE was used to evaluate changes in wave approach resulting from potential sand dredging activities. Wave conditions run in STWAVE were developed using a 20-year wave hindcast from the USACE Wave Information Study (WIS), for a station offshore of the investigated borrow sites. The same wave conditions were run for pre- and post-dredging conditions. Wave model output was then used to determine sediment transport potential along the entire shoreline for existing and post-dredging conditions. The alongshore variation in the.computed gradient of transport potential was compared to measured shoreline change to ensure that spectral wave modeling and associated longshore sediment transport potential could be used effectively to evaluate long-term alterations to the littoral system.

Existing conditions model results for the region offshore Dare County, NC and illustrate the impact of seafloor topography on the wave field as it propagates shoreward. For example, model output near the shoal in the vicinity of Borrow Area 1 indicates that wave heights behind the shoal are about 0.4 m greater than wave heights at the northern and southern limits of the shoal. The shoal refracts the wave field, causing a slight focusing of wave energy behind the feature. Because energy is conserved, the focusing of wave energy behind the shoal causes a reduction of energy at the northern and southern edges of the shoal, which is apparent by the reduced wave heights in these areas.

Output from post-dredging simulations show that wave heights within borrow sites are reduced for post-dredging scenarios. This effect is more pronounced in cases that have greater wave heights. The wave fields landward of proposed borrow sites are modified by refraction. As waves propagate across a borrow site (deeper water than the surrounding area), wave refraction will tend to bend waves away from the center of the excavation and toward the shallower edges. The net effect is to create a “shadow” zone of reduced wave energy immediately landward of the borrow site and a zone of increased wave energy updrift and downdrift of the borrow site. In the immediate vicinity of Borrow Site 2, for example, wave heights increased by a maximum of 0.05 m at the northern and southern edges of the borrow area and decreased by a maximum of 0.06 m behind the borrow area.

Circulation patterns observed at specific areas within the study region were evaluated within the context of potential offshore sand mining operations. Historical current records for data collected at the USACE Field Research Facility (FRF) in Duck, North Carolina were chosen for detailed analysis of current processes. Current measurements at the FRF locations throughout the approximate one-year period revealed temporal and spatial variability, but mean flow was southerly, approximately along the inner shelf bathymetric contours. Strongest flow was observed in the along-shelf direction, with peak velocities of nearly 150 cm/sec at the surface and 100 cm/sec near the seabed; maximum currents were directed down-shelf, or to the south. Maximum up-shelf (northward) currents occasionally reached 80 cm/sec at the surface. Up-shelf bottom currents never exceeded 40 cm/sec. Flow reversals, when the currents were directed toward the north then reversed to flow in a southerly direction, were noted frequently. In the cross-shelf direction, mean flow was oriented onshore at the surface, consistent with upwelling processes that push bottom waters up onto the shelf. Maximum across-shelf flow was 70 cm/sec (directed onshore) at the surface and 30 cm/sec (directed offshore) at the bottom. The counter flow of surface water and near-bottom currents provides evidence of a circulation cell due to upwelling.

Regional geomorphic changes for the period 1868/70 to 1975/96 were analyzed to assess long-term, net coastal sediment dynamics. These data provide a means of calibrating predictive sediment transport models relative to infilling rates at borrow sites and longshore sand transport. The predominant direction of transport throughout the study area is north to south. The ebb-tidal shoals at Oregon Inlet are skewed to the south, and the shoreline north of the inlet has migrated south greater that a kilometer throughout the historical record. Alternating bands of erosion and accretion on the continental shelf east of the federal-state boundary illustrate relatively slow but steady.reworking of the upper shelf surface as sand ridges migrate from north to south. The process by which this is occurring throughout the study area suggests that a borrow site in this region would fill with sand transported from an adjacent site at a rate of about 20,000 to 70,000 m^3 /yr. Net longshore transport rates determined from seafloor changes in the littoral zone just north of Oregon Inlet indicate a transport rate of about 150,000 to 200,000 m^3 /yr.

Given the water depths at the borrow sites, it is expected that minimal impacts to waves and regional sediment transport processes will occur during borrow site infilling. Based on offshore waves and currents, calculated infilling rates range from a minimum of 38,000 m^3 /yr (Areas 3-East and 4) to a high of 123,000 m^3 /yr (Area 2). Predicted nearshore sediment transport rates are slightly higher than those determined from historical data sets, but they are within the same order of magnitude. Potential net longshore sand transport rates vary from about 200,000 m^3 /yr to the north along the Dare County shoreline to about 400,000 m^3 /yr to the south just north of Oregon Inlet. Sand dredging impacts for for all borrow sites illustrate relatively minor changes in longshore sand transport (<5% relative to existing conditions) associated with proposed offshore dredging. Although minimal physical environmental impacts from potential sand dredging operations have been identified through wave and sediment transport simulations, predicted changes are not deemed significant because wave and sediment transport predictions are well within the temporal and spatial variability of sediment transport rates in the study area.

BENTHIC AND PELAGIC ENVIRONMENT

Results of the biological field surveys agree well with previous descriptions concerning benthic assemblages associated with shallow shelf habitats offshore North Carolina. Benthic assemblages surveyed from the sand resource areas consisted of members of the major invertebrate and vertebrate groups commonly found in the general area. Numerically dominant infaunal groups included numerous crustaceans, echinoderms, mollusks, and polychaetes, while epifaunal taxa consisted primarily of decapods, sea stars, and squid. Potential benthic effects from dredging will result from sediment removal, suspension/dispersion, and deposition. Effects on infaunal populations will occur primarily through removal of individuals along with sediments. Effects are expected to be short-term and localized. Temporal and recruitment patterns indicate that removal of sand between late fall and early spring would result in less stress on benthic populations than removal at other times during the year. While community composition may differ for a period of time after the last dredging, the infaunal assemblage type that exists in mined areas will be similar to naturally occurring assemblages in the study region, particularly those assemblages inhabiting inter-ridge troughs. Based on previous observations of infaunal reestablishment, and assuming that dredged sites do not create a sink for very fine sediments or result in hypoxic or anoxic conditions, the infaunal community in dredged sites most likely will become reestablished within two years, and will exhibit levels of infaunal abundance, diversity, and composition comparable to nearby non-dredged areas. Given that the expected beach replenishment interval is on the order of a decade, and that the expected recovery time of the affected benthic community after sand removal is anticipated to be much less than that, the potential for significant cumulative benthic impacts is remote.

Dredging should not present a significant problem for pelagic fishes offshore North Carolina. Potential effects to fishes could occur through entrainment, attraction, and.turbidity. If an environmental window is sought to protect pelagic fishes from dredging impacts, the spring to fall period would encompass the peak seasons for the economically important species. Quantitative data are lacking to support the use of an environmental window to lessen effects on pelagic fishes. Essential Fish Habitat (EFH) for several fish species (and life stages) overlap the four sand resource areas offshore North Carolina. The region encompassed by the four sand resource areas is very small relative to the mapped EFH characteristics. For this reason, the effect of dredging on EFH for the managed species is expected to be minimal. The main potential effect of dredging on sea turtles is physical injury or death caused by the suction and/or cutting action of the dredge head. No significant effects on turtles are expected from turbidity, anoxia, or noise. Potential effects to marine mammals could occur through physical injury, noise, and turbidity. Measures to minimize possible vessel interactions with endangered marine mammals may be appropriate. Zooplankton, squids, fishes, sea turtles, and marine mammals were groups in the pelagic environment considered to be potentially affected by offshore dredging. No cumulative effects to any of these groups are expected from multiple sand mining operations.

Dr. Mark Byrnes is a senior coastal scientist and principal at Applied Coastal Research and Engineering, Inc. (Applied Coastal). He received a Ph.D. in oceanography from Old Dominion University in 1988. For the past 16 years, he has been a principal investigator/program manager on more than 50 coastal and nearshore process studies as a Research Scientist at the U.S. Army Corps Coastal and Hydraulics Laboratory (formerly the Coastal Engineering Research Center), a research professor in the Coastal Studies Institute at Louisiana State University, and a senior coastal scientist at Applied Coastal. Dr. Byrnes' expertise includes coastal processes analyses, sediment transport dynamics, coastal erosion analyses (shoreline and bathymetry change), offshore sand resource assessments, sediment budget evaluations, shoreline restoration strategies, wetland loss delineation and classification, and geologic framework. He has also been responsible for managing and conducting numerous projects focused on coastal sedimentation processes and regional response of beaches, inlets, and estuaries to incident wave and current processes. He currently is conducting studies of wave and sediment transport processes, historical sediment transport pathways, and regional-scale sediment budgets along the East Florida coast between Cape Canaveral and Jupiter Inlet and at the Columbia River Littoral Cell, WA/OR.

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Mr. Tim D. Thibaut received a B.S. in marine biology from Auburn University and thereafter began his professional career as a creel surveyor for the Auburn Fisheries Department. During graduate training, he was employed as a graduate teaching assistant in the Auburn Biology Department and as a research assistant at the Dauphin Island Sea Laboratory in Alabama. After receiving his M.S. in zoology from Auburn in 1992, Mr. Thibaut joined Vittor & Associates in 1993 as a staff biologist. During his tenure at Vittor & Associates, he has specialized in polychaete taxonomy, NEPA processes, and review and analysis of impacts resulting from offshore drilling discharges, OCS sand mining, dredged material disposal, offshore and onshore pipeline construction, exploratory drilling, and other regulated activities. Mr. Thibaut has been a post-secondary educator since 1994, serving as adjunct instructor of biology at Faulkner State Community College in Fairhope, Alabama, for 24 academic terms of lecture instruction.

SESSION 1F

DEEP GULF OF MEXICO BENTHIC STUDY (DGOMB)

Chair: Dr. Robert Avent, Minerals Management Service
Co-Chair: Mr. Gary Goeke, Minerals Management Service

Date: January 9, 2002

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Mr. Andrew W. Remsen, Mr. Chuanmin Hu, and Dr. Frank E. Müller-Karger, College of Marine Science, University of South Florida

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INTRODUCTION TO THE DEEP GULF OF MEXICO BENTHOS STUDY (DGOMB)

Dr. Gilbert T. Rowe
Texas A&M University

Deep Gulf of Mexico Benthos (DGoMB) is a study of the structure and function of sea-floor communities of the deep Gulf of Mexico (GOM). Increasing exploitation by industry of fossil hydrocarbon resources offshore has prompted the Minerals Management Service of the U.S. Department of the Interior to support an investigation of the diverse assemblages of organisms that live in association with the sea floor sediments. Community structure is being used to test hypotheses about what controls the distribution of animal communities in the deep sea. Community function or dynamics is being investigated by measuring critical fluxes in a food web carbon model that portrays the relationships between carbon input and carbon flow through the near-bottom biota. The field work covers the entire northern GOM continental slope from depths of 300 meters on the upper slope out to greater than 3,000 meters seaward of the base of the Sigsbee and Florida escarpments. Sampling during three separate years will allow the hypotheses and the models to be revised and re-tested in an iterative fashion in years two and three. Plans are underway to extend the studies onto the Sigsbee Deep abyssal plain in cooperation with the National University of Mexico (UNAM).

Presentations at the 2002 ITM give an overview of progress being made in geochemistry and biology, along with an introduction of the kinds of studies that are going to be conducted with Mexico in the year of field work. An extensive process of permit applications has been initiated, with the help of Mexican counterparts at the National Autonomous University of Mexico in Mexico City. This joint work will take place in June and August of this year. Most of the work will be carried out on the abyssal plain of the eastern GOM within the Mexican Exclusive Economic Zone. The workup of the samples will be carried out jointly, and the work will be published as jointly authored papers in international peer-refereed journals. The program is also being extended nine months beyond its present termination date of August 1993 in order to coordinate all the collaborative studies being pursued between the marine scientists of the two countries. Most of the specimens will be retained in Mexican taxonomic collections, with types being contributed to the U.S. National Museum at the Smithsonian as well.

Gilbert T. Rowe is Professor of Oceanography and DGoMB Program Manager in the Department of Oceanography at Texas A&M in College Station.

OCEAN COLOR CLIMATOLOGY OF CHLOROPHYLL AT DGOMB STATIONS IN 1998, 1999, AND 2000 AND ITS USE AS A PROXY FOR POC FLUX TO THE SEABED

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Texas A&M University

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Mr. Chuanmin Hu
Dr. Frank E. Müller-Karger
College of Marine Science
University of South Florida

The amount of particulate organic carbon (POC) reaching the seabed is determined by the annual primary production in near surface waters, less losses from grazing and/or remineralization in the water column. Because primary production covaries as the time rate of change in phytoplankton biomass in near surface waters, we compiled time series of variations in chlorophyll (CHL) at each of the DGoMB stations from SeaWiFS ocean color data (Figure 1F.1).

During DGoMB Year Two, all available SeaWiFS imagery for the Gulf of Mexico (GOM) for 1998 and 1999 was composited biweekly to produce a 2-year time series of 26 biweekly means per year x 2 years = 52 biweekly averages. The mean CHL in the first optical depth at each of the 43 DGoMB stations was then computed for each biweekly interval, as the mean of a 5 pixel x 5 pixel grid centered on the pixel closest to the specified Lat+Lon location of each DGoMB station. This biweekly averaging was first done with SeaWiFS data with pixel resolution of 4.1 km 2.8 km, making the effective area around each DGoMB station that was being averaged at each biweekly interval about 28.7 km^2. The results are reported in a DGoMB Interim Report (section 5.3.2 in: Rowe and Kennicutt, *in press*). But for this ITM paper, the biweekly averaging has now been done a second time, using not just two but three years of ocean color data 1998, 1999, and 2000, and with the high-resolution SeaWiFS data set which has 1 km x 1 km pixel resolution. For the averages presented here, the area around each DGoMB station has been focused to 25 km^2.

CHL in the first optical depth in the deepwater GOM undergoes a well-defined seasonal cycle which is generally synchronous throughout the region. Müller-Karger *et al.* (1991) reviewed monthly climatologies of near-surface phytoplankton pigment concentration from multiyear series of coastal zone color scanner (CZCS) images for the period 1978-1985. They reported that highest near-surface CHL occurs between December and February and lowest values occur between May and July. There is only about three-fold variation between the lowest (~0.06 mg m^{-3}) and highest (0.2 mg m^{-3}) deepwater near-surface CHL, however. Model simulations show that the single most important factor controlling the seasonal cycle in near-surface CHL concentration is the depth of the mixed layer (Walsh *et al.* 1989). Müller-Karger *et al.* (1991) concluded that because of this dependence, annual cycles of algal biomass are one or more months out of phase relative to the

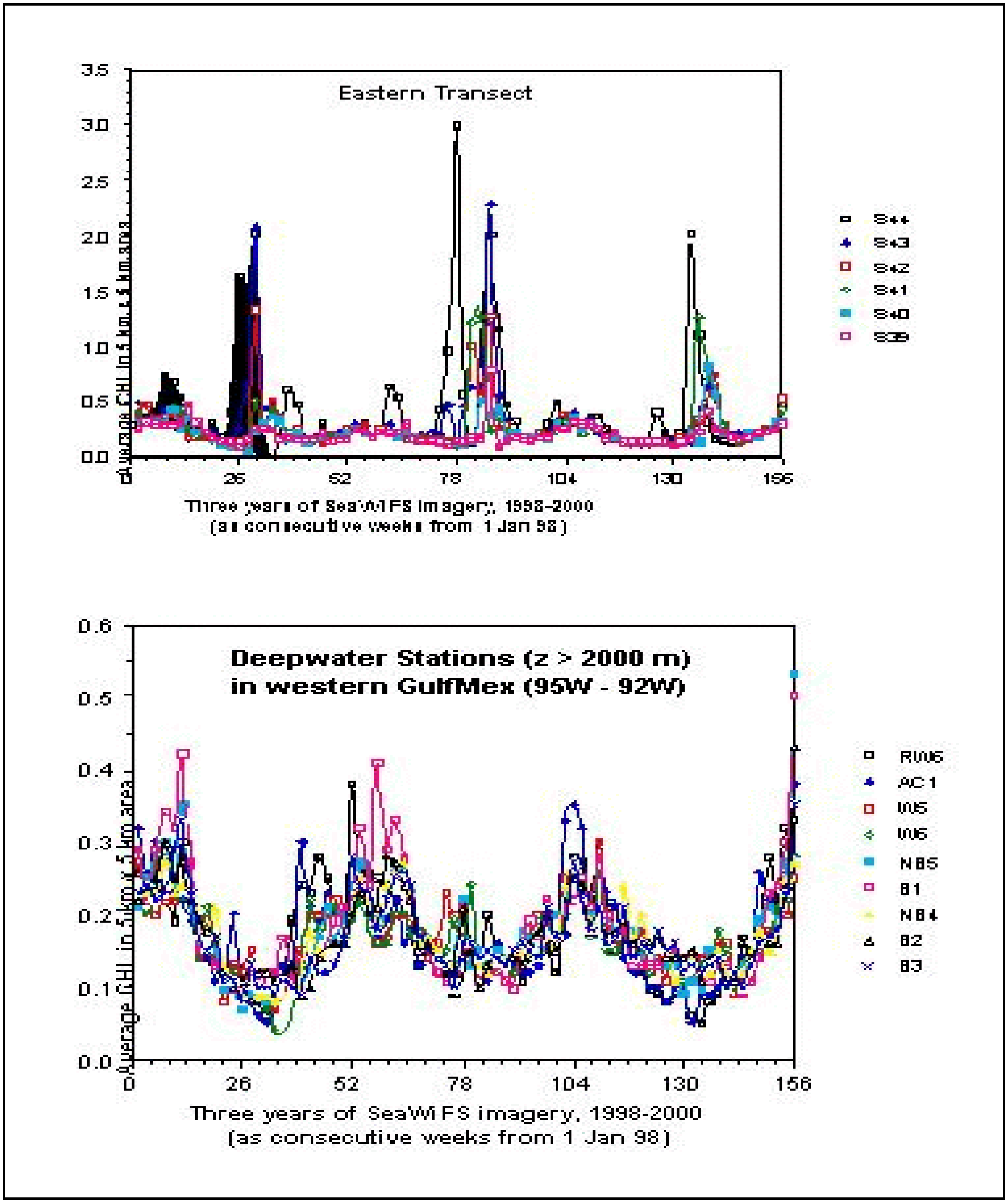

Figure 1F.1. Three year climatology of SeaWiFS ocean color data shows that annual maxima in CHL concentration at continental margin stations along DGoMB Eastern Transect (S stations, top panel) reach higher concentrations and are out of phase with those in the deepwater western Gulf of Mexico (bottom panel).

seasonal cycle of sea surface temperature. Subsequent study of CZCS imagery by Melo-Gonzalez *et al.* (2000), who looked at three-month averages, has reinforced this conclusion.

Not surprisingly, then, the annual cycle of CHL at the deepest stations (water depth > 2 km) shows the high-in-winter, low-in-summer pattern previously reported from analysis of the CZCS archives by Müller-Karger *et al.* (1991). The annual cycle of CHL at the Western Stations (W1-W6) and at the Lousiana Slope Stations (the cluster of nine stations between 93°W and 91°W) also shows this "deepwater" pattern. Moreover, the annual cycle of CHL at the Far Western Stations (RW1-RW6) generally follows the "deepwater" pattern, but there are several periods of the year in which CHL at the shallower stations (RW1 and RW2) exceeds 0.5 mg m^{-3}. Not all of this high CHL signal occurs November-February.

East of 91°W, the typical "deepwater" annual cycle in CHL is swamped by unusually high summertime CHL. In summers 1998, 1999, and 2000, warm slope eddies (WSEs) that were centered over DeSoto Canyon acted to entrain low salinity, high CHL "green water" from the Mississippi River and transport this plume seaward into deepwater. As a result, high surface CHL in summertime was evident at all DGoMB stations on the Mississippi Trough Transect (MT1-MT6), and at the three stations farthest upslope along the Central Transect (C1, C7, C4), and at the three stations farthest upslope along theDeSoto Canyon Transect (S35, S36, S37). High summertime CHL was evident, as well, at three of the stations along the Eastern Transect (S44, S43, S42).

How much of the primary production from surface waters reaches the seabed? In the central and western deepwater GOM, the standing stocks and biological productivity of the plant and animal communities living in the upper part of the water column are also in general those that might be expected in a nutrient-limited ecosystem. In the late 1960s, as part of a review of plankton productivity of the world ocean, Soviet scientists characterized the deepwater GOM as very low in standing plankton biomass, with mean primary productivity of just 100-150 mg C m^{-2} d^{-1} (Koblenz-Mishke *et al*. 1970). A few years later, extensive surveys of phytoplankton chlorophyll and primary production that span the period 1964-1971 were summarized by El-Sayed (1972) in atlas format, as averages within 2° squares of latitude and longitude. These atlas maps show that surface CHL generally ranges 0.06 - 0.32 mg m^{-3} in deepwater central and western GOM. There is usually a subsurface "deep chlorophyll maximum" (DCM) within which concentrations are two-to three- fold higher. Thus, the atlas reported that CHL in deepwater could reach 21 mg m^{-2} when integrated from the surface to the base of the photic zone. Most values, though, ranged 5-17 mg m^{-2} where water depth was > 2 km (El-Sayed 1972). Low values of primary production (< 0.25 mg C m^{-3} h^{-1}) are typical for surface waters at the majority of the oceanic stations in this atlas, equivalent to < 10 mg C m^{-2} h^{-1} when integrated from the surface to the base of the photic zone. If there are on average 12 hours of sunlight per day, this rate is equivalent to < 120 mg C m^{-2} d^{-1} and so is in good agreement with the characterization by Koblenz-Mishke *et al.* (1970). Allowing for primary production to proceed 300 days a year in the GOM because of its subtropical climate, this rate of primary productivity is < 36 g C m^{-2} y^{-1}. As a consequence the deepwater GOM is usually placed at the low end of the estimated range of 50-160 g C m^{-2} y^{-1} that is generally accepted for the annual gross primary production in open-ocean ecosystems (Smith and Hollibaugh 1993).

If on average 10% of the primary production sinks out of the photic zone, and if 3-10% of this flux in turn reaches the seabed, then at a typical deepwater location just 100-360 mg C m^{-2} y^{-1} might reach the benthos. However, productivity in "hot spots" of locally higher nutrient concentrations over the continental slope can be more than an order of magnitude higher than the typical 100-150 mg C m^{-2} d^{-1} (Biggs and Ressler 2001). For example, Gonzalez-Rodas (1999) documented ^{14}C uptake of > 2 g C m^{-2} d^{-1} in the northern margins of two deepwater eddies interacting with the continental slope of the central GOM. When/where such eddy interactions with the slope are common, as they appear to be in DeSoto Canyon during summertime, we suggest that POC flux to the seabed at these locations is likely to be significantly greater than the deepwater average of 100-360 mg C m^{-2} y^{-1}. In fact, most of the stations along central and eastern DGoMB transects C, MT, and S probably have substantially higher-than-average POC input rates.

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Frank Müller-Karger is Professor and Director of IMaRS at the College of Marine Science University of South Florida. His research focuses on primary production in the sea, and he uses remote sensing (ocean color, SST, SSH) to study the importance of continental margins, including areas of upwelling and river discharge in the global carbon budget.

BENTHIC BIOGEOCHEMISTRY

Dr. John W. Morse
Department of Oceanography
Texas A&M University

Geochemical studies consist of measurements of sediment solid phase and pore water chemical properties. They include determination of bacterial sulfate reduction rates and are interfaced with benthic lander flux measurements. As with other components of the program, the geochemical studies are divided into a set of measurements for survey sites and a much more comprehensive array of measurements at survey sites selected for the study of benthic processes.

At the survey sites selected, metal and organic compounds are determined as indicators of potential natural and anthropogenic contaminants that might influence community ecology. Additionally, a limited number of pore water (e.g. SO_4^{2-}, DOC, nutrients) and solid phase (organic-C) bioreactive components are determined in order to estimate relative biologic activity. The process sites receive a more comprehensive set of measurements generally performed down core to provide depth profiles. Of special note are the additional measurements made with microelectrodes, sulfate reduction rate measurements using $^{35}SO_4^{2-}$, and determination of sediments accumulation and mixing rates based on a variety of radioisotopes. These analyses were conducted by several investigators (Drs. Cifuentes, Morse, Presley, Santschi and Wade) and by students and technicians in their lab groups.

Analyses associated with the survey sites from Cruise 1 have been completed and were previously largely reported. The analyses of samples from Cruise 2 are primarily associated with process sites and, although still incomplete, have progressed far enough to permit several interesting observations to be made. However, they should be taken with considerable caution until this work is complete and more fully integrated with other components of the program.

At all stations the sulfate reduction rates are low but fall within the expected range as noted by a previous study (Lin and Morse 1991) of ~100 mmol m^{-2} d^{-1}. Numerical values must await further analyses such as dissolved sulfate and chloride. Microelectrode core measurements were also made at the process stations and data are now complete. At site MT3 a good profile was obtained with strong evidence of manganese reduction. Profiles were measured every 2 mm from water-sediments interface to 2 cm, then measured every 5 mm to 15 cm sediments depth. Values for pH were profiled similarly with typical values around 8.0. Oxygen concentrations depleted to zero soon after the water-sediment interface. After oxygen disappears, manganese and sulfide concentrations begin to increase. Highest manganese concentrations occurred at depths 3-8 cm. After 8 cm, manganese concentrations decrease indicating a possible layer change. No iron was detected throughout the core. At site MT6 oxygen concentrations were significantly higher in both the water column and in sediments porewaters. Oxygen concentrations were present 8 cm into the core. This was a result of the top 2-3 cm being high in water content. The oxygen may have oxidized any reduced manganese or iron present in the core. Sulfide concentrations however co-existed with oxygen for part of the profile. A possible explanation presumes that bacterial respiration rates for sulfate reduction must have been faster than the rate of sulfide oxidation. Sulfide values were very low, and began around 2.5 cm. At site S36 oxygen concentrations penetrated to a depth around 4 cm. There was slight overlap between small sulfide and oxygen concentrations. The profile was similar to MT6; however, there was a small increase in sulfide concentrations between 4 and 7 cm depth. Even the highest sulfide concentrations were small, averaging around 2µM. No iron or manganese was detected. Site S42 was profiled with success and characterized by deeper oxygen penetration depths and small sulfide concentrations (>2.0uM). Oxygen penetrated to about 3 cm, where small sulfide concentrations began to occur. This site appeared similar to the other sites. No iron or manganese was detected here as well. pH was profiled using a Cole-Parmer semi-microelectrode. Hansson's buffer was used to calibrate the electrode at around 8.3. The sediment may have had adverse effects on the electrode, creating non-believable readings. A side experiment was performed using squeezed porewater to measure pH opposed to sediment porewater profiling.

Analyses of nutrients, dissolved organic carbon (DOC) and dissolved inorganic carbon (DIC) isotope ratio ($\delta^{13}C$) for process sites have been completed, but DIC concentration and elemental analyses of sediments are outstanding. Site MT3 was most active, showing strong trends with depth, particularly for phosphate, ammonium and urea. Depth profiles for DOC were similar at all sites, but evidence for mineralization of organic matter was provided by the $\delta^{13}C$ of DIC at stations MT3 and MT6. The ^{13}C-depleted value measured at station S42 may be an outlier. Finally, comparison of total inorganic nitrogen (TIN) and phosphate with the expected slope of 16:1 suggests loss of nitrogen. Both dentrification and conversation to dissolve organic nitrogen are possibilities.

The radiochemistry group is still processing radiochemical samples. Preliminary results indicate mixing depths varying from 1 to 6 cm. The extent of excess-^{219}Pb($^{210}Pb_{xs}$) penetration into surface sediments (Table 1F.1) also varies over an order of magnitude, ranging from 2 to 18 cm for the four stations. This layer, which contains sediments, which had accumulated or mixed over the past century or so roughly, agrees with the layer with largest porosity gradient.

Table 1F.1. Summary of preliminary results.

Station #	Boxcore #	Sample ID #	Bioturb. Depth (cm)		$^{210}Pb_{xs}$ layer depth (cm)
			$^{234}Th_{xs}$	$210Pb_{xs}$	
MT3	P-2	1	6	6	17
S36	P-2	11	1	4	18
MT6	P-1a	15	1	1	2
S42	P-2	9	2	2.5	10

REPORT DGOMB CRUISE 2
SULFATE REDUCTION RATE MEASUREMENTS

Summary

Initial assessment of approximate sulfate reduction rates determined by the $^{35}SO_4$ method indicated a pattern not consistent with other biologic rate-related patterns and extent of sulfate reduction. A careful and detailed assessment of all measurements in the process indicates that the rates were probably close to or below the limit of detection when cumulative errors are considered using the standard procedure and are, therefore, as relative measurements not meaningful. Although reliable values could not be obtained, they do set an upper limit at low rates that are generally consistent with other studies in deep water sediments.

Example – We were obtaining counts on the order of 10 dpm above a background count of about 33+/-3 obtained from a solution that contained a count of about 4,000 dpm for $^{35}SO_4$ on the same sample size. Blank tests indicated highly stochastic values for individual extractions that approached or in some cases exceeded non-blank values. This was probably associated with the occasional transfer of a particular aerosol in the gas stream containing $^{35}SO_4$.

Immediate Remedy

Sulfate reduction rates will be estimated from changes in sulfate concentration with depth. In the area studied it is very likely that transport by molecular diffusion will dominate over bioirrigation and, therefore, the results should be reasonably reliable and give at the worst minimum values. We hope to have the analytical data to do this calculation before the end of January.

Future Remedy

At the very low rates of sulfate reduction in these deep water sediments it will be necessary to use an approach that does not produce a profile but rather a single average value by combining extracts (a common approach used by biologists such as Doug Nelson). This will give an approximate order of magnitude increase in this “signal to noise” ratio. Additionally aerosol traps will be added to the extraction line. This will be done to prevent the carry over of any $^{35}SO_4$ containing particles produced by the bubbling of gas through the extraction solution and should significantly reduce blank values. Finally, triplicate measurements will be made at each site to produce a sounder statistical assessment of rates.

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Lin, S. and J. W. Morse. 1991. Sulfate reduction and iron sulfide mineral formation in Gulf of Mexico anoxic sediment. American Journal of Science. 291:55-89.

Dr. John W. Morse is the Luis and Elizabeth Scherck Endowed Chair Professor of Oceanography at Texas A&M University. He obtained his Ph.D. from Yale University and has served on the faculties of Florida State University and the University of Miami, as well as Acting Director of the NSF Chemical Oceanography Program. He is currently Editor-in-Chief of the journal *Aquatic Geochemistry* and Associate Editor of *Marine Chemistry*. His primary interests are in the physical chemistry of sedimentary minerals and benthic biogeochemistry.

DEEP GULF OF MEXICO BENTHOS (DGOMB) PROGRAM REPORT ON THE BENTHIC BIOLOGY

Dr. Gilbert T. Rowe
Texas A&M University

The study was designed to gain a better ability to predict variations in the structure of animal assemblages in relation to depth, geographic location, time and water mass. This predictive capability was adopted because it was realized that it was not feasible to investigate every physiographical feature of the Gulf. Eight hypotheses are being tested on the basis of community structure. These hypotheses propose that community structure will vary as a function of

1. water depth
2. east vs. west geographic extremes
3. association with canyons
4. association with mid-slope basins
5. surface productivity
6. proximity to hydrocarbon seeps
7. variations in time (seasonal scale)
8. association with the base of escarpments

The structural characteristics of the communities used in the tests are variations in diversity, similarities in taxonomic composition between geographic locations (zonation, for example, with depth), variations in biomass and abundance, and mean size of individuals within functional size categories.

A carbon model (Figure 1F.2) is being used to represent each of the principal components of the food chain measured in the survey of standing stocks. The model includes demersal fishes, megafauna, scavengers, macrofauna, meiofauna and heterotrophic bacteria. This can be linked, as appropriate, with a simplified model of the seepage of fossil hydrocarbons that are utilized by chemotrophic organisms, including large invertebrates that contain symbiotic chemotrophs. The boxes represent standing stocks which have units of biomass in terms of carbon whereas the arrows represent flows of carbon between boxes and hence have units of l/time. For consistency, the units are mg C m^{-2} and mg C $m^{-2}day^{-1}$. The fluxes of the model are being measured with a benthic lander and ship-board radio-labeled tracer experiments. A numerical simulation of the carbon budget is being employed to predict how inputs of particulate organic carbon in varying intensities and periodicity affect the components of food web structure and biomass over time.

An extensive survey on the northern Gulf of Mexico continental slope was completed in 2000 (Figure 1F.3). The data generated allow maps to be constructed of the principal taxonomic groups in each size category. Statistical analyses accompanied by the detailed maps are providing tests of the eight hypotheses. On the basis of the survey, four sites were selected for intensive studies of community biogeochemical processes. The measured rates of fluxes produced by the metabolic processes are being compared to *de novo* carbon budget and associated simulations. The experimental protocols and the evolving model are being improved together in iterative fashion to improve our understanding of how the deep Gulf functions. While there are no management implications associated with the results so far, the model may prove of some significance to understanding a wide range of potential impacts in the future. New studies in collaboration with UNAM scientists will include study sites on the abyssal plain of the Sigsbee Deep in the eastern Gulf.

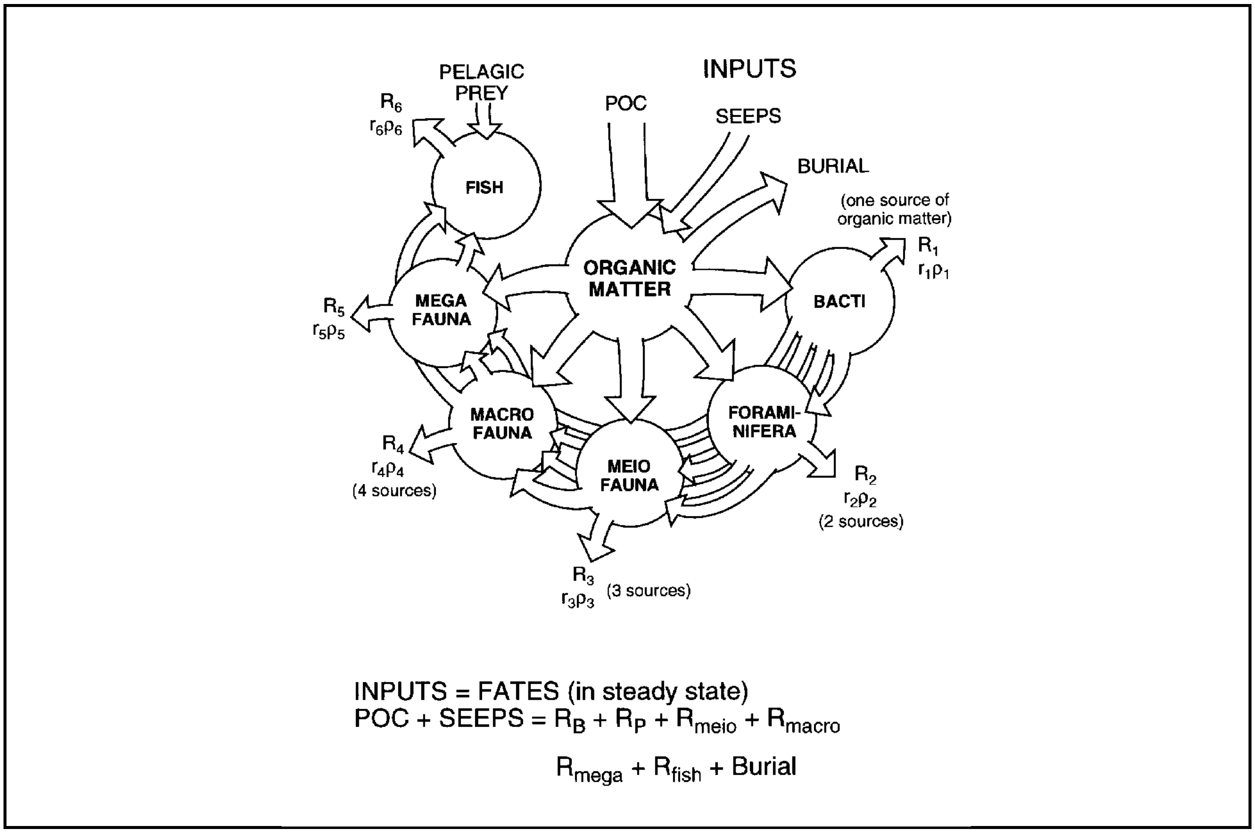

Figure 1F.2. Conceptual model of carbon cycling by the deep benthic food web of the northern Gulf of Mexico.

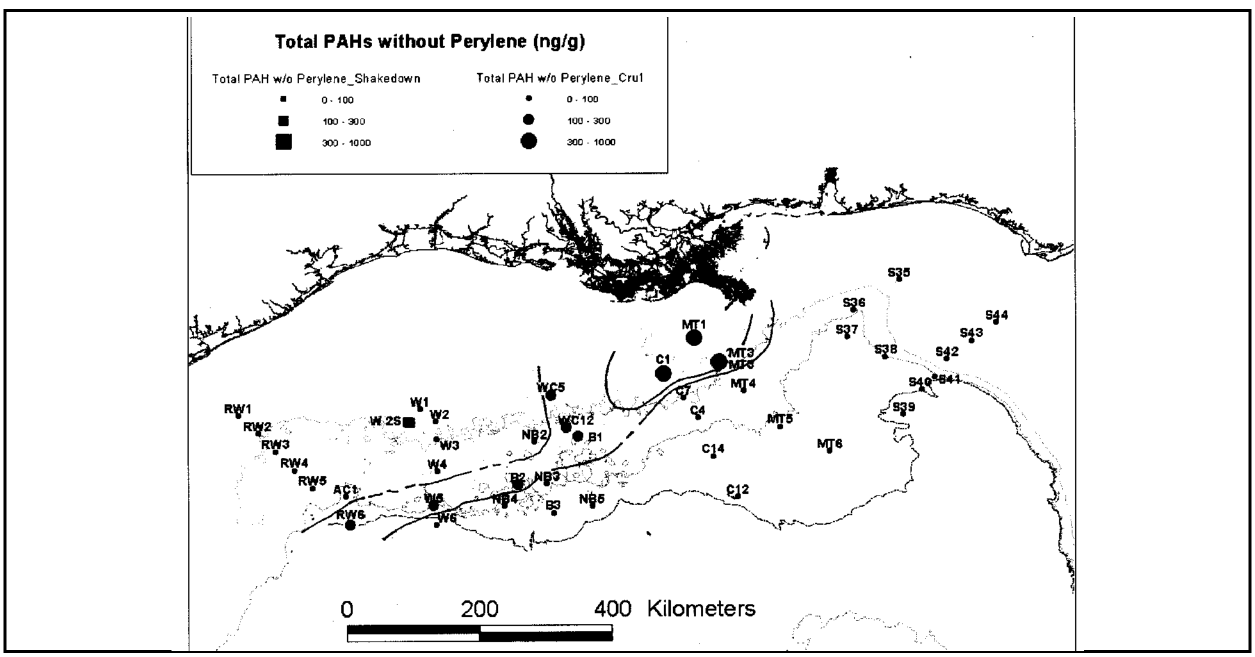

Figure 1F.3. Distribution of survey sites investigated, with concentration of PAHs in the sediments.

Gilbert T. Rowe is Professor of Oceanography and DGoMB Program Manager in the Department of Oceanography at Texas A&M in College Station.

BIOLOGICAL STUDIES IN THE SIGSBEE ABYSSAL PLAIN

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The Sigsbee Deep, located in the tropics is well known by its low primary productivity and characterized among the most oligotrophic basins in the world ocean. Due to these conditions export of biogenic carbon is limited to seasonal input. Wind and hydrodynamic mesoscale features contribute to pulses of organic matter that reach the deep-sea floor providing the deep-sea communities with patches of fresh material. Ongoing research by UNAM scientists in the deep sea Gulf of Mexico (GOM)has focused on describing the patterns of distribution of the infauna (meio- and macrofauna). These patterns include variation in the depth gradient, the local and geographical scales, and changes in time. This text describes the changes recorded by the meio- and macrofaunal biomass with increasing depth at two transects in the Southwestern GOM.

Sediment samples were collected in two cruises on board the R/V *Justo Sierra* in triplicate with an US-NEL spade corer. All the sediment was sieved on board, meiofauna was considered fauna retained in 42 µm sieves, and macrofauna was considered the fauna retained in a 250 µm. Additional replicates allowed us to characterize the sediment and the water column. The fauna was sorted in the lab and the data were processed using a zonation scheme previously used in the Gulf. Areas where collections were made include a northern transect off Tamaulipas, a southern set of transects in the of Campeche. Sound (Figure 1F.4).

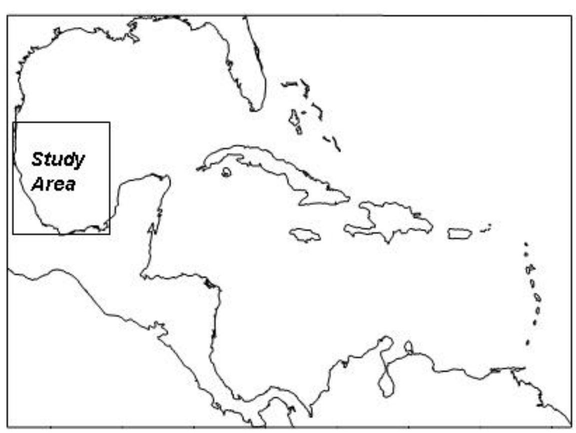

Figure 1F.4. Area of study.

NORTHERN TRANSECT

The polychaetes, together with nematodes and some crustacean groups (peracaridean shrimps and harpacticoid copepods) were the dominant components. These three taxa contributed with >90% of the total infaunal (meio- and macrofauna) biomass in all five depth zones (Figure 1F.5).

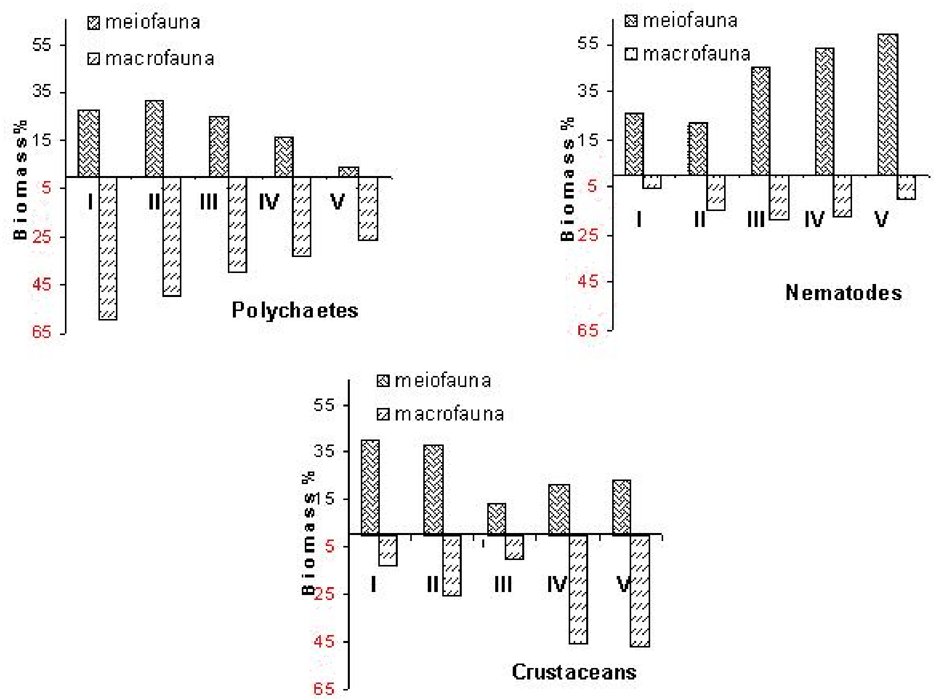

Figure 1F.5. Relative biomass (expressed as percentage of the total biomass) of the dominant infaunal taxa of both meio- and macrofauna. Zones codes: I= Shelf- Slope transition, II=Lower continental slope, III= Continental rise, IV= Northern abyssal plain, V= Southern abyssal plain.

Changes in the ratio of occurrence were recorded in the dominant infaunal taxa. The macrofaunal polychaetes that dominanted (50% of total biomass) in the shelf-slope transition zone were replaced by the crustaceans in the continental rise and abyssal zones. The meiofaunal crustaceans were replaced by the nematodes in the continental rise and abyssal plain stations. A significant decrease of the biomass values with increasing depth was recorded in the polychaetes. In contrast, the meiofaunal nematodes increased the biomass values with depth. The total meiofauna biomass displayed a parabolic pattern with increasing depth with the largest biomass values (0.119 and 0.124 $gC.m^{-2}$) were recorded on the shelf-slope transition zone and the abyssal plain. The lowest values

(0.008 gC m^{-2}) were recorded on the lower continental slope (Figure1F.5). Macrofauna contributed with largest values of biomass on the shelf-slope transition zone (0.078 gC.m^{-2}) and decreased to 0.034 gC.m^{-2} with the increase of depth.

The distribution patterns of the infauna correlates with the content of organic matter in the sediment and the bottom dissolved oxygen concentration that mainly contributed to explain the pattern recorded in macrofaunal crustacea.

Larger values of meiofauna in the abyssal plain suggest that this size group is better adapted to the food-limited, adverse conditions of the GOM deep-sea. A tight coupling between meio- and macrofaunal biomasses has been recorded (Figure 1F.6). This coupled variation has been attributed to trophic interactions.

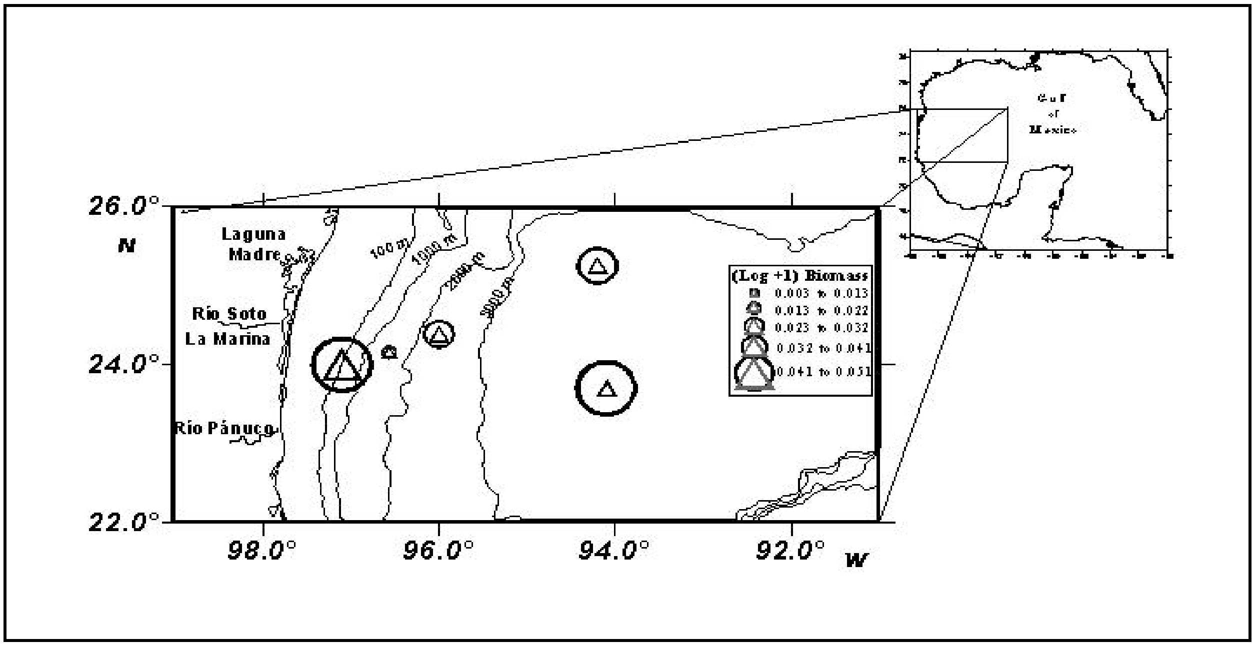

Figure 1F.6. Distribution of the meio ()) and macrofaunal (?) biomass log n+1 transformed mean values.

SOUTHERN TRANSECTS

The lowest meiofaunal and macrofaunal biomass values were recorded on the continental rise and upper abyssal plain. The largest values occurred on the continental margin (Figures 1F.7 and 1F.8). The upper slope values attained lower biomass values than values recorded on the middle slope. The former values were attributed to high organic matter content in the superficial sediment.

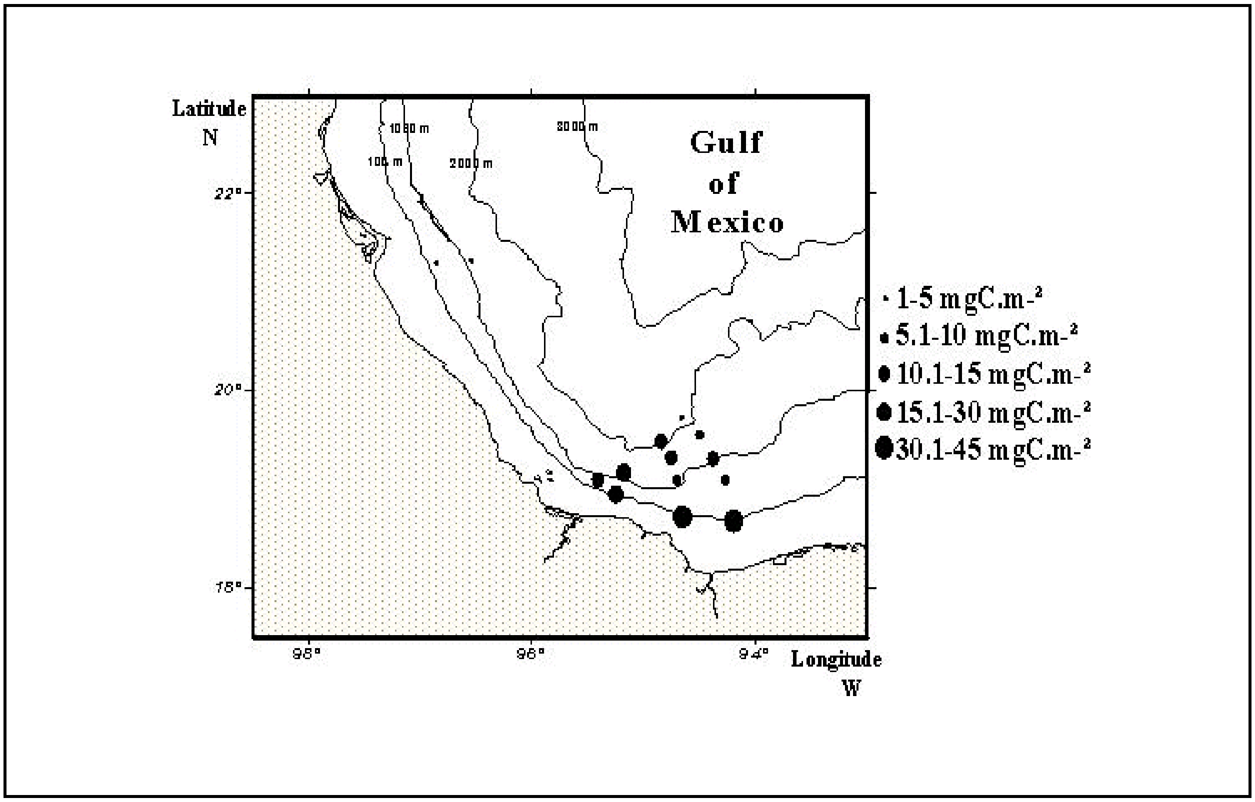

Figure 1F.7. Spatial variability of the meiofaunal biomass in the SW Gulf of Mexico.

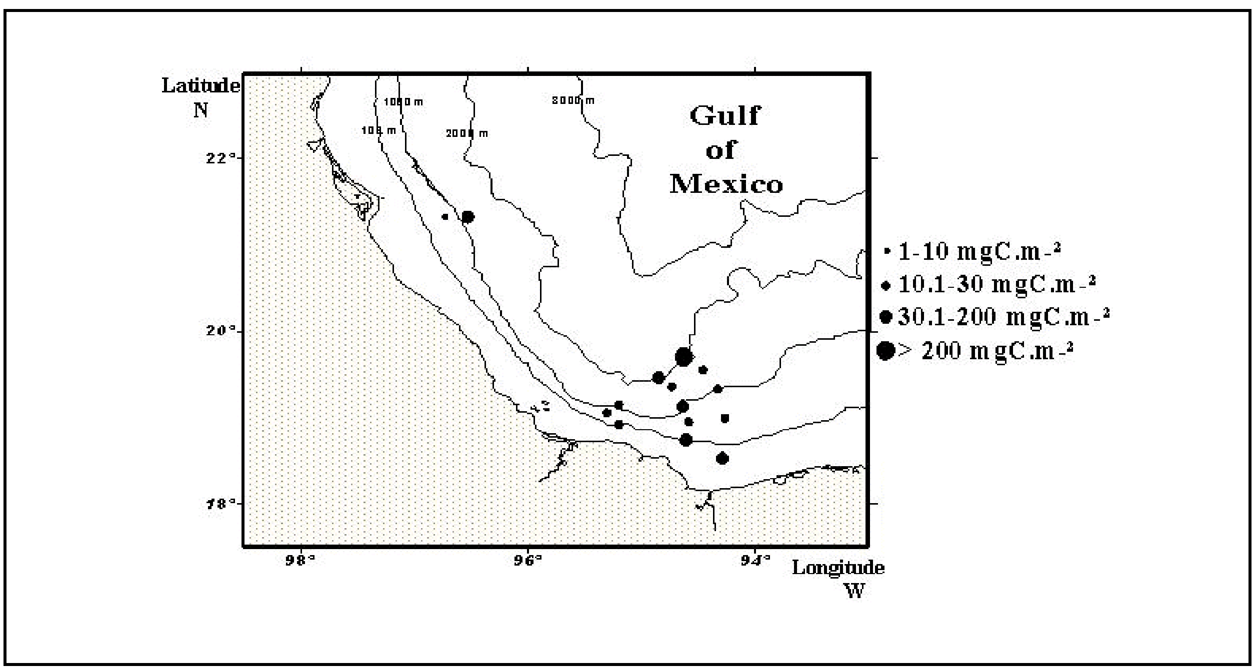

Figure 1F.8. Spatial variability of the macrofaunal biomass in the SW Gulf of Mexico.

ACKNOWLEDGMENTS

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Elva G. Escobar-Briones has been a professor with the Institute of Marine Sciences and Limnology (ICML) of the National Autonomous University of Mexico (UNAM) since 1993. Dr. Escobar-Briones received an undergraduate degree in biology from the Metropolitan Autonomous University (UAM) in 1981, completed a master's degree in fisheries and ocean sciences at UNAM in 1984 and defended a doctoral dissertation in Biological Oceanography in 1987, also from UNAM, on the structure and function of benthic communities in the Southwestern Gulf of Mexico. Dr. Escobar-Briones has been recognized on the biology of benthic communities with some 40 peer-reviewed articles and over 30 reports and articles on related topics. Dr. Escobar-Briones has been the head of the Academic Unit in Coastal and Ocean Systems since 1999, teaches graduate and undergraduate levels at UNAM, and coordinates the research program in deep-sea benthos of the Southwestern Gulf of Mexico at ICML UNAM, program that is carried out in collaboration with the Department of Oceanography at Texas A&M University.

Diana R. Hernández is a graduate student in the Marine Sciences and Limnology Program in Biological Oceanography, National Autonomous University of Mexico, defended a thesis on ecology of the Tanaidacea (Crustacea-Peracarida) from the western Gulf of Mexico deep sea in June 2002.

Citlali Díaz is a graduate student in the Marine Sciences and Limnology Program in Biological Oceanography, National Autonomous University of Mexico working on her M.S. degree on the efficiency evaluation of slope and abyssal meiofauna collection, sieving and sorting methods used in the Gulf of Mexico since August 2001.

Juan Antonio Salas is a graduate student in the Marine Sciences and Limnology Program in Biological Oceanography, National Autonomous University of Mexico, working on his M.S. degree on the efficiency evaluation of slope and abyssal macrofauna collection, sieving and sorting methods used in the Gulf of Mexico and the tropical ocean since August 2001.

Penelope Rodriguez is a graduate student in the Marine Sciences and Limnology Program in Biological Oceanography, National Autonomous University of Mexico working on her M.S. degree in macrofaunal community structure seasonal variability along a depth gradient (shelf to abyss) in the Southwestern Gulf of Mexico since January 2000.

SESSION 2D

EARLY HISTORY AND EVOLUTION OF THE OFFSHORE OIL AND GAS INDUSTRY

Chair: Dr. Harry Luton, Minerals Management Service
Co-Chair: Ms. Claudia Rogers, Minerals Management Service

Date: January 9, 2002

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Dr. Tyler Priest, University of Houston-Clear Lake
Dr. Joseph Pratt, University of Houston

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Dr. Donald Davis, Energy Programs, Louisiana State University

INTRODUCTION AND OVERVIEW

Dr. Harry Luton
Minerals Management Service

This session presented results from the first eight months of MMS's offshore petroleum history project, funded as a cooperative agreement between MMS and the Louisiana State University. Allen Pulsipher, the LSU project director, and Harry Luton, the MMS COTR, introduced the session. Dr. Pulsipher then conducted the session and introduced each speaker.

Dr. Luton opened the session by noting that this project is not the kind of socioeconomic study than MMS has funded in the past. The history project is more like a humanity; it lacks the typical emphasis on measurement and prediction. The project aims at collecting primary data—interviews—while most MMS socioeconomic studies build on existing information. The project intends to collect more material than it will analyze. A primary concern is preservation and archiving while most MMS socioeconomic studies expend their effort on analysis.

Nevertheless, most reasons MMS supports this project are typical of those for other research. NEPA charges MMS with assessing the onshore social and economic effects of the offshore program. Many effects are revealed by examining the past. For example, available literature analyzes the effects of offshore work scheduling and periodic father absence on family life. The history project has already rediscovered that this pattern of offshore commuting also let oilpatch settle in one place when, previously, they could not. MMS also designed the history project as a kind of scoping, as a forum for the people who created the offshore industry, who work in it, and who live around it to meaningfully discuss its effects. Still, in MMS, the study team, and the already extensive group of people who have participated in and contributed to this effort, lurks a feeling that this project should be supported because it should be done. The offshore industry is a remarkable human achievement. It was born here, and those who gave it body and breath are passing away while their achievement has not been documented.

Dr. Pulsipher reiterated the sense of urgency that is shared by the project team. He stated that he, the other team members, and others are donating many hours to this project because they recognize its importance and share its goals. This ability to elicit volunteer labor from academics and bureaucrats is unusual, Dr. Pulsipher noted, and he listed other characteristics that make this an unusual government project. First, MMS was not pressured into doing it. Agency leadership and staff was the catalyst for a needed action. Second, the project addresses a subject too large to grasp, it emphasizes information and detail, and it does not seek a concise answer to a specific question. Most government research is problem oriented, assembles huge amounts of easily available data, and boils it down into something simple. Third, the project began by bringing together a lot of people who already knew a great deal about the subject and were already interested in pursuing it.

Harry Luton is employed by Minerals Management Service and works primarily on the Gulf of Mexico Region's Studies Program. He completed his Ph.D. in American studies at the University of Michigan. After working on native subsistence issues in the Alaska OCS office for a decade, he served a stint in Headquarters before moving to the Gulf in 1994.

TECHNOLOGY AND STRATEGY IN THE EARLY HISTORY OF OFFSHORE GULF OF MEXICO

Dr. Tyler Priest
University of Houston-Clear Lake

Dr. Joseph Pratt
University of Houston

This paper discusses the key developments and milestones in the technology and strategy of offshore oil in the Gulf of Mexico (GOM) during its formative period. Our research is based on numerous interviews with industry officials, many from Brown & Root and Shell Oil, leaders in the industry whose histories we have written, but also interviews with individuals who have been inducted into the Offshore Energy Center's Hall of Fame, and with an increasing array of people from various segments of the industry. Our information also comes from voluminous trade journal articles, internal company publications, and technical papers we have collected and are continuing to collect and process.

Offshore is the big story in the history of the oil industry for the late twentieth century. From negligible production in 1947, the total production of offshore oil grew steadily to account for about 14% of world oil supply in 1974 and about 33% in 1996. Over the same period, worldwide natural gas production rose to around 228 billion cubic feet per day, 20-25% of this total accounted for by offshore gas (percentages even greater today—huge additions in deepwater GOM, offshore West Africa, Brazil, and eventually the Caspian Sea) (Pratt *et al.* 1997).

Technically, "offshore" exploration and production began at the turn of the century, as piers were used to develop offshore extensions of onshore fields in California and the Caspian Sea. Humble Oil's drilling in 1938 off McFadden Beach on the upper Texas Gulf Coast used a pier more than a thousand feet out into the Gulf and a separate platform built off the end of the pier.In Louisiana in 1937, where experience had been gained by operating in inland lakes and marshlands, Pure Oil and Superior Oil made a more fundamental move into the open waters of the GOM, with the construction of a massive (180 feet by 300 feet) wooden platform for the Creole field in about 15 feet of water -- one mile from shore, thirteen miles from nearest supply point at Cameron, Louisiana (Alcorn 1938). But offshore did not become a viable terrain for the oil industry until after World War II. The years 1945 to 1962 were formative in the emergence of offshore oil and gas as an *industry*, changing the perception of offshore GOM changed from an extension of what they were doing onshore Louisiana to a new and unique oil province.

Although there were a few strategic leaders, this industry really took shape as a collective endeavor with specialized segments or components. This is because the basic challenge of offshore was such a great one, requiring technological innovation in the search for new sources in progressively deeper water. Although the "deepwater" frontier is much discussed today, companies were focused on deepwater from the beginning. What has changed over time is just the definition of deepwater—first greater than 30 feet, then greater than 60 feet, than 200 feet, then 600 feet, then 1,000 feet. The only constant definition of deepwater over time has been "the depth of the water just past the deepest platform."

The central theme in the history of offshore development is how the interplay between the physical environment, market conditions, and regulatory requirements shaped the efforts of thousands of individuals working within hundreds of companies to create the technical systems needed to map, drill, produce, and transport petroleum from offshore fields. Moving into the offshore domain was an unprecedented undertaking. Exploring for oil and building large, free-standing structures in open waters had never been attempted. Each step into this unique and unknown environment presented unusual organizational challenges, business strategy problems, and sobering risks for even the largest and most technically sophisticated oil firms. But at each step, there was also the possibility of rich rewards.

Driving the industry deeper over the past fifty years have been four broad forces:

1. Price of Oil and Gas/Size and Productivity of Reserves: Economic conditions obviously shaped the determination of which prospects could be given serious consideration (repeated refrain: "we can build anything as long as it is economical").

2. Access to Offshore Lands: The leasing and regulatory systems run by state and federal governments governed the pace and scope of offshore exploration and development.

3. Availability of Equipment and Labor: From specialized construction vessels to ever larger launch barges to the workforce needed to operate them, the tools and people available to work offshore have also shaped the pace of development.

4. Technology: It is useful to distinguish between two types of technological change that expanded our capacity to retrieve oil from greater depths and harsher environments. The first—which I will call *incremental innovation* and some others might label *reengineering*—is a series of changes that go forward through the efforts of thousands of technical people in hundreds of offshore companies in all the different areas needed to perfect and extend existing technologies to meet new challenges. The oil and gas companies, those in design and construction and drilling, the numerous supply and service companies, specialists in studying wave, soil, and wind forces, all of these and many others in the "offshore fraternity" have steadily pushed the edge of existing technology, allowing it to be almost continuously extended. The second important type of technological change—which we call "*bolts from the blue*" or epoch-defining innovations—has gone forward in stops and starts somewhat outside the process of incremental change. Here a fundamental innovation in thinking about offshore problems or in applying a new technology, at times from outside the petroleum industry, basically alters the economic situation, redefining the possibilities for the offshore industry.

The 1945-1962 period witnessed both kinds of change. Incremental innovation took place in the evolution of fixed platform technology, as knowledge about wave, wind, and soil forces was gradually accumulated and applied. Meanwhile, specialized construction and support companies sprouted up along the Gulf Coast to assist these efforts. More radical, bolt-from-the blue innovation came from the advent of mobile drilling, and especially the semi-submersible drilling unit, first successfully demonstrated in 1962 by Shell Oil. The semi-submersible redefined deepwater, launching a new era of feverish development in which the individual companies engaged in offshore operations would mature into a full-fledged industry.

In early years of offshore, the key thing redefined was "water," not "depth." As oil companies took tentative steps from the swamps, marshlands, and protected bays of Louisiana into open water, one lesson became clear: offshore development in waters far removed from land would require much more than simply the adaptation of traditional technology; it would also require new ways of doing things if oil were to be recovered at a cost that would allow it to be competitive with onshore fields.

The first forays out into the oceans sought to retain an admittedly tenuous tie to land by building piers or trestles out into the water, thus allowing "offshore" rigs to be serviced from land-based facilities via rail tracks. Such piers proved inadequate in the soft sands of the Gulf and limited off California, where in some places one can drive a golf ball into 500-foot depths. Pure Oil and Superior Oil's open-water platform in the Creole field off Cameron was the first successful break from land. As an exercise in "stickbuilding"—that is, using work barges to piece together a wooden structure out in the ocean—this project was only a distant cousin to the metal structures of later eras, but it helped oil men identify the key problems that would have to be overcome to operate in the Gulf. The most obvious of these was the impact of hurricanes. Lacking any reliable data on wave heights in the Gulf, the designer of the Creole platform settled for an interesting compromise made possible by the fact that the work force commuted daily to the platform on shrimp boats. The designer simply placed the deck at fifteen feet above water and sought to design it so that high waves would wash it away while leaving the remainder of the structure intact. For an initial investment of $150,000, the Creole platform produced more than 4 million barrels of oil over the next 30 years. Clearly, money could be made offshore despite the many difficulties to be confronted (Alcorn 1938).

World War II suspended further development, as German submarines prowled the Gulf and the oil industry focused on production for the war. But once the conflict ended, a group of companies jumped back offshore. The war had greatly improved knowledge of the sea, communications techniques, salvage techniques, and other ways of working in marine environments. With pent-up demand for oil caused by the war unleashed, the economics of offshore exploration made sense to many southwestern U.S. companies, who assumed correctly that the prospects for large discoveries offshore were better than those in highly explored onshore areas. Most companies active in the southwestern oil fields had major refineries in the area from Houston to Port Arthur, Texas, and new discoveries in the Gulf could supply these plants. The postwar shortage of steel and other vital commodities hampered the construction of new equipment, but ingenuity and the use of war-surplus materials eased this constraint somewhat. The most pressing problem was the lack of knowledge about environmental factors and the risks presented by nature.

In 1945, the State of Louisiana held its first offshore lease auction (earlier drilling was from individual concessions), prompting a more concerted move to drill in open water as well as litigation with the federal government over the ownership of submerged lands. During the next several years, Magnolia (Mobil) and Humble (Exxon) led the way in creating big, largely self-contained platforms both to explore and produce oil. The Magnolia and Humble platforms, costing more than a million dollars each, did not discover enough oil in quantities to justify further development. Two significant innovations, however, came out of these platforms. In 1946-1947, Magnolia (drilling five miles off Pont Au Fer, Louisiana, ten miles southeast of Eugene Island) pioneered the substitution of steel pilings for wood on parts of the structure. Humble's Grand Isle Block 18 platform (six miles south of Grand Isle in 45 feet of water) was even more ambitious. The structure supporting these decks incorporated two advances that became the norm in offshore platform construction: it was all steel and introduced the use of pre-fabricated templates, or "jackets," built onshore and installed at site. Templates minimized the installation problems of stick-building while also producing a stronger, less expensive platform. The Humble design also included living quarters on the platform, an arrangement that became the norm after improved transportation and communication enabled platforms to be evacuated more rapidly (Anon. 1947; Magee 1949).

Still, the economic message in both cases was sobering: large investments in offshore facilities for what were essentially wildcat wells held great risks and uncertain rewards. Unlike on land, most of the offshore structure was not reusable in the event of a dry hole. In the late 1940s, Kerr-McGee and later Humble pursued a different approach with the development of a "small platform with tender," using refitted war-surplus vessels to house the personnel and much of the equipment needed by a much smaller platform. This offered a short step in the direction of reducing the risks of exploration. Excellent and relatively inexpensive war surplus vessels were readily available. In the event of a dry hole, much of the investment could be reused by towing the tender vessel to a new location and building a new small platform using some of the materials salvaged from the initial location. In this sense, Kerr-McGee's much heralded "first-out-of-sight-of-land" oil flow from Kermac 16 in November 1947, 10.5 miles from shore, came from a "semi-mobile" drilling system (oil barged ashore) in 18 feet of water (Pratt *et al*. 1997).

This approach entailed serious difficulties, including the need to protect the platform from the tender in high seas and the loss of many days when rough conditions prevented the safe transfer of men and material from the tender to the platform. But it was cost-effective compared to any available alternatives and enjoyed brief ascendancy as companies began to bring in new production from state leases obtained in the late 1940s. In 1949-1950, 11 new fields were found in the GOM from 44 exploratory wells. Many of these fields—in areas like South Pass, Main Pass, Bay Marchand, and West Delta—were fairly large by U.S. standards, and they proved that money could be made offshore (Anon. 2001).

During the early 1950s, as development work proceeded on these fields, mainly in 20 to 30 feet of water, exploration into deeper waters stalled. First, jurisdiction over submerged lands was in question, as the states and the federal government waged battle in the courts; and second, platform designs still needed improvement. A 1949 hurricane wiped out many self-contained platforms, and the technology for building jackets, piles, and platform decks was still in a state of flux. But answers and improvements eventually arrived.

First, in 1953, the so-called "Tidelands" dispute between the states and the federal government was temporarily settled through a series of Supreme Court decisions and the passage of the Submerged

Lands Act and Outer Continental Shelf Lands Act, which established a system of shared control in which the federal government had the authority to lease all lands outside three from shore (three leagues for Texas and west coast of Florida). With this new legal framework, companies were cautiously optimistic about extending offshore operations into deeper water. In 1954, the federal government held its first offshore lease sale in the GOM (Rankin unpub.).

Once the legal framework was established, conceptual advances poured forth from many people and companies eager to see what was out there in the Gulf. In cooperation with researchers at Texas A&M, the University of California at Berkeley and other leading research universities, engineers gained a more sophisticated understanding of wave forces, lateral loads, joint designs, and the interactions between the pile and surrounding soil, which allowed them to build cheaper and more structurally sound platforms (Geyer *et al*. 1955). In the 1950s, major oil and construction companies began to shift to purpose-built vessels designed with specific offshore tasks in mind—such as derrick barges (first purpose-built in 1949), launch barges, pipelaying barges (first use of pipelaying ramp and barge in 1952), and supply boats. Increasing specialization in the industry helped produce concerted action on the various problems posed by offshore development. J. Ray McDermott out of Morgan City and Brown & Root from Houston emerged as the leading specialists in template and platform engineering and construction, as well as marine pipelaying. Independent offshore service companies appeared to provide specialized transport services such as helicopters (first commercial helicopter company formed in 1949) and crew and supply boats. Specialized diving companies helped extend practical working depths. Innovation, practical knowledge and support came from a variety of sources in a highly entrepreneurial climate in which there was little distinction between the designers and builders of marine structures.

Before their incremental innovations could go forward to push the industry deeper offshore, however, a fundamental change was required to reduce the cost of exploration. This came in a spectacular wave of innovations in mobile drilling. The most obvious place to look for ideas was inshore Louisiana, where submersible drilling barges had been used for decades. The first successful mobile rig for offshore use, the Breton Rig 20, which employed a submersible-pontoon design for drilling in 20 feet of water. Originally developed in the late 1940s for Barnsdall Petroleum by John Haywood, the Breton Rig 20 reflected its antecedents in the swamps. But it, and others such as ODECO's Mr. Charlie, revolutionized offshore exploration in relatively shallow waters (Howe 1969).

The advent of mobile drilling established a major new segment of the industry: the independent offshore drilling contractors—such as SEDCO, The Offshore Company, and ODECO and others—who were all generating and testing new ideas about how to plum deeper waters. Various kinds of submersibles sharply reduced the risk and costs of exploration while extending the capacity to drill offshore to 30-, 40-, 50-foot depths. So-called "jack-up rigs" soon followed. Inspired by the famous Delong jacks first used by the U.S. Navy in the western Pacific to install and elevate docks, such rigs consisted of a barge platform which was towed to the site and elevated out of the water by legs extended, or jacked, to the bottom. Jack-ups such as Glasscock Drilling's Mr. Gus and LeTourneau's Scorpian, extended drilling to 100-foot depths, but the instability of these early units led engineers to look for other solutions. Drillships, such as the CUSS 1, made their appearance, promising to extend drilling much deeper. But drillships could not be relied on to keep the platform directly above the well, and they also experienced substantial downtime in rough weather (Anon. 1957).

By the late 1950s, the nascent offshore industry was cultivating the skills to perform all facets of offshore petroleum development in 50- to 135-feet. With mobile drilling rigs leading the way in exploration, companies bid on and developed leases obtained in federal auctions in 1954 and 1955. It should be noted that development during this period, and in this entrepreneurial climate, involved a high degree of improvisation and trial-and-error. There were no uniform "recommended practices" or guidelines for building structures, although companies were beginning to move in similar directions. Environmental and safety regulations were minimal or non-existent. Accidents, mishaps, discharges and spills were frequent compared to later years. The Coast Guard and Army Corps of Engineers were just trying to keep up with all this new-fangled activity in the Gulf, and the Department of Interior had no systematic plan for developing offshore acreage. According to John Rankin, long-time head of the OCS regional office in New Orleans, there were only about 28 people involved with offshore at the BLM and USGS, many only part-time, when he arrived in 1959, and there was very little interest in what was going on from the highest levels in Washington (Rankin 2000).

The year 1958 ended what might be called the first major phase of offshore development in the GOM. The next several years marked a significant transition from this formative era of wide-open, uncoordinated development to a new era in which offshore interests coalesced into a significant industry unto itself, with a greater sense of commercial and technological purpose. There was also greater recognition from the government that this was a significant economic enterprise. In the late 1950s, exploration activity in the Gulf had slowed considerably. First, leasing was delayed during 1956-1959 by Louisiana's legal challenge to further federal lease sales. Second, a severe recession and harsh weather in 1958 disrupted offshore activity. The downturn of the late 1950s severely exposed unsecured investments, speculative leases, and careless construction. Hardest hit were drilling contractors and service companies. With two-thirds of marine rigs idled, many of these companies either went out of business or were acquired. The frequency of accidents increased with bad weather, and budgetary cutbacks often sacrificed safety (Anon. 1956).

An interim agreement between Louisiana and the federal government allowed "drainage" sales in 1959 and the resumption of general leasing in 1960. But while companies were itching for more sales, there was also some uncertainty as to how much deeper offshore development could be taken. Many people thought that offshore operations might be practically and economically limited to 50-150 feet. Bouwe Dykstra, Shell Oil vice president for the New Orleans region, who had been an early offshore visionary and had signed the first day-rate contract in the industry for ODECO's Mr. Charlie, insisted that it would never be safe or economical to operate beyond 60 feet (Redmond 1999).

Dykstra lost the internal company debate over whether or not to press into deeper water, for Shell at the time was already working secretly on a new technology that would prove to be a watershed for the industry. In 1962, the company put to sea the first semi-submersible drilling rig, the converted Bluewater 1, which redefined what was possible in offshore exploration. By demonstrating that stable and effective drilling could be performed from a floating vessel, the semi-submersible launched offshore exploration into 600-foot depths and beyond. This was a true bolt from the blue that radically pushed back the horizon. At the same time, Shell successfully tested the first, open-water subsea well completion (wellhead on the seafloor, rather than on the platform) (Anon. 1962).

Shell successfully tested its new drilling technology in January 1962, in preparation for the March 1962 landmark federal lease sale offshore Louisiana. In this sale, the OCS decided to speed up the process and offer every tract nominated by industry—3.75 million acres. Spread over two days, this sale took in $445 million in cash bonuses, more than Oregon and California timber sales and onshore mineral leasing combined. Needless to say, government analysts in Interior took note and initiated more systematic scheduling and planning of lease sales (Rankin unpub.). The 1962 sale initiated a second phase of offshore leasing and a second phase of offshore development in which the role of the federal government would become more active and pronounced.

Another significant development came out of the 1962 lease sale. Shell Oil bid on some tracts ranging out to 600 feet, but the company was the only bidder on these. As a result, the government did not honor those bids. Shell's senior management concluded that there had to be competition, both to enable Shell to acquire the deepwater acreage and to stimulate the commercialization of the technology. Thus, in January 1963, Shell Oil held its famous "million dollar school" (actually charged $100,000 per company), which brought other oil and drilling companies in the industry up to speed on the new technologies the company developed, allowing many firms to move into progressively deeper water together (Anon. 1984).

In the 1960s, the offshore industry acquired new sophistication as exploration and development was systematically extended into greater depths and technology was transferred to other parts of the world. But we should not forget the remarkable achievements of the early pioneers in forging this new industry. The variety of human responses to the difficulties and risks of establishing a foothold in the ocean and the unique kinds of innovation that emerged from the swamps and marshes of southern Louisiana in developing a system for operating in "shallow" water, are what makes this such a compelling story.

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WORKER AND COMMUNITY PERSPECTIVES ON THE EARLY HISTORY OF THE OFFSHORE OIL AND GAS INDUSTRY

Dr. Diane Austin
Dr. Tom McGuire
University of Arizona

Working in communities throughout southern Louisiana, social science researchers are utilizing techniques of ethnography and oral history to assemble a database of materials on the development of the offshore oil and gas industry. These materials will be analyzed by project researchers during the course of the project and will be deposited in public archives throughout the region for future use by scholars and the interested public. The first phase of the project, conducted between April and December 2001, concentrated on recording and preserving the recollections of those who were instrumental in the move offshore. Of critical interest to this research as well is an understanding of how the communities of southern Louisiana were shaped by the development of the industry. During the initial phase of the project, researchers focused on communities in the parishes of Iberia, St. Mary, Terrebonne, and Lafourche. Subsequent phases will expand the study to Plaquemines and St. Bernard parishes to the east, and Lafayette, Vermilion, and Calcasieu parishes to the west.

Ethnography, the primary research strategy used by social anthropologists, involves the collection of data to describe human behavior in a variety of settings. It has several key features. Ethnography is carried out in a natural setting—a community, an organization, a factory—not in a laboratory. It involves face-to-face interaction with participants. It strives to present an accurate reflection of participants' perspectives and behaviors. It uses multiple data sources, including quantitative and qualitative data. Ethnography frames all human behavior and belief within a sociopolitical and historical context. And it uses the concept of culture—the knowledge, beliefs, and behaviors of people—as a lens through which to interpret results.

Oral history complements archival and documentary research in history by recording the discussions and commentaries of people about events of the past. As a discipline in the United States, oral history began as a study of "elites," the recorded, often off-the-record personal commentaries of major actors in government, industry, and society. In the 1970s, new generations of historians and other social scientists began looking at history "from the bottom up," recoding the recollections of "ordinary" people who nonetheless may have been extraordinary storytellers or participated in the shaping of historic events, technological changes, or ways of adapting given technologies to local environments. Anthropologists, for their part, have long drawn upon oral histories in studies of societies without extensive written documentation.

Both approaches, ethnographies of communities and oral histories of individuals, begin by establishing contact with individuals knowledgeable about local institutions, resources, and people. Some of these individuals may be official "gatekeepers," such as town mayors or company officials, whose permission may be necessary to carry out the study. Others may be other local researchers or professionals with long associations in a community. In either case, these individuals can provide essential information on the demographic characteristics of communities and populations, other background information, and insights into potential political constraints or cultural concerns with carrying out the study. They also can identify specific people who might facilitate the introduction of the study into the community or institutional setting. Once these initial steps are taken, the researchers identify potential study participants, explain the purposes of the project, conduct discussions, and, upon exiting the discussions, seek referrals to other potential participants.

In social science terminology, this procedure for finding participants is called "snowball" or "opportunistic" sampling. Two key features of the procedure contribute to the validity of the data collected. First, multiple points of entry into social networks are used. These assure the researchers that the information collected about given events or historical processes are obtained from multiple perspectives. Second, the research "triangulates" around events, descriptions and, recollections. This is the process of obtaining sufficient descriptions about events of interest from several participants with varying perspectives so that a coherent picture of those events comes into view.

During the first phase of the offshore history study, researchers from the University of Arizona met with dozens of community and industry leaders and conducted over 125 discussions with men and women working in the industry or living in the study communities between the 1930s and 1960s. The objective was to cast a wide net and try to get at least a rough outline of the overall picture as well as to capture especially the oral histories of those people involved in the earliest stages of the industry. A summary of each discussion was completed, and the collection of summaries was organized in ways suggested by the information in them. The first cut yielded four topics that were discussed: (1) community structure and dynamics; (2) personal history in the industry—by sector; (3) personal history in the industry—by company; and (4) general industry and work issues.

COMMUNITY LEVEL FOCUS

The oil and gas industry brought new people, businesses, and ideas to southern Louisiana. The communities within which it grew and evolved existed prior to the arrival of the oil and gas industry, and their histories helped shape local responses to the industry. To explore the evolution of these communities and this industry over time, researchers are talking both to the oil and gas workers and families who lived in these communities and to the civic leaders and other residents outside of the industry who were responsible for maintaining the communities over time. This segment of the research will focus on community history, the interaction of oil and gas with other local industries, the camps and other living arrangements that evolved to meet the needs of workers and families, examples of home-grown businesses that emerged to play a role in the industry, and the physical and environmental impacts of the industry and local responses to them.

WORKER AND FAMILY FOCUS

It is impossible to treat all sectors and all companies in a single history of this vast and complex industry, so the researchers elected to focus on patterns among career paths in the industry and in that way capture some of the diversity of experiences and occupations without become overwhelmed by the details. Individual career paths can be compared along important dimensions of time, space, and industry sector. Occupational timelines, which record individual jobs and the reasons for taking and leaving them (Figure 2D.1), help capture these dimensions and reveal significant patterns. The patterns will guide the selection of participants to ensure diversity. With the participants, the researchers will then explore the general industry and work issues encountered. These issues include type and source of workers, diversity in the workforce, work ethic and attitude, and the attributes of the offshore lifestyle.

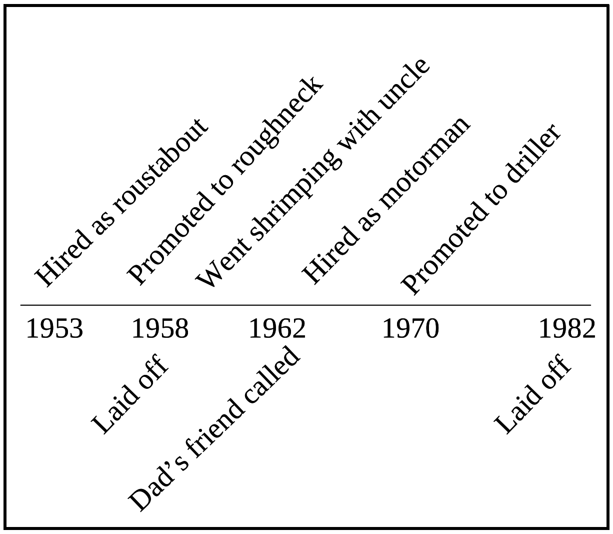

Figure 2D.1.   Sample occupational timeline for a driller.

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A PHOTOGRAPHIC TOUR OF THE LOUISIANA OILPATCH: RECOLLECTIONS OF WORK AND LIFE IN THE ACADIAN OILPATCH, 1930–1950

Mr. Andrew Gardner
The Bureau of Applied Research in Anthropology

INTRODUCTION

The offshore oil industry is a mighty agglomeration of technology and people. In its contemporary manifestation, the companies at the root of these efforts offshore are massive, global concerns. But many of the companies active in the energy industry today had their humble beginnings in the Acadian oilpatch. The history of the contemporary industry, then, is rooted in the bayous and communities of southern Louisiana—in the entrepreneurs and laborers that carried the industry offshore.

As part of the project described by Dr. Austin and Dr. McGuire, I spent five months in Acadiana, interviewing a diverse set of individuals with experience in the early days of the oilfield. The participants' experiences and recollections became the basis of our project. Altogether, we have at this point gathered over 100 oral histories from oilfield laborers active in the years the industry moved offshore. We also discovered, however, that many of the study participants had collections of photographs from these decades past—photographs they had perhaps taken themselves, or in other cases, inherited from a father or uncle from that first generation of oilfield pioneers.

This paper shows some of these photographs—drawn from the scrapbooks and musty boxes in the possession of the study participants. In addition, it incorporates their words. Where possible, these words directly relate to the photographs. In other cases, the photographs complement the descriptions provided by the participants. Together, these words and photographs are designed to carry us back to the early years of the industry, and to convey the experience of this portion of what Tom Brokaw has called "the greatest generation"—the men and women whose experience brings us back to the 1930s, 1940s and 1950s.

EXPLORATION AND SEISMOLOGY

Many of the men I spoke with got their start in exploration. Graduating from high school in the 1930s, they found employment with the oil companies who were, at the time, recent arrivals in Southern Louisiana. The oil companies knew there was oil underneath the marshes and swamps of the region, and many of the young boys of the communities—with experience fishing and trapping in the swamps and marshes—helped the oil companies navigate the swampy maze of Acadiana.

As one old Shell hand recalled his first day of work, "It was August the 9th, 1936…during the Depression. …I was working in the sawmill, and [a fellow named] Slim Wells…said he was looking for some hands. He said, "we're getting ready to run a surveyor behind Berwick, and we’re going to a place called Bayou Lewis…you know anything about Berwick?” I said, “I know all those woods back there.” So he said, “ and how about Amelia?” I said, “There too. I can take you all over the woods there.” So he said, “well, okay, you’re hired,” and he told me to meet him at a restaurant right there on Brashear Avenue…. So I went over there [to meet him], and he asked, “ do you know a couple of other guys?” I told four or five of the boys—workers, trappers…. So anyway, we went out. It was Sunday morning, I’ll never forget…boy was it hot…we were cutting right-of-ways with a sweeper and an axe…. The surveyors were first, and after that, that’s when the shooters came…and we had to carry our pipe. Pipe was in 12 foot joints, about 3½ inches around…we carried dynamite out there on our backs. We carried everything we needed…and just before dark we’d come out of the woods.” (Jake Giroir)

For many Cajuns, these crews were the first signs of the coming oil industry. After mapping the terrain, the seismograph crews would follow.

Another participant recalled, “[As a boy], I could see [signs that the oil industry was starting to go], because on the plantation my father operated, the seismograph people would explode huge amounts of dynamite. They would blow holes in the ground—I might be exaggerating—maybe anywhere from 30 to 50 feet in diameter, and maybe 15 feet deep or so. They would never refill them. They had holes like that on the back part of the plantation…. It made for pretty good fishing later on, you know.” (Parker Conrad)

Getting around in the swamps and marshes of Southern Louisiana required unique technology, and much of it was designed and built by local hands. An old Shell hand recalled the first marsh

Figure 2D.2. An early locally designed and built marsh buggy.

buggies used by the seismograph crews (Figure 2D.2): “This is not the first marsh buggy we brought out. We had another marsh buggy before this particular one. It looked like a little tank. It was able to negotiate through solid marsh, but not through soft marsh. Whenever we came to a body of water, we had to put it on a barge and bring it around, and we were always digging it out of mudholes. But this was the marsh buggy they brought out a little later on. As you can see, they had to put extensions on the wheel to make them more adaptable to riding around the marsh…. This is the Cheramie buggy. He manufactured them on Bayou Lafourche, right around Golden Meadows…we used these buggies for many years.” (Russell Poiencot)

For many of the Cajun men of Southern Louisiana, exploration and seismology provided them with their first experience in the oilfield. At the same time, the activity signaled the coming of the oil industry—an industry that grew several times over in the decades that followed.

DRILLING ON THE STEAM RIGS

Many of the participants got their start on the old steam rigs—once the mainstay of the Acadian oilpatch. Their vivid memories and recollections of work on these rigs were a common discussion point in our interviews.

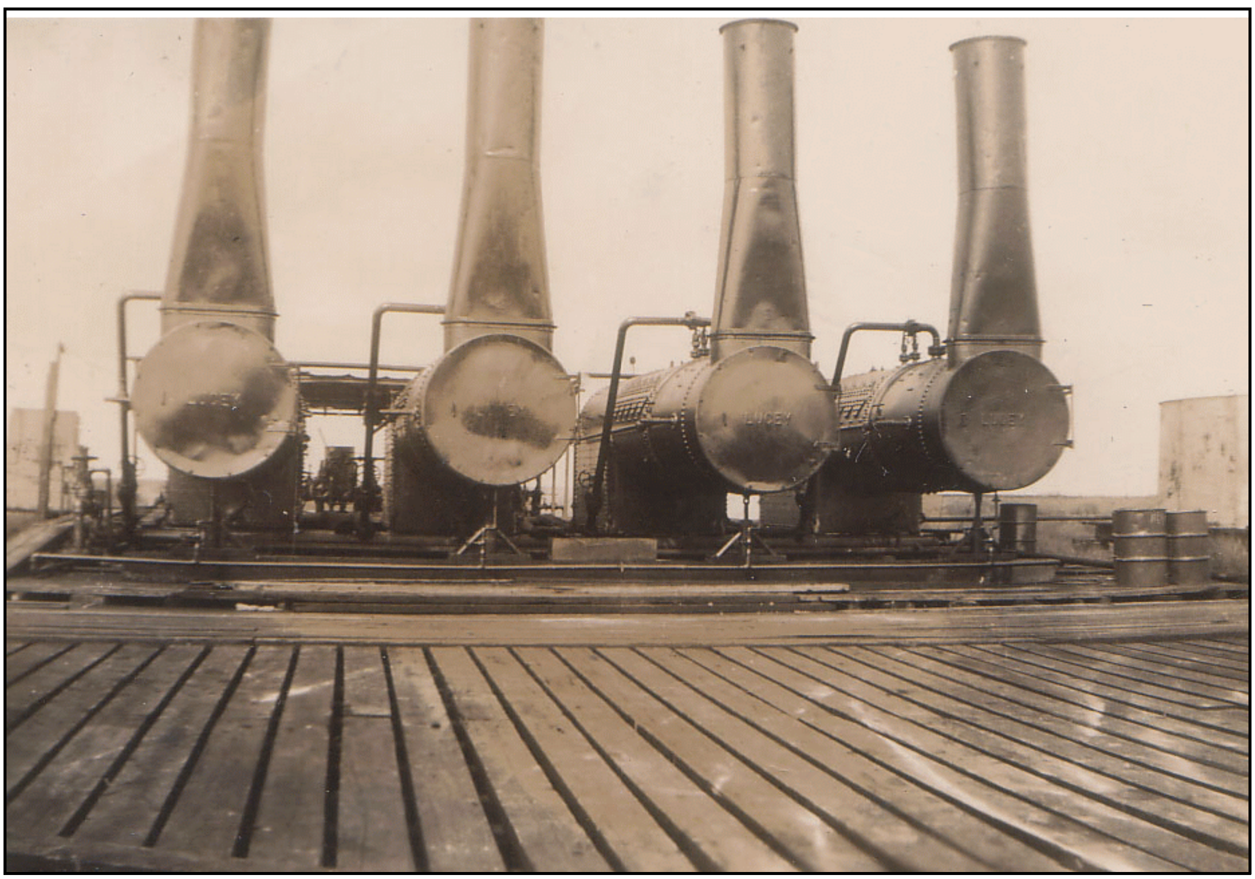

Figure 2D.3. A rig floor with an old steam draw works.

"[In Figure 2D.3], you're looking at the rig floor, the draw-works and the chain coming over to the rotary. Down in the left-hand corner you see the roller and the kelly sticking up. This is an old steam draw works…and if you look up in the background, that's the driller. He's looking at his weight indicator, and that's my dad right there, on the right. He's drilling. I knew most of them old hands that used to work for him…. The hands back then were more of a friendly deal…. In them days, in my early days, when a driller had a drilling job, he'd hire people from his local area—people he knew. And it was more of a friendly deal. Like when you drive back to home in the afternoon, daylight or morning hour, you'd stop at a bar and get a few drinks before you'd go home…. You don't see that no more. Like the bars down in bayou Lafourche, they used to have signs that said, "Dogs and Roughnecks not allowed!" (Donald Naquin)

The steam rigs were big, loud and hot. However, they were limited in the depth that they could drill. As one of the participants described Figure 2D.3, "[You're] standing on the board road looking at your boilers. And you can determine the size of your rig by the number of boilers you had. These four boilers here, that's probably a 10,000, 12,000 foot rig. …at that time, that was a pretty good sized rig. Very few rigs would get any deeper than 12,000 or 14,000 feet. You'd get some with five boilers, and they'd get around 18,000 feet…but the typical rig was about a four boiler job. Most of the time you were running three boilers and one boiler was either being re-tubed, doing something with it, a little maintenance to it. There were very few times that you would run all four boilers." (Donald Naquin)

"[Rigging up was the tough part]. Everybody would work days when you were rigging up. There was no breaking crews. Everybody would work days. It might take you five or six days to rig one of these steam rigs up at one time. Nowadays, it don't take us as long, but in them days there, it might take you four or five days…. [Later on] all of that was trucked in there. Last time I went out there as a kid, with Dad, I spent a few days with them, back and forth, and you'd see them bringing in the boilers down that board road…. That big old tandem truck, pretty good sized in those days…he'd have to get a pretty good head start to run across the marsh so he wouldn't sink in and go out of sight. He couldn't stop. Once he started, he was going." (Donald Naquin)

Most of the men I spoke with were happy for the technological innovations that made their jobs easier and the work of the rigs more efficient. At the same time, many related a sadness about the passing of steam technology—the sounds and smells of the steam rigs were a part of their early careers, a part they would never forget.

CAMPS AND KITCHENS

As the industry moved away from land, many of the oil companies built a series of camps to house and feed the laborers. Work in the kitchens was another common starting point for men who would eventually move through the ranks to driller, toolpusher, gangpusher, and other positions of responsibility. Furthermore, life on the water—and away from home—became the hallmark of the offshore oil industry.

One participant recalled his first years at a Texaco camp: "[When I started with Texaco as a roughneck, everybody worked 12 hour shifts, and we stayed at the camps]…. Henderson had a camp, West Cote Blanche here in Vermilion Bay had a camp, Horseshoe Bayou had a camp, so when you left to go to work, you stayed there six days…. Those camps were on pilings in the middle of the bay, edge of the canal, whatever…with rooms and all that…and when you lived at those camps you had the best of food! You couldn't beat the way they treated you. But they always charged you a dollar a day. They didn't want to just give it to you… . It took a hurricane to finally shut them down…. A hurricane destroyed the camp I was at, at West Cote Blanche…. They just started closing the camps [after that]." (Hubert Chesson)

Another participant recalled getting his start in the industry in the kitchens at one of the camps. As he describes, "We all got along well. Those guys [in Figure 2D.4] were nice, and the kitchen was open all the time. Those are some young men there…. That was fifty, fifty-two years ago there! I was in my prime there. [Anyway], it was all twelve hour shifts…. We'd get up at 4 o'clock in the morning and go until seven at night, and we'd get a nice break in the afternoon. After 1:00, we'd get a few hours of rest there. The men were working on the lake and all…. They'd come in…for dinner, and some would stay out in the field, and we'd send them a lunch box out." (James Crochet)

Figure 2D.4. The kitchen crew at one of the camps.

The camps also provided a central location for oilfield labor. Because many of the executives at the oil companies in those days had themselves come up through the ranks, visits to the camps were common. As a retired Texaco executive recalled, "[In the old days, the boss] used to come on the drilling rig and visit with all the roughnecks, and talk to them, wanting to know how they were making out, how they were being treated and everything…. Up until the time I retired, I visited quite a bit. I'd go out in the field, and I knew so many people, and I'd go and talk to them, and want to know how everything was going at home, pat them on the back." (Jimmy Gibbens)

These visits became less common as time went by, and slowly the companies began to close down the camps. Better transportation systems allowed men to move back and forth to their place of employment more quickly, and the camps moved onto the rigs and platforms themselves. Nonetheless, these camps were an integral component of the early oilpatch in southern Louisiana.

SAFETY AND DANGER IN THE OILPATCH

Safety and danger were recurring themes in the discussions of the study participants. Over the course of their careers, they witnessed dramatic changes in the safety regulations governing their activities. Many, if not most, had weathered close calls themselves.

As one participant recalled, "I should have stayed with Texaco—I had a good future with them—but I got hurt…. I was working with the tongs, and they had mud all over them…. I slipped and fell onto a piece of iron, and that mud felt…. I was hurting, but the mud felt so good, and I was so tired, I just laid back down. They got out one of those baskets…[they use] to bring you to the hospital. I must have been hurt bad because I passed out. So they put me in the basket, put me on a boat, brought me to the landing, and in the meantime the ambulance came…. On the way to the hospital, the ambulance got a flat tire, so the ambulance driver was trying to change the tire, and a drunk came along and hit the ambulance, knocked it off the jack. I didn't know what happened…. They must have given me something…. The next day, Mr. Roy, the toolpusher on the rig [came to see me]…. He told me the story, and he said, "you should be glad you're alive today!" I was out about eight weeks." (Harold Dugas)

Another retired oilfield worker described his accident: "[Four months after we were married, I had an accident on the rig]. It was a stupid thing! There's no such thing as an accident—not with me or anybody else. Somebody done something stupid somewhere! They either do something they shouldn't do or didn't do something they should have done. In this case…we had to release some pressure…. We had a release valve underneath the derrick floor on a two-inch line, and the driller told me and a friend of mine to go release that pressure. It was a plug valve, and you had to have a long bar to open it up [as shown in Figure 2D.5]. I remember leaving the pumps with the bar on my shoulder and Sweet Pea following me, and the rest of this story is what I've been told. I opened up the valve, and no fluid came out…. Sweet Pea knelt down there and looked into the piece of pipe, and said, "you don't have it open. I see a little bitty crack." I said, "I know damn well I have—get out of the way and let me look!" And when he did he hit that bar and all that back pressure came out and hit me in the face. It should've blown my head off. I say, that was no accident. It was pure stupidity. I knew better than to do it. I knew better, but he and I were arguing, and I wasn't thinking." (Charles Gardner)

Figure 2D.5. A newly opened pressure relief valve.

Another old oilfield hand described the loss of his son in the oilpatch: “There were no safety rules whatsoever [when I started working in the oifields in Texas]…. [My son Johnny] was pumping…and they were just putting one of them production platforms on line, and Johnny had went up there to talk to them about it…. He told them, he said, “it’s not ready to go on line.” He said, “one thing, the blow-down line is not tied down anywhere.” And he said, “ Another thing, the engineers have made a bad job of it, because they had eleven L’s.” I’ve always heard all my life that twelve L’s was equal to a valve shut. But they didn’t pay no attention…. We was needing gas and they was wanting to get it on, so they put it on line in two or three days. The pressure had failed some, and the pumper didn’t know exactly how to raise…. He radioed Johnny to come up there and show him how to raise the pressure…. He stopped and started to raise it a little bit, and the safety head blew,and just like that…the pipe went slapping everything, breaking off and everything, and he was at the corner of the platform…. The pipe blew him overboard and cut the top of his head off. He never knew what hit him.” (Bill Williams)

Improved safety regulations and an increasing focus on safety training helped minimize these sorts of accidents, but the danger of work in the oilfield was never completely absent.

A CAREER IN THE OILPATCH

Despite the dangers of the oilfield, most of the participants in the study were proud to have been a part of the American oil industry and its move offshore. For many of the men and women of Acadiana, the oilpatch was the only life they knew, and over the twentieth century, the communities and people of Southern Louisiana grew with the oilpatch.

As one oilfield hand noted, “Where goes the oilfield goes the rest of the economy in Southern Louisiana…. But I’m prejudiced, because I’m oilfield through and through. My daddy was with Exxon Pipeline 47 years. I was raised in a company camp that had six houses, all furnished by Exxon Pipeline. Ten dollars a month to live in them. They had yard people, yard men. We wanted for nothing…. You don’t have that anywhere else. You don’t have the camaraderie…working like we all worked together.” (Red Gremillon)

Figure 2D.6 shows people happy to have good jobs in the oil industry. Many came from humble beginnings, and the oilfield provided a chance for them to better themselves and their family. As a retired engineer from a major oil company noted, “Economically, [the impact of the offshore oil industry] was one of the most rewarding experiences for people who lacked education, who didn’t have an education, into jobs where they could afford to build their own homes, have their own cars, educate their own children, and have police forces—to afford police forces in their areas. I don’t know what people [around here] would have done [otherwise].” (B. T. Green)

Another participant noted, “[The people from Acadiana really took to the industry], they really did. It made life real good for these people. People lived a good life through the oil industry. Now not everybody wanted to go offshore…. But the money was in the oilfield. When I started out washing dishes for Shell, I started out at $1.33 an hour, and when I went to roughnecking, I made $2.20 an hour. That was 1954, [and you just couldn’t do better than that around here].” (Al Rivet)

The booming industry of the1940s and 1950s—and, in a larger sense, the industry’s move offshore—not only provided employment to the local peoples of Louisiana. It also drew people from neighboring states, many of whom eventually made their homes in the communities of Acadiana. One Texan, recalling his move to Louisiana, talked about his adjustment to the move: “I kinda like Louisiana! I married a nurse over here…. Her grandpa’s buried over yonder in the cane fields…. All us Texans crossed the creek. See, when Exxon sent you down here—when Humble sent you down here, you couldn’t get back across that creek…. Once they got you down here, [you were here to stay!]” (Clyde Hahn)

Many came from the nomadic lifestyle of Texas wildcatting, and they welcomed the chance to set down roots in Louisiana. Coming across “the creek” between Texas and Louisiana, they remember, was like entering a foreign country. A couple that got their start in Texas told me of these early days: “At least every 60 days we’d move, and you never knew where you were

Figure 2D.6. The oil industry provided good jobs to many Acadiana residents and drew new people from neighboring states into the area.

going. They'd call you up and tell you we want you at such and such a place, in the morning. One time…we were working in Hackberry, and one day, about noon, they told us, "we want you in Morgan City tomorrow to go to work." So we got off at four o'clock, the wives were in Lake Charles, and when we got home they was all packed and everything, and we got into Morgan City at one o'clock on New Year's Eve of 1940. Every three months we'd have to put everything in the car, dishes, towels…we couldn't own too much. We were like a bunch of nomads…but I'll be honest with you: [All the Texans] did was make jokes about these Cajuns…and I never had any trouble. I found that if you paid them a little respect, they'd respect you, and go about your business. His wife, a Cajun, added that, "[my husband] didn't eat rice…. He didn't care for seafood—like crabs, crawfish, or something like that, but he learned!" (Mr. And Mrs. Charles Gardner)

Acadians and outsiders: the oilpatch left an indelible mark on the lives of those who worked the rigs and platforms of the offshore oil industry. Speaking of her husband, Charles, who worked his entire life in the oilfield, Mrs. Tisdale recalled that, "he worked in the oilfield so long, he's been retired since 1973. "I dream about it sometimes," Charles noted. Mrs. Tisdale added that, "some mornings, he can't get up to drink his coffee because he's too tired. He was dreaming about the oilfield, and he worked all night long. And he can't roll over in his sleep because he's got a tool in his hand!" (Mr. And Mrs. Charles Tisdale)

These indelible marks left upon the men and women of the oilpatch go back to the formative years of the industry. Acadians, and the outsiders that joined them, helped to build an offshore industry unrivaled at its time. The Louisiana oilpatch became the heart of the oil industry, a place where technology was pioneered and experienced hands were forged. The first and second generation of these pioneers are now in the twilight of their lives. They are the generation that carried the industry offshore, a move that is now largely relegated to the dim memories and recollections of a generation nearly gone.

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MOSQUITOES, ALLIGATORS, SUCCESS AND FAILURE: BIRTH AND REBIRTH OF AN INDUSTRY

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ABSTRACT

When one considers the difficulties of exploring for fossils fuels with heavy machinery on muck land, or even no land at all, it is easy to understand why it took so long for oil entrepreneurs to exploit Louisiana's oil and gas wealth. September 2001 marked the 100th anniversary of the oil and gas business in Louisiana. Hydrocarbon exploration and development have been a vital part of Louisiana economy for over a century. In the latter part of the 1980s, the industry was considered dead or dying. Exploration and development had declined throughout the state. In the 1990s Louisiana's industry was reborn in the deepwater of the northern Gulf of Mexico (GOM)—a region where between December 1992 and 1999 production rose more than 500%. The area holds enormous potential in water depths that create unique production challenges. With high natural gas prices and oil in the $24 to $30 per barrel range, the industry has pushed exploration limits within these environments. They have met the challenges and are safely operating in water depths soon to approach 10,000 feet.

Three-and four dimensional seismic surveys, horizontal drilling, renewed interest in deep geologic formation, along with a long list of technological advances, have contributed to renewed interest in Louisiana's hydrocarbon reserves. With completion in 1987 of a well in East Feliciana Parish (county), fossil fuels are now produced in all of the state's 64 parishes. Consequently, from the state's perspective, nearly one-fourth of all its revenues are energy related. To maintain this industry, a large and diverse group of people and businesses sell a wide variety of services to a vase array of companies involved in meeting the industries' various needs. These are the vendors who are a vital link in maintaining the industry's presence in Louisiana. Many of these small- to medium-size businesses rely on this industry for their economic survival. The industry has prospered from their services. Their presence in many communities within the state has contributed to the economic well-being of these communities. The communities and the state benefit from the favorable geologic structures that underlie Louisiana. Thousands of individuals and families gain all or part of their livelihood from direct or indirect employment in the oil industry.

In retrospect, exploration and development of Louisiana's oil and gas reserves was so rapid that by the early 1930s approximately three-quarter billion barrels of oil had been produced from the state's shallow fields. In the first three decades of the industry, an average of two new fields were being discovered every month. The industry was booming, largely because of the discoveries associated with the state's salt-dome structures (Barton 1930; Branan 1937). One geologist noted "… Louisiana has one of the world's greatest petroleum reserves…but we have barely scratched the surface…." (Branan 1937). The oil was there; it just had to be found, and it was.

Through time, the industry flourished. Admittedly, some parishes produce more hydrocarbons than others. Regardless, every parish benefits in some way from the "spin-off" industries associated with this production. In the industry's infancy, timber contractors were one of the earliest groups providing support to the drilling effort. When operated at maximum load, boilers used to generate steam employed in the drilling process required at least 15 cords of wood each—a unit equal to a stack 4 feet wide by 4 feet high by 8 feet long. When one considers the number of derricks in some of these early fields (also built of wood), it is clear the timber required was large and necessary—simply an early example of the support services required to keep the wells operating at maximum efficiency. To move these items—either wood or boilers or heavy equipment—required a 20-mule team; thus, transportation was critical, as it is today. It takes one technology to discover and produce the product and another to get these mineral fluids to market. Both technologies developed simultaneously. In less than a decade, the industry was using oil to power its derricks. Each operating derrick consumed about 30 barrels of crude oil per day. Therefore, if there were 600 wells in a field, they required 18,000 barrels per field per day—a significant use of the field's production.

Early on it was apparent that industry leaders would need to build their own infrastructure. The Texas Company (Texaco), for example, discovered its own clay and fuller's earth beds, so as to be independent of suppliers of these materials essential to refining. Texaco made their own oil cans. They acquired timberlands and a sawmill to produce lumber for their kerosene packing cases. For a while, Texaco made their own tank wagons. It was considered more profitable and advantageous to control every aspect of the industry rather than to rely on outside vendors (Rankin 1938). For a time this approach worked, since it was prudent to make everything required internally. A century later, the Louisiana oil and gas industry is so large, and requires such a wide diversity of expendables and services, that outside vendors meet their needs. In many cases, this silent work force allows the companies to prosper. Valves, gages, pipe, electrical supplies, safety equipment, and numerous other items (the list is as large as a small telephone directory) come from local or regional vendors. Without these sources of supplies, the companies would be hard pressed to meet exploration and production schedules. Further, each supplier gains from the company's demands. The local labor force and tax base also benefits. It is a circle of profits, advantages, and benefits; each group benefitting the other. Contemporary business strategy involves a large coterie of vendors. The concept of a totally integrated company has been replaced by specialized service companies.

As technology changed, or was developed to meet the industry's needs, new frontiers were explored. Today, the frontier continues to expand, and Louisiana is the beneficiary of this activity. One hundred years after the first discovery well in Louisiana, the state has produced more than 14 billion barrels of oil and over 80 quadrillion cubic feet of natural gas. In meeting this production, there have been more than 250,000 oil and/ or gas wells drilled in the state. From the uplands, to the swamps and marshes and into the deepwater of the GOM, Louisiana has been a leader in helping meet the nation's energy demands.

Historically, south Louisiana development may be divided into four periods:

1. 1901-1925 when 10 fields were discovered in the state;

2. 1926-1937 when improvements were implemented in drilling equipment capable of penetrating Louisiana's deep structures, and of barge-mounted rigs that opened exploration in the state's alluvial wetlands;

3. 1938-1948 when deep drilling techniques led to new finds; and

4. the offshore/deepwater era—with the deepwater zone considered the "new" frontier in the United States energy future and the most prolific "lower 48" exploratory trend in decades.

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For the last 10 years, Dr. Donald W. Davis has served as the Administrator of the Louisiana Applied and Educational Oil Spill Research and Development Program in the Office of the Governor. Since completing his Ph.D. at LSU, he has spent nearly 30 years investigating various human/land issues in Louisiana's wetlands. During that period he has written or co-authored more than 150 items related to various coastal related issues. He is currently working on a number of problems related to the oil and gas industry and on projects intended to help restore Louisiana's wetlands.

SESSION 2E

OUTER CONTINENTAL SHELF SAND AND GRAVEL: REGIONAL MANAGEMENT, NUMERICAL MODELING, AGGREGATE DREDGING STUDIES, AND OTHER RELATED ISSUES AND ACTIVITIES

Chair: Mr. Barry Drucker, Minerals Management Service
Co-Chair: Ms. Sarah Tsoflias, Minerals Management Service

Date: January 9, 2002

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NUMERICAL MODELING EVALUATION OF THE CUMULATIVE PHYSICAL EFFECTS OF OFFSHORE SAND DREDGING FOR BEACH NOURISHMENT

Mr. Sean W. Kelley
Mr. John S. Ramsey
Dr. Mark R. Byrnes
Applied Coastal Research and Engineering, Inc.

The Minerals Management Service (MMS), a bureau within the U.S. Department of the Interior, has responsibility for managing all mineral resources on the federal Outer Continental Shelf (OCS), a zone that extends three (3) miles seaward from state coastline boundaries to 200 miles offshore. Although most interest in this zone relates to oil and gas resources, the potential for exploitation of sand resources as a source for beach and barrier island restoration has grown rapidly in the last several years as similar resources in state waters are being depleted or polluted. Extraction of sand changes, resources in federal waters may be preferred relative to state waters because of concerns over in physical oceanographic conditions resulting from large quantities of material dredged from resource sites impacted by waves and currents. This has generated a need for technical information to ensure that offshore minerals are developed with due concern for potential environmental considerations.

The purpose of this study was to examine the potential for negative impacts to coastal and nearshore environments, particularly from alterations to the local wave and sediment transport regime, due to significant removal of sand from shoals offshore southern New Jersey, southeastern Virginia (Sandbridge Shoal), North Carolina (north of Oregon Inlet), and Cape Canaveral, Florida. Figure 2E.1 illustrates these four areas, where selected sites with beach compatible material are outlined in black. Shoals in these areas are expected to serve as long-term and continual sources of borrow material, due to existing beach renourishment cycles, and to repair damage from severe coastal storms. In certain instances, such as Sandbridge Shoal offshore southeastern Virginia, several jurisdictions or entities want to use the same borrow area(s) on different cycles. This raises the issue of cumulative effects of multiple sand dredging events and/or dredging at multiple sites, particularly related to alterations to the local wave and sediment transport regime. In natural continental shelf settings, wave energy typically concentrates at shoals and diverges at holes due to wave refraction. The interaction between waves and bathymetric surface geometry dictates the resultant pattern of wave energy propagation. As such, patterns of wave energy transformation across the continental shelf depend on changes in bathymetry and the level of incident energy.

The most effective means of quantifying incremental and cumulative physical environmental effects of sand dredging from shoals on the continental shelf is through the use of wave transformation numerical modeling tools that recognize the random nature of incident waves as they propagate onshore. As such, the U.S. Army Corps of Engineer Steady-state spectral WAVE transformation model (STWAVE) was applied in this study to evaluate the potential negative impacts to coastal and nearshore sites from long-term dredging and significant removal of sand from offshore sand borrow sites. Although the interpretation of wave modeling results is relatively straightforward, evaluating the significance of predicted changes for accepting or rejecting a borrow site is more complicated.

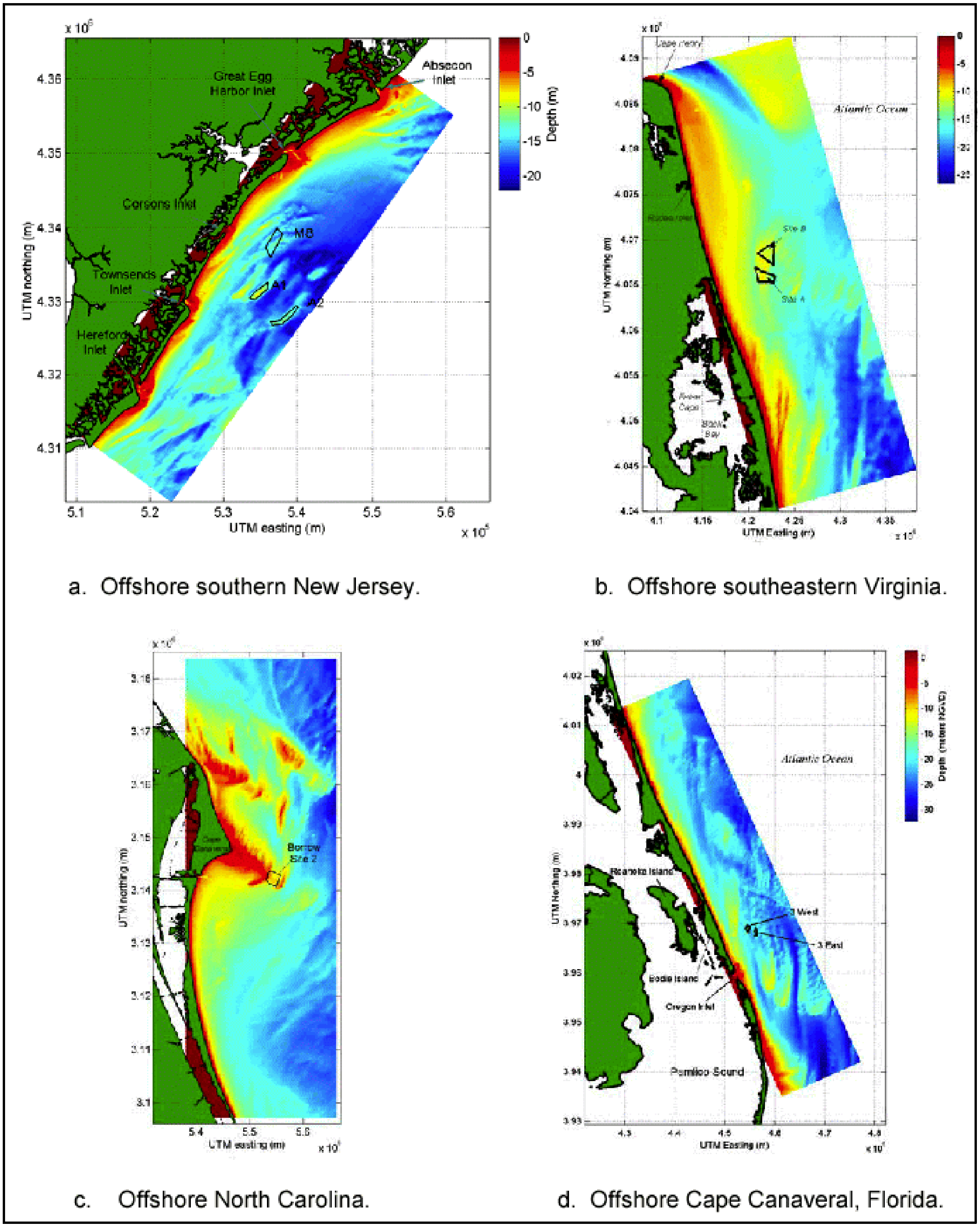

Figure 2E.1. Location diagram illustrating potential offshore sand borrow sites along the U.S. East Coast study area.

A substantial part of this study was aimed at assessing the significance of simulated changes between existing and post-dredging conditions versus natural variability in wave climate and potential sediment transport rates to determine the relative importance of predicted changes.

WAVE AND SEDIMENT TRANSPORT ANALYSIS

Spectral wave input for STWAVE model runs performed for all but one of the study sites was developed using Wave Information Study (WIS) hindcast data (1976 to 1995). For the Sandbridge Shoal study site offshore southeastern Virginia, a five-year spectral wave data record from an offshore buoy maintained by the National Data Buoy Center (NDBC) was used to develop model input spectra. The NDBC data were used over available WIS data for southeastern Virginia because the buoy record was adequately long and represented actual long-term wave conditions in the area. Along with input spectra, bathymetry grids were developed for existing and post-dredging scenarios. For each of the four modeled areas, two coarse grids were developed that have the same geographical coverage and differ only by modifications to bathymetry in the borrow area.

Overall, post-dredging wave model output for the four study sites illustrates reduced wave heights landward of borrow sites and increased wave heights at the longshore limits of the borrow site. This effect is more pronounced for cases with larger wave heights and longer periods. In addition, borrow sites in relatively shallow water tend to have greater influence on wave climate. As waves propagate across a borrow site (deeper water than the surrounding area), waves bend away from the center of the borrow site and toward the shallower edges. The net effect is to create a shadow zone of reduced wave energy immediately landward of the borrow site and a zone of increased wave energy updrift and downdrift of the borrow site. Redirected wave energy alters nearshore wave patterns responsible for longshore sediment transport.

By developing average annual sediment transport potential curves from wave modeling results, the influence of borrow site excavation on nearshore sediment transport can be quantified. Comparisons of average annual sediment transport potential were performed for existing and post-dredging conditions to indicate the relative impact of dredging to longshore sediment transport processes. Sediment transport potential is a useful indicator of shoreline impacts caused by offshore borrow sites because the computations include the borrow site influence on wave height and direction. Therefore, transport potential computations provide a quantitative evaluation of changes in incident wave energy, and they indicate how these changes in wave height and direction influence shoreline position.

ASSESSING IMPACT SIGNIFICANCE

To directly assess the impacts of offshore sand mining to coastal wave and sediment transport processes, an approach was developed that considers spatial (longshore) and temporal aspects of the local wave climate. Wave modeling was performed for the entire 20-year WIS record and five 4-year blocks of the WIS record. As such, temporal variations in wave climate are considered relative to average annual conditions. From these wave model runs, sediment transport potential curves are derived for average annual conditions (based on the full 20-year WIS record) and each 4-year period (based on the five 4-year wave records parsed from the full record). From on this information, the average and standard deviation in calculated longshore sediment transport potential is determined every 200 m along the shoreline.

Assuming the temporal component of sediment transport potential is normally distributed, the suggested criterion for accepting or rejecting a potential borrow site is based on a range of one standard deviation about the mean. If any portion of the sediment transport potential curve associated with a sand mining project exceeds one.standard deviation of the natural temporal variability (which incorporates 2/3 of the inter-annual variability) in sediment transport potential, the site would be rejected. As a management tool, this methodology provides several advantages, including:

- Observed long-term shoreline change is compared with computed longshore change in sediment transport potential. Close comparison between these two curves indicates that longshore sediment transport potential calculations are appropriate for assessing long-term natural change. Therefore, this methodology has a model-independent component (observed shoreline change) used to groundtruth the model results.

- The method is directly related to sediment transport potential and associated shoreline change. Therefore, impacts associated with borrow site excavation can be directly related to their potential influence on observed coastal processes (annualized variability in shoreline position).

- Site-specific temporal variability in wave climate and sediment transport potential is calculated as part of the methodology. For sites that show little natural variability in inter-annual wave climate, allowable coastal processes impacts associated with borrow site dredging similarly would be limited, and *vice vers*a. In this manner, the inter-annual temporal component of the natural wave climate is a major component in the determination of impact significance.

The final results of this analysis provide a spatially-varying envelope of allowable impacts in addition to the modeled impacts directly associated with borrow site excavation. The methodology accounts for spatial and temporal variability in wave climate, as well as providing a defensible means of assessing significance of impacts relative to site-specific conditions.

For the southern New Jersey shoreline, erosion and accretion trends are predicted well at all locations, including in the vicinity of tidal inlets. Along the southeastern Virginia coast, model results predict similar trends as observed long-term shoreline change, where much of the coastline is stable or slightly erosional. The location of highest erosion rates is predicted accurately by the modeling analysis. Overall agreement between modeled trends and measured shoreline change also was achieved for the North Carolina coast north of Oregon Inlet. Discrepancies between predicted and measured results likely are a result of the significant historical migration of Oregon Inlet. Along the Cape Canaveral coast, STWAVE modeling was not capable of evaluating changes in wave climate resulting from wave diffraction processes across Canaveral Shoals. In addition, these shoals likely serve as a sediment source to the beach in this region. South of Port Canaveral, away from the influence of the Cape's topographic and bathymetric features, the trends predicted by the sediment transport potential model match well with historical shoreline change.

Because modeled longshore gradients in sediment transport potential generally matched the trends in observed shoreline change, wave and sediment transport modeling provided an appropriate basis for evaluating long-term impacts associated with offshore sand mining. The methodology utilized to determine impact significance depended on a region's site-specific wave characteristics, where the method considered temporal (inter-annual) and spatial variability in wave conditions. Because the natural variability in inter-annual shoreline migration changes along the coast, certain portions of a given shoreline naturally will be more tolerant of alterations to the wave climate and associated sediment transport. Based on site-specific analyses for each of the four sites, the impacts.associated with dredging at all borrow sites were deemed acceptable. However, due to limitations with the wave modeling effort, further analyses would be required to accurately assess impacts caused by dredging for the shoreline north of Port Canaveral.

CUMULATIVE EFFECTS

To evaluate cumulative impacts associated with incremental dredging of a single site and/or the combined effects of dredging borrow sites in the same region, a cumulative assessment strategy was developed. For evaluating cumulative impacts of sand dredging at an offshore borrow site, two types of borrow site configurations were investigated. The first group of cumulative impacts involves the interaction of multiple sites in close proximity, where borrow sites cause overlapping areas of shoreline impact. The second grouping of cumulative impacts involves multiple dredging events at a single site, where dredging creates a deeper excavation for each successive event.

For the analysis of borrow sites in close proximity to each other, two case studies were evaluated: 1) Sandbridge Shoal, offshore southeastern Virginia, and 2) offshore North Carolina, in the vicinity of Oregon Inlet. At Sandbridge Shoal, the two borrow sites were oriented side-by-side and parallel to the shoreline. For offshore North Carolina, sites 3 East and 3 West were oriented front-to-back in a line perpendicular to the shoreline. To evaluate the influence of individual borrow sites relative to the combined influence of both borrow site excavations, wave model runs were performed for cases where each borrow site was excavated individually and both borrow sites were excavated in a single event. Annual sediment transport calculations were then performed for each wave modeling scenario. Superimposing the effects of individual borrow site excavations on to the sediment transport potential curve developed from the combined excavation model run was used as the basis for comparison. The results from these two cases (Virginia and North Carolina) suggest that borrow sites located in close proximity illustrate additive impacts. Therefore, the influence of multiple sites on sediment transport along a coastline is a simple additive effect, rather than a more complicated non-linear effect or amplification.

The second type of cumulative impact analysis evaluated the effect of multiple dredging events at a single site. As a borrow site is excavated to greater depths, the impact that it has on sediment transport along the shoreline will increase. Taken to extreme depths, the magnitude of impacts would be expected to reach some asymptotic value, but how these impacts vary through a range of reasonable depths was the emphasis of this study. In addition, the performance significance criterion established in Chapter 3 was tested to see what depths of excavation the criterion would be violated. Site M8, offshore southern New Jersey, was used in this analysis because the site is positioned close to shore and it has a relatively large perimeter. Therefore, deep excavations at this location would have pronounced effects on modeled sediment transport patterns at the shoreline. From the five model runs, change in transport potential varied linearly with depth of excavation.

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John Ramsey is a senior coastal engineer at Applied Coastal Research and Engineering, Inc. and has served as Project Manager and/or Principal Investigator for regional shoreline management plans, beach nourishment and coastal structure designs, estuarine water quality/flushing studies, coastal embayment restoration projects, hydrodynamic and sediment transport evaluations, and environmental studies required for permitting of coastal projects. He has authored over 60 reports, papers, and presentations in these areas of interest. He has 15 years of diverse experience in both coastal and geotechnical engineering at New York State Department of Transportation, Aubrey Consulting, Inc., and Applied Coastal. Since co-founding Applied Coastal in 1998, Mr. Ramsey has performed and provided technical oversight for projects involving coastal engineering services and numerical modeling of coastal processes. He has managed a broad range of projects including a weir and jetty design for the restoration of a coastal pond (Oyster Pond in Falmouth, Massachusetts), analysis of wave climate to determine shore protection and wave attenuation needs for a series of ferry terminals (Bermuda), beach nourishment design and offshore sand source evaluation (Winthrop, Massachusetts), analysis and design of marsh restoration channels for a dredge disposal site (Poplar Island, Maryland), and several estuarine flushing/water quality studies (e.g. Back River in Bourne, Chatham's coastal embayments, Popponesset and Waquoit Bays in Mashpee, and Nauset Marsh in Orleans). He currently is evaluating the wave climate and related sediment transport processes for a beach nourishment project in Plymouth, Massachusetts.

ON THE IMPACT OF MARINE AGGREGATES ON THE SEABED RESOURCES: PART I - SEABED SEDIMENTS

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In the United Kingdom, marine aggregate dredging has in recent years averaged some 25-28 million tons per annum, (Crown Estate 2000), which equates to 15-21% of the total UK demand. The industry maintains some 2,000 employees, over 40 British registered dredgers, and accounts for a turnover of some £180 million per annum.

Such an intensive resource-based activity will unavoidably have impacts on the environment. It is important therefore that the industry is appropriately regulated and, better still, *self-regulated* to minimize the impacts of the activity wherever possible. The United Kingdom has in place a competent, workable and sustainable licensing system to formulate and regulate the exploration and exploitation of the resources and is managed by the Crown Estate Commissioners. Notwithstanding this, the industry itself has responsibly developed effective codes of practice to improve integration of their operations with those of other sea users.

Over the past 10-15 years, a good deal of concern has been raised regarding the potential impact of marine aggregate extraction on coastal resources. These include impacts on the physical composition and stability of seabed features, on the coastline itself, on fish and fisheries, on wildlife resources and on the marine food webs upon which life in the sea and on the coastal margins depends. During the past 5-10 years, there has been a corresponding increase in the knowledge of the processes of dredging, on the marine environment and the interaction between (aggregate) dredging and the environment. This has been in response to the development of national and international laws, industry codes of practice and an increasing drive towards better efficiency while minimizing environmental conflicts. In addition to the survey and research work undertaken by the industry, primary research is funded and undertaken by the Crown Estate Commissioner (CEC), Department of the Environment, Transport and the Regions (DETR) and the Ministry of Agriculture, Fisheries and Food (MAFF).

ENVIRONMENTAL IMPACTS

EC Directive 85/337/EEC “The Assessment of the effects of certain public and private projects on the Environment” was adopted in June 1985 and came into effect in July 1988. This directive requires that certain development projects may require an Environmental Assessment (EA) to be carried out prior to granting of consent. The extraction of marine aggregates may, under certain circumstances, come under the listing of this directive.

Three groups of impacts must be considered when preparing an Environmental Assessment (from Campbell 1993). It is important to remember impacts can be positive as well as negative and that impacts will vary in their significance. Importantly, impacts will also vary on a case by case basis.

- Impact on Physical Resources
- Impact on Biological Resources
- Impact on Other Legitimate Users of the Sea

PHYSICAL RESOURCES

By the very nature of the activity, the processes of dredging will impact on the seabed and the surrounding physical environment. The effects and their significance will vary according to the type of dredging, but there will be broad similarities between the many mechanisms of dredging.

One can quickly realise that a large body of data is required to illuminate the impact of dredging activities. Good scientific quality field data will greatly enhance the application for development of any licence to dredge.

Before aggregate dredging, it is common practice to employ competent marine survey companies to prospect for prime resource locations. These companies use a range of high technology equipment, which enables not only the surface extent of the resource but also the depth and distribution of the resource to be assessed. The data will include the possibilities of any contaminants such as silts and obstructions such as wrecks. Survey companies use digital echosounders with heave compensators to give a true profile of the seabed prior to dredging. Sidescan sonar allows the surface topography and micro-topographical structures such as sand waves and ripples to be mapped. Digital mosaicing of the sonar data allows high resolution maps to be produced (Figure 2E.2).

Shallow continuous seismic profiling provides estimates of the depth of the resource below the seabed and thus allows the total potential volume of the resource to be assessed. Physical samples obtained with large grabs and vibrocoring techniques will groundtruth the electronic information and provide tangible evidence of the quality of the resource.

During these surveys or subsequent detailed surveys, if not determined in sufficient detail by the desktop study, data may also be obtained on

- local hydrography including tidal and residual water movements – alteration of water depths by removal of the substrate may create new patterns of water flow, thus creating erosion or deposition in areas not previously affected;

- wind and wave patterns and characteristics, average number of storm days per year – removal of an offshore bank may allow storm waves to reach previously protected beaches;

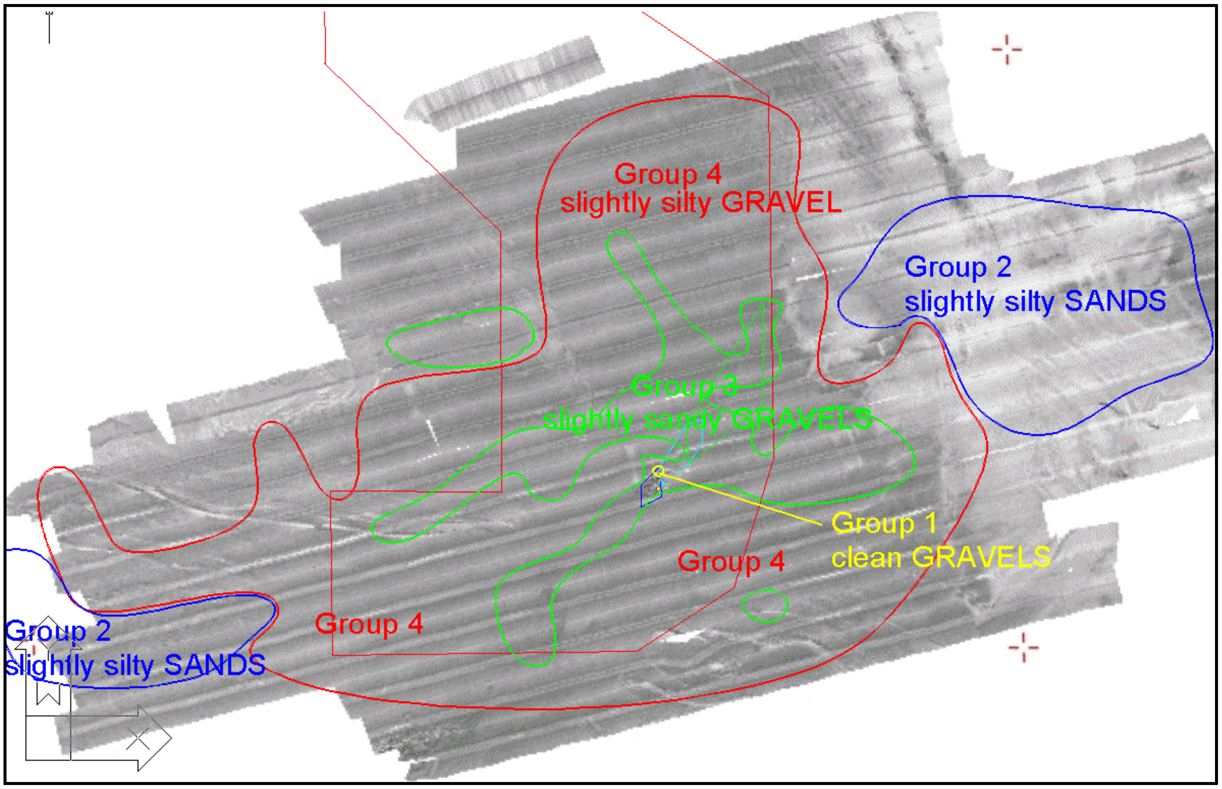

Figure 2E.2. Sidescan sonar mosaic of the actively dredged and surrounding seabed of Production Licence Area 122/3 North Nab on the South coast of the UK, East of the Isle of Wight in the English Channel. Statistical non-parametric multivariate analysis of some 150 sediment samples enables contours of sediment boundary to be determined. Changes in the natural distribution of the sediments due to modification by the dredging activity is visually more identifiable.

- bedload sediment transport including occurrence of sand waves – high transport rates will infill disturbances caused by dredging and possibly indicate that the indigenous biological communities may be already adapted to a higher level of natural disturbance and be more capable of coping with anthropogenic disturbances;
- alterations to natural suspended sediment loads;
- relationship and significance to storm or wave-induced bottom activity;
- transport and settlement of fine sediment suspended by the dredging activity;
- dispersion of an outwash plume resulting from hopper overflow or onboard processing and its impact on normal and maximum suspended sediment load;
- implications for prevailing wave/current regime and local water circulation resulting from removal or creation of (at least temporarily) topographical features on the seabed;

- implications for the modification of longer term processes and bed-load movement; and
- nature and type of nearby coastline and implications for coastal erosion

Sediment Plumes

The dredging process by its very nature disturbs large quantities of sediment. In recent years a growing collection of alleged and largely unsubstantiated concerns of the impact of sediment plumes formed in the water column have developed. Allegations have, for example, suggested dredging turns the seabed into a 'biological desert' around the dredge site by smothering all forms of bottom-dwelling life.

Sediment plumes may, in the case of trailing dredgers, be formed by the action of the draghead on the seabed, by the rejection of unwanted material from the dredger during onboard processing ('screening') and from over-spilling of surplus sediment laden waters from the dredge hopper. For grab dredging with a conventional clamshell grab, the potential effects may stem from the action of the grab on the seabed, losses from the grab whilst ascending and losses by over-spilling from the cargo hopper. Potentially there may be a small loss as the grab descends to the seabed and is 'washed clean.'

Sediment plumes have been a serious object of concern because, amongst other concerns, the potential impact has been perceived to continue well outside the actual area of dredging. In the UK, early modeling studies were based purely on standard settling velocities for the various fractions of sediments, estimated to be present in the overspill. Plumes of very fine sand settling in 50m of water may then travel up to 11km from the dredge site, fine sand up to 5km, medium sand up to 1km, and coarse sand up to 50m based on simple Gaussian diffusion simulations. While this is indeed possible, two questions arise: (1) does this phenomenon actually occur? and (2) will it have a significant impact?

We have over the past eight years conducted an extensive series of research campaigns, both physical and biological, in order to understand the scope of the potential problem on a most realistic or probable case basis rather than the worst case precautionary approach. This data is then input back to the modeling process in order to calibrate and refine the predictive models. Various projects have been financed by individual dredging companies, associations and national government bodies.

With respect to the question 'does the phenomenon actually occur' we have published clear evidence that although the plumes undoubtedly travel a distance beyond the dredge zone, this distance is generally an order of magnitude less than at first predicted. The work has involved extensive field measurements of the 'source terms' i.e. measuring what quantities of sediments are actually lost to the water column and are therefore used to estimate settling thicknesses etc. Further, the plumes themselves have been mapped in detail to provide snapshots of the size and quantities of sediment in suspension at different distances from the dredger. This has provided, for the first time, real field calibration of what the models were trying to predict. It was observed that the sediments over-spilling and rejected by screening do not behave with typical settling velocities and that they act together to form fast moving 'density currents'. These drive themselves towards the seabed far faster

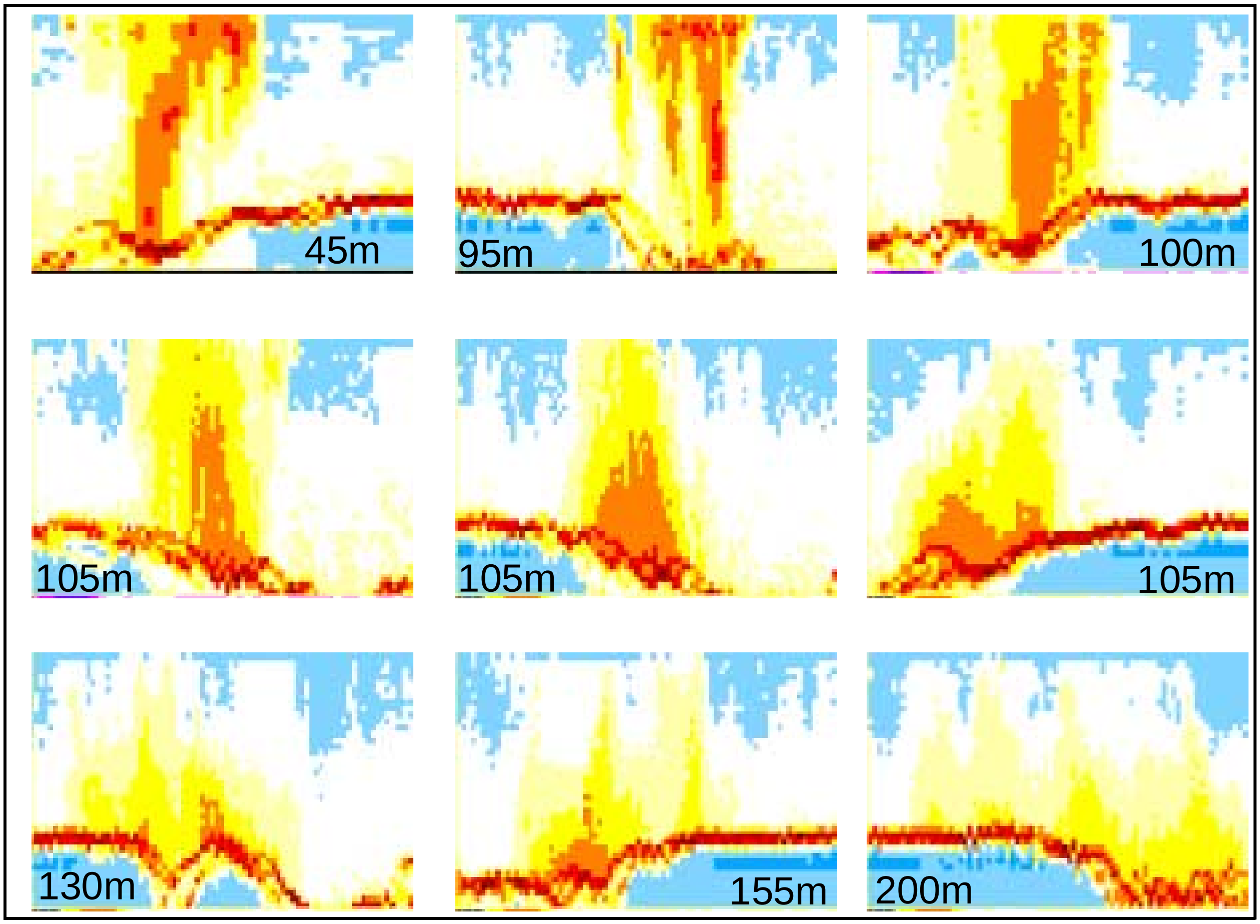

Figure 2E.3. ADCP backscatter plumes from the anchored suction dredger City of Chichester loading an all-in cargo without screening. Plume is virtually back to background conditions at 200m.

than single particles might alone fall, thus limiting the spatial extent of the plume. Sediments are now known to reach the seabed largely within a distance of 300-500m from the dredge site, with the finer sediments reaching distances of only 1-2km in currents of two knots before being indiscernible from background suspended solids concentrations. These discoveries, simultaneously but independently observed elsewhere in the world by other workers (Land *et al.* 1994; Whiteside *et al.* 1995), have resulted in new predictive models being developed, the latest of which will be employed in a study just commencing in the UK. Such field results are important in proving not only how far the sediments have traveled but also whether or not suspended sediment plumes may reach sensitive seabed communities such as coral reefs or protected areas such as sites of special archaeological importance.

To assess the question 'is the impact significant?' and therefore attach the correct emphasis to this issue in comparison with other issues (given only a finite financial resource for assessment) we have recently completed a fundamental study of a non-screened dredge area on the south coast of Britain. This site has been dredged since 1991 by anchored suction dredgers and rarely (since late 1998) by trailing suction dredgers, removing a total of nearly 2 million tons over that period. The gravelly

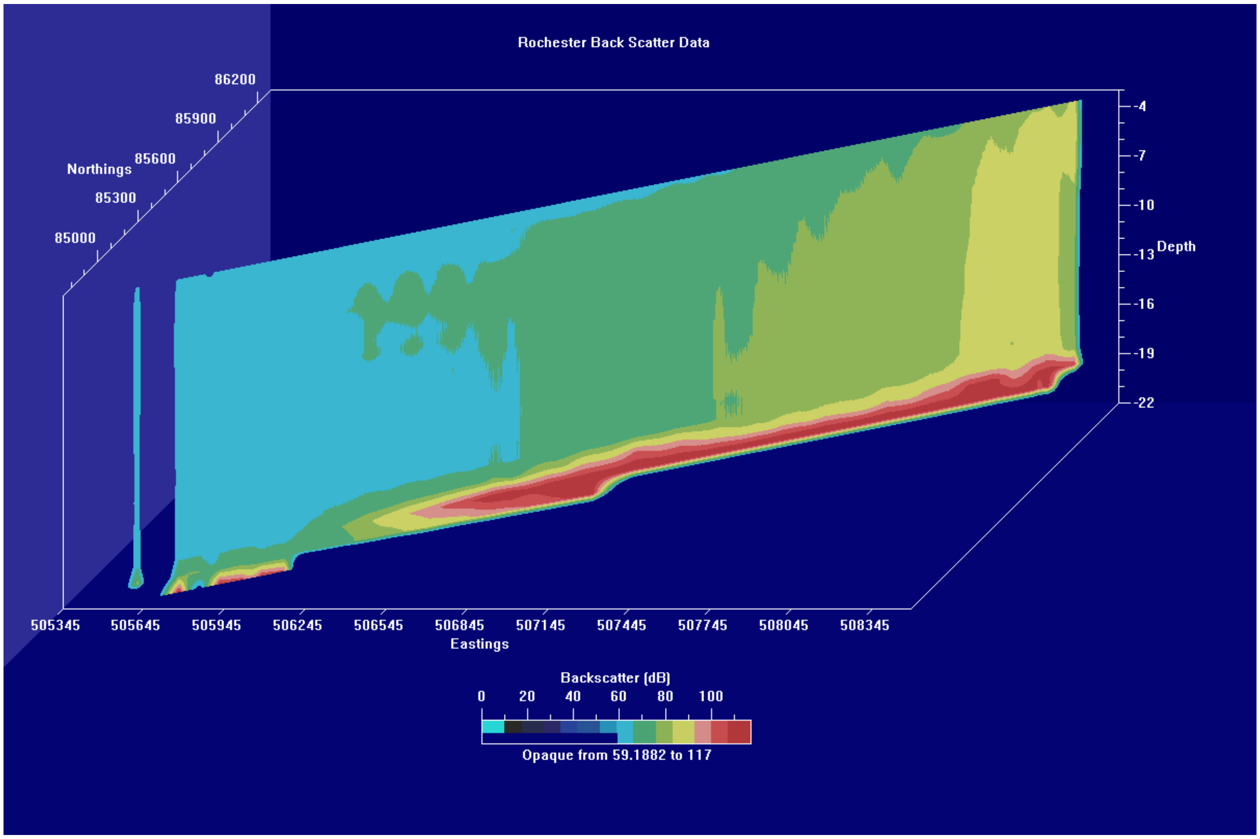

Figure 2E.4. Cross section ADCP backscatter data (not compensated for attenuation) which may show the existence of the dynamic phase of the density current followed by development of a near bed benthic boundary layer of suspended sediments (Owers Bank 1995).

resource has been extracted from a very small target area of roughly 400m x 400m, within a larger licence. Detailed sidescan sonar mapping has confirmed the areas that have been dredged by observing the extent of small pits formed on the seabed.

We have closely studied the seabed surrounding the dredge pits and worked area to ascertain the physical and biological impacts that may have been caused by the working of the licence. Over 200km of high-resolution sidescan sonar imagery and 130 seabed samples have been obtained. The study area extended up to 10km either side of the dredge zone (one tidal excursion) in order to identify far-field effects. The results so far clearly show that the physical impact of dredging on the seabed (without screening) is limited to a zone within approximately 300m downtide of the dredge area. There is no evidence of suspended sediments falling to the seabed beyond this zone, which may be manifested as infilling of small pits by fine sediments, siltation within crevices or development of migratory sand ripples. However, there is some statistical evidence that the surface sediment samples have a greater sand fraction within the excursion track of the plume than those samples on either side. Further sampling of the seabed and analysis will confirm or disprove this link.

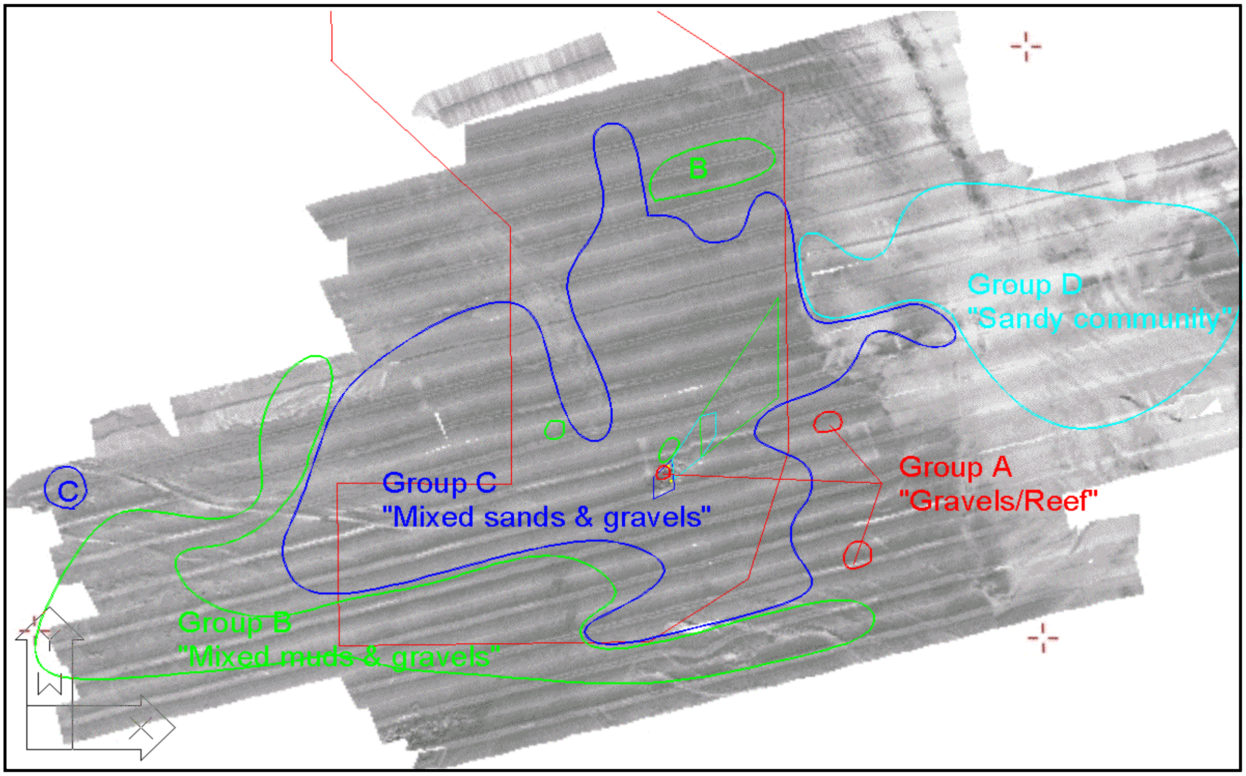

Figure 2E.5. Sidescan sonar mosaic of Production Licence Area 122/3 (active area pinpointed by the Group A community type in center of licence). The fact that there are no distinctive breaks in the community type along the axis of the tidal dispersion (to the SW and NE of the site) indicates that there are no benthic biological impacts of significant magnitude to alter community type. Specifically the extension of the Group B (muddy gravels community) across the south of the site, and lack of any Group C (sandy community) reinforces this.

The biological information shows us that there is a reduction in the species diversity and population density within the actively dredged zone as may be expected. However, the data also shows us that small areas (less than 250m^2) not dredged very recently (within last few weeks / month) may have already begun to recover exhibiting a slight increase in diversity. Other sites which show older dredge marks (from the sidescan sonar) have increasing population density as well as increasing species diversity.

The data clearly show that, for the no-screening scenario, impacts ‘experienced’ by biological communities are confined to the immediate dredge area, significantly within 100m and certainly within 300m downtide. Further, examinations of the data suggest that recolonisation may be much quicker than hitherto considered.

SUMMARY

The instinctive emotional impressions of aggregate dredging activities are that, among a variety of impacts there will be mass disturbance at the seabed, substantial loss of benthic resources through disturbance and smothering and subsequent devastational impacts on fisheries, other marine life and ultimately, man. Coastal erosion is also often quickly linked with dredging activities. However, the majority of the scientific evidence does not support these views where activities are rationale, sensible and planned. Obviously, on a worldwide basis there are cases of real conflict, but these cases should be rare and largely avoidable.

This paper attempts to show that while the potential for impact may be large, through careful objective planning and monitoring the actual impacts can be reduced. Effective mitigation strategies and procedures can be developed and implemented with minimum cost and real benefits.

This study was funded by the Minerals Management Service, U.S. Department of the Interior, Washington, D.C., under Contract Number 1435-01-99-CT-30980. The study was supported by members of the UK British Marine Aggregate Producers Association, in particular United Marine Dredging Ltd.

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ON THE IMPACT OF MARINE AGGREGATES ON THE SEABED RESOURCES: PART II - BENTHIC BIOLOGICAL RESOURCES

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The biological "footprint" of impact of marine aggregate dredging has been established at an intensively dredged licence on the south coast of the United Kingdom. The species diversity, population density and biomass of benthic macrofauna to the east of the Isle of Wight, UK, is typical of that recorded in UK waters. Average benthic macrofauna biomass as a whole is equivalent to 4.06 grams Carbon per m^2. Benthic biomass values for the North Sea and Baltic Sea are reported to be 1.7g C per m^2, with an equivalent value for estuaries being 10-17 g C per m^2.

Carried out in collaboration with Coastline Surveys Limited, the studies have established that dredging while at anchor, using a modern 2,000-ton suction dredger, at the North Nab study site is associated with a reduction of species diversity of 66%, population density (87%) and biomass (80-90%) of benthic invertebrates. The deposits are loaded as an 'all-in' cargo with no discharge of screened material at this site. In this case, the suppression of invertebrate species variety, population density and biomass appears confined to the dredge sites themselves, with no evidence of impact outside the boundaries of the dredge pit.

Some distance outside the dredge site, there is evidence of an enhancement of benthic diversity and biomass in an elongated 'halo,' which extends for a distance of up to 3 km from the dredge site. Average benthic macrofauna biomass is equivalent to 17 grams carbon per m^2, some 4 times greater than the surrounding deposits. It is worth noting that these values are similar to those in estuaries where benthos is enhanced by fragmented debris from coastal wetlands.

Figures 2E.6 and 2E.7 show the sensitivity of species diversity to dredge scenario. In Figure 2E.6 we can see that one single species accounts for only some 20% of the total within the non-dredge area, with 32% corresponding to the dredged site. However, in Figure 2E.7 we can see that within the anchor dredge site one species accounts for almost 80% of the total diversity, compared to nearly 40 species accounting for a similar fraction of the total species present in the trailer dredge site.

The cause of this enhancement is unknown, but from studies elsewhere it is possible that the zone of faunal enhancement reflects the settlement of organic components associated with fragmented invertebrates discharged in the outwash stream. From our monitoring aboard the dredge vessel, an estimated 17.36 tons ash-free dry weight of organic matter may be released per year in the outwash of dredgers operating within the restricted worked site within the much larger North NAB licence as a whole. This material is likely to be carried beyond the boundaries of the Licence Area along the axis of the tidal excursion: whether this is sufficient to account for the enhanced values of biomass 1-3km from the dredge site is unknown.

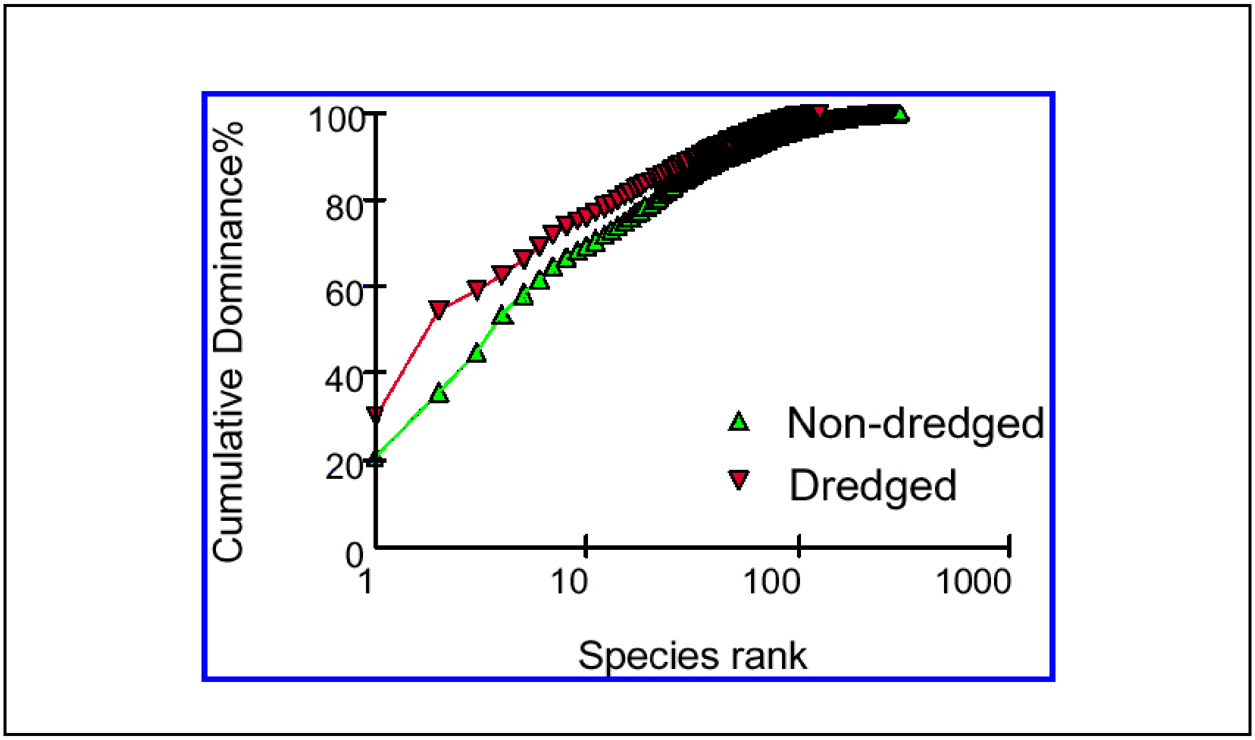

Figure 2E.6. Dominance curves plotted for pooled samples from dredged and non-dredged sites of Production Licence 122/3 North Nab.

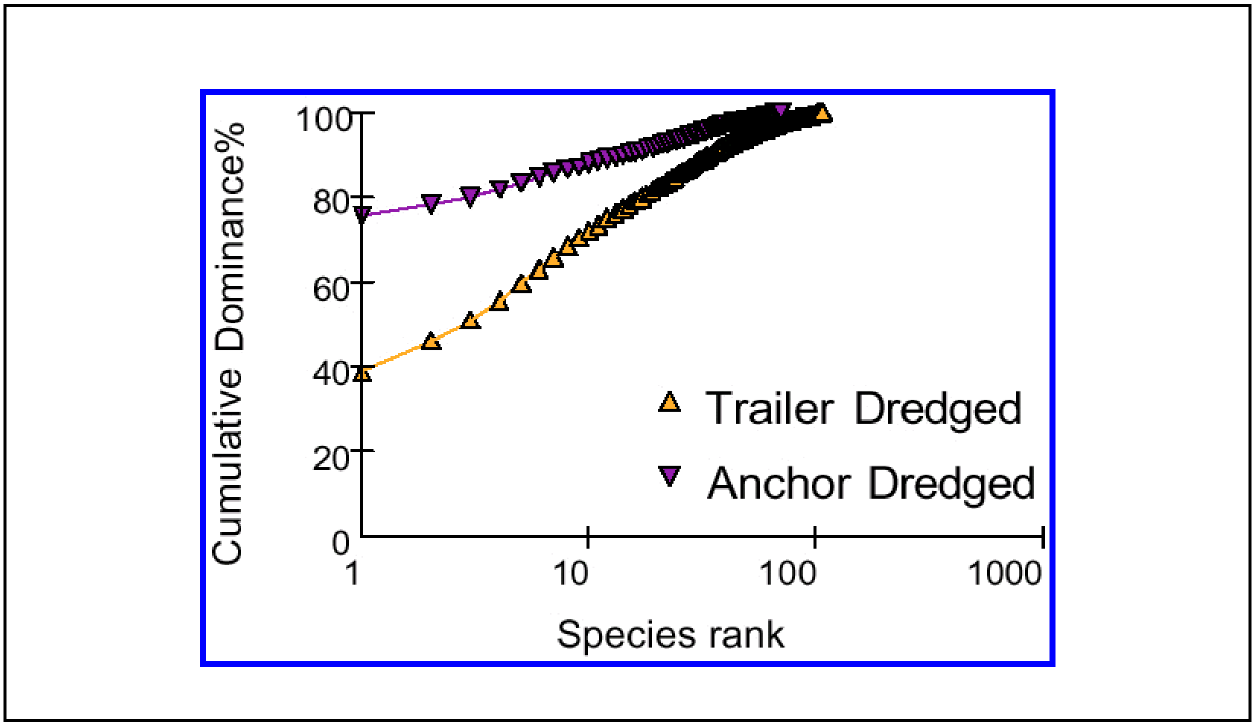

Figure 2E.7. Dominance curves plotted for pooled samples from within the anchor dredge site and within the trailer dredge part of Production Licence 122/3.

In contrast with the intensively anchor dredged site, the trailer dredged site has been less exploited. Communities within this site are largely similar to those in the surrounding deposits. This suggests that the processes of recolonization and recovery are sufficient to keep pace with the rate of removal of biomass when dredging. It must be noted that the key factor here may be *intensity* rather than *method* of dredging used.

Examination of the invertebrate communities at sites that have been left undredged for known times suggests that initial recolonization by mobile components of the benthos can occur within weeks with some 70-80% of the species variety returning. This process is often accompanied by a similarly rapid increase in population density, although not as frequently, but with both of these stages in the recolonization sequence being substantially completed within three to six months after cessation of dredging. Restoration of biomass is achieved by growth of the small individuals that recolonise the deposits. This stage is incomplete even after 18 months compared with areas some distance away from the dredge site. This finding is in keeping with anecdotal information available from the literature.

The results for trailer-dredged studies indicate that species diversity may initially recover much quicker, as mentioned above. Population density is not dissimilar to anchor dredge sites, with biomass recovering to within 80% of the undredged sites within three months.

A further study (not reported here) has been carried out at a dynamic wave-disturbed site in the North Sea. The composition of the cargo is adjusted by screening of the dredged material, excess sand being discharged overboard. In this case, the rate of recolonization was sufficiently fast to be in equilibrium with the rate of trailer dredging. No significant suppression in species variety or population density was recorded compared with communities in the surrounding deposits. Neither could we detect any net effect of screening on species variety and population density outside the dredged area, despite the significant quantities of material rejected to the seabed. As in the case of the North Nab study, however, restoration of biomass evidently takes at least 18 months following cessation of dredging.

We have the following general hypothesis based on the two study sites:

1. The degree of suppression of the fauna in the dredge site itself is clearly dependent on the intensity of dredging. In high intensity dredging (North Nab) the suppression of population density, species variety and biomass can be as high as 60-80%. In areas that are dredged less intensively by trailer techniques, the suppression is either less than at anchor dredge areas (North Nab), or undetectable (North Sea).

2. There is no evidence of an impact outside the immediate dredge sites.

3. Both sites show some evidence of an enhanced biomass and population density at some distance from the dredge site, possibly reflecting the deposition of organic components from fragmented invertebrates discharged in the outwash.

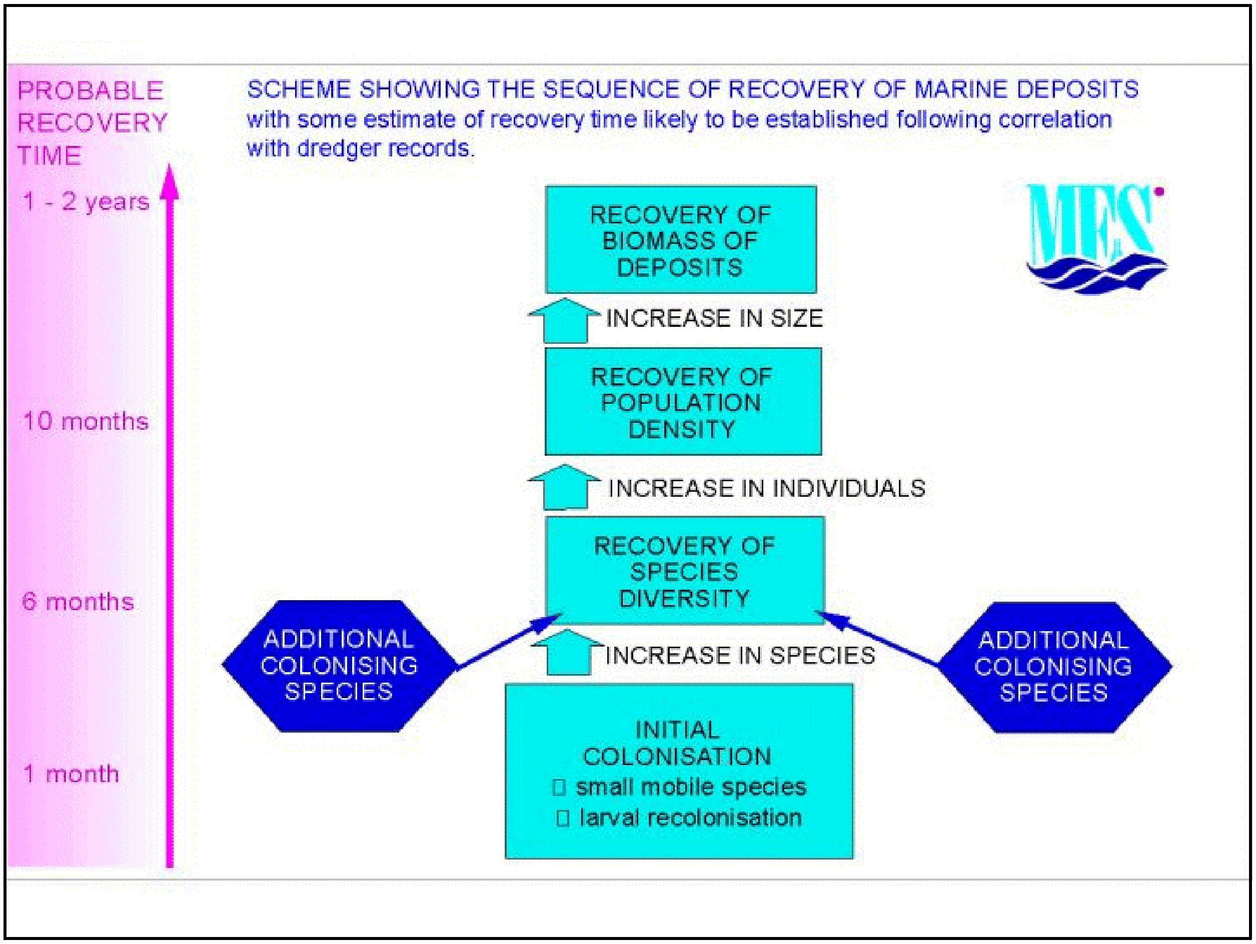

Figure 2E.8. Generalized flow diagram showing the sequence of recolonization and recovery in marine gravel deposits, based on the population density and species diversity in gravel deposits following known periods since the deposits were anchor dredged.

4. Recovery of population density and species variety can be very rapid indeed. This depends on the degree of disturbance to which the area is subjected under natural conditions. In shallow water wave disturbed areas such as the North Sea, colonising species are mobile and well adapted to rapid recolonization. In more stable (equilibrium) communities such as occur on coarse rocks and cobbles, recolonization is slower.

5. Recovery of biomass is achieved by growth of the recolonising individuals. In this case restoration of biomass generally requires at least several years. In some of the deeper water communities that we have recently analysed, individual species may be at least 20 years old. This implies that deep-water stable equilibrium communities may require a time of at least 20 years for recovery, compared with two to three years in shallow water coastal sands.

6. Anchor dredging has a significant impact on the species variety, population density and biomass of benthic macrofauna, although without screening is largely limited to within a hundred meters of the active dredged zone. Trailer dredging, on the other hand, appears to

have a much smaller impact on species variety, population density and biomass, although this may be limited to the lower intensity of trailer dredging activities in the study areas. However, species recovery data suggests that recovery is quicker for trailer dredge areas, due to the reduced distance of 'inwalk' for colonising species (only the widths of trailer tracks), compared with the larger total destruction of an anchor dredged area.

7. On the available evidence collected herein, we would suggest that trailer dredging over a wide area at an intensity carefully matched to the potential times for species recovery (indicated by the response times to natural disturbances e.g., turbulent shallow water or less disturbed deeper waters) will be more sustainable than intensively dredging small areas of seabed.

Importantly, the detailed analyses of these and other data for this project have revealed the susceptibility of analysis methods to 'noise' within the datasets. This is caused by inter-sample variability due to significant under-sampling of the diverse benthic macrofauna of sands and gravels by conventional methods. We have shown that single samples of macrofauna obtained from a 'Hamon' type grab contain sufficient taxa to use non-parametric multivariate analytical techniques to define community composition. Values for individual variables, such as species variety are, however, heavily dependent on the number of replicate samples taken. At least three replicate samples are required to obtain a satisfactory assessment of the species composition of the macrobenthos of sands and muds, but that 13 or more replicates are required for gravels. The repercussions of this in terms of scale, frequency, density of sampling sites and number of replicate samples and subsequent cost implications must be carefully considered when designing suitable monitoring protocols.

This study was funded by the Minerals Management Service, U.S. Department of the Interior, Washington, D.C., under Contract Number 1435-01-99-CT-30980. The study was supported by members of the UK British Marine Aggregate Producers Association, in particular United Marine Dredging Ltd.

Dr Richard Newell graduated from the University of London in 1962 with First Class Honors and obtained his Ph.D. in 1964. He was awarded a D.Sc. in 1974 for contributions to marine science. Publications include over 150 research papers on various aspects of marine ecology, books on marine plankton (1963, with five subsequent editions), books on biology of intertidal animals (1970 and 1980), and on the physiology of marine animals (1976). Dr. Newell is Managing Director of Marine Ecological Surveys Limited, a consultant company that he established in 1975.

DEVELOPMENT AND DESIGN OF BIOLOGICAL AND PHYSICAL MONITORING PROTOCOLS TO EVALUATE THE LONG-TERM IMPACTS OF OFFSHORE DREDGING OPERATIONS ON THE MARINE ENVIRONMENT

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BACKGROUND

The Minerals Management Service (MMS) International Activities and Marine Minerals Division is charged with environmentally responsible management of federal Outer Continental Shelf (OCS) sand and gravel resources, that is, those resources lying seaward of the state/federal boundary. These resources must be managed on a long-term, large-scale, system-wide basis to ensure that environmental damage will not occur as a result of continual and prolonged use. Sand sources that are to be used repeatedly may require additional biological and physical monitoring to ensure that adverse impacts to the marine and coastal environments do not occur. Therefore, MMS funded this current study to develop biological and physical monitoring templates for the federal OCS sand resources.

OBJECTIVES

The project objectives were to 1) develop field monitoring systems to evaluate the physical and biological impacts of using federal offshore borrow areas on a long-term basis; 2) examine the feasibility, appropriateness, and desirability of putting these monitoring systems into place and identification of the need for collection of supplemental biological data or physical modeling information in the federal borrow areas; and 3) identify the need for and collection of any additional geological/ geo-physical data to define available sand supplies for planned projects within the study areas.

DESCRIPTION

This study consisted of a comprehensive literature review to identify the geophysical processes and biological ecosystems that would be affected by OCS sand mining for beach nourishment and habitat protection. Then, the project team identified those ecological resources (physical and biological) that would have the greatest potential for being affected by offshore sand mining, both directly and indirectly. Impacts occurring from a one-time dredging event at a given location or as repeated dredging of an area over some time period were included.

Direct physical impacts to seabed characteristics include removal and disturbance of the substrate and exposure of an underlying layer with different characteristics and changes in grain size of surficial sediments due to settling of fines from overspill plumes or sediment reworking. Indirect physical impacts include changes related to erosion and deposition. These changes will only be significant where they result in biological impacts. Indirect impacts include changes to the waves within and beyond the borrow area, changes to bed shear stresses and related seabed mobility due to changes to waves, and changes to near bed current velocities driven by tides, wind, and large-scale phenomena. Based on the literature review, it was determined that, from a purely physical perspective, the only change of consequence is the potential impact of dredging on shoreline change. All other physical changes and impacts caused by dredging are important only if they result in a biological impact, directly or indirectly. Thus, four physical monitoring and modeling protocols were developed to address these issues (summarized in Table 2E.1):

1. Bathymetric and Substrate Surveys
2. Sediment Sampling and Analysis
3. Wave Monitoring and Modeling
4. Shoreline Monitoring and Modeling

For marine biota, the biological communities and associated habitats that were determined as most likely affected by OCS sand dredging were soft substrate benthic communities; nekton; and marine mammals and wildlife. Studies of the recovery of soft substrate benthic communities following dredging have indicated that communities of comparable total abundance and diversity can be expected to re-colonize dredge sites within several years. However, even though these re-colonized communities may be similar in terms of total abundance and species diversity, their taxonomic composition, in terms of dominant species and species abundance, is often very different from pre- to post-dredging. The ecological utilization of ridge/shoal features by fish species as critical habitat for spawning, overwintering, or foraging area is relatively unknown, and should be addressed. However, the greatest potential effect to the fish community utilizing a dredge borrow area is an alteration in trophic energy transfer from the benthos to the fish population. For marine mammals and other marine wildlife such as sea turtles and birds, of the identified direct and indirect impacts, the greatest potential for serious effect is associated with direct collision with the dredge vessel or entrainment in the suction dredge. Thus, two biological monitoring protocols were developed to address these issues (summarized in Table 2E.2):

1. Benthic communities and their trophic relationships to fish
2. Marine mammal and wildlife interactions during dredging

A key component of any long-term scientific study or monitoring program is the need to adapt the original study design and approach to reflect information and understanding gained from on-going studies during the execution of the program. Thus, it is recommended that the MMS establish a permanent scientific review/advisory board to oversee the implementation and evolution of the OCS sand monitoring program and advise the MMS on the program components. Another key role of the scientific advisory board is to ensure the scientific validity and integrity of the monitoring programs and their findings. Long-term monitoring programs will create extremely large databases of

Table 2E.1. Summary of requirements of the physical monitoring protocols.

<table>
<tr><th rowspan="2">Protocol</th><th rowspan="2">Potential Impact</th><th rowspan="2">Objectives</th><th colspan="2">Requirements</th><th rowspan="2">Cost/Year</th></tr>
<tr><th>Monitoring</th><th>Modeling</th></tr>
<tr><td>Bathymetry and Substrate</td><td>Changes to the morphology and substrate characteristics of the borrow deposit and surrounding area (particularly for ridges and shoals) and potential physical (waves and shoreline change) and biological impacts.</td><td>1. Determine the location and quantity of sand removed and change to bathymetry caused by dredging operations.
2. Quantify subsequent changes to bathymetry in the immediate vicinity of the borrow area.
3. Quantify potential changes to the overall borrow deposit feature (e.g. ridge or shoal if one exists)</td><td colspan="2">1. Hydrographic Survey (single beam acoustic) plus Side Scan Sonar: or,
2. Hydrographic Survey with Multibeam technique; or,
3. LIDAR/SHOALS or other methods that are able to achieve specifications and requirements of the Protocol.</td><td>$77,500-130,000</td></tr>
<tr><td>Sediment</td><td>Changes in sediment texture and total organic content and subsequent biological impacts.</td><td>1. Define changes to texture caused by removal, sedimentation and indirect erosion/deposition processes.
2. Potential changes may serve the assessment of changes to morphology of features at the borrow deposit (e.g. ridges and shoals).
3. Determine changes in TOC to assess potential impact to benthic communities.</td><td colspan="2">Collect sand samples at the location of benthic samples and test for grain size distribution (both sieve and hydrometer test or equivalent) and TOC method based on high temperature combustion.</td><td>In biological protocol costs</td></tr>
</table>

Table 2E.1. (continued)

Protocol	Potential Impact	Objectives	Requirements		Cost/Year
			Monitoring	Modeling	
Waves	Change to wave transformation patterns over the dredged area with possible ultimate impact of shoreline change	1. Develop a continuous record of wave conditions starting from first access of borrow deposit. 2. Assess influence of initial changes to bathymetry. 3. Assess influence of subsequent (direct and indirect) changes to bathymetry.	Deepwater wave data through combination of measured directional data and non-directional data and available hindcast data.	Complete nearshore wave transformation modeling to transfer deepwater waves to the borrow deposit, over the borrow deposit and into shore (ultimately for input to the shoreline change model).	$113,000-154,000
Shoreline	Shoreline erosion directly attributable to dredging at the borrow deposit.	1. Document actual shoreline change (regardless of cause). 2. Assess the impact of dredging at the borrow deposit.	1. Beach and Nearshore Profile Surveys twice per year every 300 m. 2. Georegistered aerial photographs and digitized shoreline twice per year.	Apply GENESIS model or equivalent to assess longshore sand transport and related shoreline change with and without project prior to and after dredging commences (comparing to measured change in latter case).	$28,000-51,000

Table 2E.2. Summary of requirements of the biological monitoring.

Protocol	Potential Impact	Objectives & Justifications	Requirements		Cost/Year
			Monitoring	Analysis	
Benthos and Fishes; Trophic Transfer	1. Total removal/ loss of infauna and epifauna at borrow site with recolonization by benthic organisms occurring within 1-5 years (possibly longer) to a community with comparable pre-disturbance abundance, diversity and biomass but different species composition and community structure. 2. Altered foraging efficiency with resultant effects on individual size and weight. 3. Altered species composition of fish prey base; altered productivity and energy transfer effects on the food chain.	• To determine the effects of dredging activities on benthic communities and the transfer of energy from benthic communities to fishes. While overall abundances of benthic organisms have been shown to return to pre-dredging levels in some cases within a year or two after dredging, species composition may be different and the ability of fishes to utilize such altered assemblages for prey is uncertain.	1. Collect 0.10 m^2 benthic infauna samples from multiple strata at both impact and reference locations prior to dredging and in years 1, 3, 5 and 7 following dredging. 2. Collect stomachs from numerically dominant or recreationally important species from multiple strata at both impact and reference locations prior to dredging and in years 1, 3,5 and 6 following dredging.	1.a. Infauna taxonomy for comparison with fish gut contents analysis and for determining secondary productivity values. 1.b. Biomass measurements for determining secondary productivity values. 1.c. Carbon and Nitrogen stable isotope measurements of key benthic prey species for fish. 2.a. Fish gut analysis for comparison with infauna taxonomy. 2.b. Carbon and nitrogen stable isotope measurements of fish muscle tissue.	1. \$110,000-\$169,900 2. \$105,460-\$147,900

Table 2E.2. (continued)

Protocol	Potential Impact	Objectives & Justifications	Requirements		Cost/Year
			Monitoring	Analysis	
Marine Mammals & Wildlife	Injury or death of animal; potential disorientation	1. To obtain site-specific marine wildlife observation and behavior data during OCS dredging events. This information will assist state and federal regulatory agencies in assessing the appropriateness of imposed marine mammal and wildlife protection mitigation requirements and guide any necessary revisions of future mitigation requirements. 2. To obtain and assess marine wildlife stranding data for potential relationships between stranded animals and animals observed during OCS dredging. This information will assist state and federal regulatory agencies in assessing whether there exist any obvious relationships between post-dredging marine wildlife strandings and the OCS dredging event. 3. To provide a means for implementing environmental mitigation requirements designed to minimize potential hazardous interactions with marine mammals and protected wildlife during dredging events. (This is the only "operational control" monitoring program element included in the OCS sand dredging protocols.)	1. Collect observation and behavior data on marine mammals and wildlife during OCS dredging events. 2. Collect marine mammal and wildlife stranding data for a 60-day period following dredging operations. 3. Implement imposed environmental mitigation requirements designed to minimize collisions or harmful interactions between marine wildlife and dredging equipment.	1. Compare observation data with stranded animal data and document marine wildlife behavior during dredging events. 2. Compare marine wildlife data with observation data collected during the dredging event as well as with stranding data recorded for comparable time periods during non-dredging years.	No cost estimated

information that must be properly organized and documented with appropriate metadata. Therefore, data management guidelines are recommended that will optimize use of the data for identifying potential long-term impacts and support of decision-making.

The report identifies information gaps that will need to be addressed either prior to the implementation of the monitoring program or concurrent with its implementation.

Study Products:

Research Planning, Inc., Baird & Associates Ltd., and Applied Marine Sciences, Inc., 2001. Development and Design of Biological and Physical Monitoring Protocols to Evaluate the Long-term Impacts of Offshore Dredging Operations on the Marine Environment. U.S. Department of the Interior, Minerals Management Service, International Activities and Marine Minerals Division (INTERMAR), Herndon, VA. OCS Report MMS 2001-089, 116pp.

Jay A. Johnson has an M.S. from San Diego State University in marine ecology, and both a B.S. and B.A. in biological oceanography and marine biology, respectively, from Humboldt State University. He is a principal and managing partner at Applied Marine Sciences, Inc., Livermore, California, an environmental consultancy specializing in aquatic ecosystems. Mr. Johnson has over 25 years of experience assessing marine and aquatic ecosystems and involvement on major industrial projects gained through 14 years as a marine biology consultant and 11 years with a major multi-national oil and gas company. He has been involved in the design and execution of marine baseline surveys and long-term monitoring programs for coastal nuclear and fossil fuel power plants, wastewater treatment plants, coastal and offshore oil and gas platforms and facilities, and fiber optic cable installations. He has worked on projects in California, Alaska, the Gulf of Mexico, the North Sea, the Gulf of Arabia (Middle East), South America, Russia, and Kazakstan.

Rob Nairn is a principal with Baird & Associates, coastal and river engineers and scientists. He specializes in numerical modeling of sand and cohesive sediment erosion/sedimentation processes in offshore regions, along coasts and in rivers and estuaries. He has a background in wave generation, nearshore wave transformation, hydrodynamics, sediment transport and erosion/sedimentation processes. Dr. Nairn has extensive experience in applying this background to engineering and scientific investigations involving assessment of natural processes and evaluation of the impacts of a wide range of projects associated with this environment including dredging, coastal protection, ports and harbors. Dr. Nairn has a Ph.D. in coastal processes from Imperial College, London, England, and an M.S. in coastal engineering and a B.S. from Queen's University, Canada.

Jacqueline Michel received her Ph.D. in geology from the University of South Carolina in 1980. She is currently the president of Research Planning, Inc. She is a member of the National Academy of Sciences, Ocean Studies Board and is on the Science Advisory Panel to the President's Ocean Policy Commission. Dr. Michel is an expert in oil and chemical spill science, coastal processes, natural resource mapping, and natural resource damage assessment.

EXAMINATION OF REGIONAL MANAGEMENT STRATEGIES FOR FEDERAL OFFSHORE BORROW AREAS ALONG THE UNITED STATES EAST AND GULF OF MEXICO COASTS

Dr. Jacqueline Michel
Research Planning, Inc.

BACKGROUND

The Minerals Management Service (MMS) International Activities and Marine Minerals Division (INTERMAR) is charged with environmentally responsible management of federal Outer Continental Shelf (OCS) sand and gravel resources, that is, those resources lying seaward of the state/federal boundary. As the demand for sand for shoreline protection increases, OCS sand and gravel will become an increasingly important resource. Between 1995 and September 2001, MMS conveyed over 14,600,000 cubic yards of OCS sand for ten projects. MMS's mission is to make timely, streamlined, and environmentally sound and fiscally responsible decisions to access OCS sand resources. To support their mission, they have formed cooperative agreements with ten states to identify and evaluate OCS sand resources as potential sources for future beach nourishment projects. As of 2001, MMS has provided $4.6 million in funding to support geological and geophysical studies to identify and quantify OCS sand sources. MMS has also taken an active role in identifying the potential environmental impacts of dredging OCS sand by conducting baseline studies of selected OCS regions and funding research on specific areas of concern.

OBJECTIVES

Now, in the early stages of resource utilization, is the time to establish the mechanisms for long-term management of this resource. MMS identified the need to formulate options and recommendations for including federal, state, and local governments and other stakeholders in an overall planning process to manage the federal offshore borrow sites in an environmentally responsible and cost-effective manner over the long term. MMS undertook this project to the feasibility of a regional sand management approach to improve coordination among the relevant regional parties, organizations, and agencies with interest in the use of OCS sand resources for beach and coastal restoration. Important objectives of the MMS program were the demonstrated cost savings and value-added benefits that can be achieved through regional management. This work was part of a larger project that also included development of field monitoring systems to evaluate the physical and biological impacts of using federal offshore borrow areas on a long-term basis. The monitoring protocols are presented in a separate report.

DESCRIPTION

The first step of the process to determine the feasibility of a regional management strategy was to identify two areas where pilot studies could be conducted to solicit input from stakeholders on how to best achieve the above objectives. The two areas would represent different physical and biological settings, technical issues, environmental concerns, interested parties, and agency policies on the issues. Texas and New Jersey were selected. Key agencies and staff in each area were identified and contacted to discuss their perspectives on what kind of management strategies would be most appropriate. The next step was to conduct a one-day workshop in each state and identify the key issues and concerns about use of OCS sand resources. All of the information obtained from discussions with MMS staff, agency representatives, and at the workshops was formulated into a set of recommendations and a framework for managing OCS sand resources.

The goals of OCS sand management were identified as follows:

- Avoid or minimize the environmental impacts to OCS sand borrow sites that may represent long-term sources of sand for coastal communities.
- Reduce the time and costs to efficiently access OCS borrow sites.
- Promote coordination among beach nourishment/coastal restoration projects to maximize cost-effectiveness.
- Allow for adaptive management, learning from past projects to better manage future projects.
- Evaluate the current process for planning, implementing, and coordinating beach nourishment projects, and identify problem areas. Set priorities for working on problems.

STUDY RESULTS

Recommendations to achieve these goals are summarized below.

1. Regional management of sand resources is feasible and essential to the MMS goals for managing OCS sand resources in a cost-effective and environmentally sound manner.

   There are many serious issues associated with dredging of OCS sand that must be addressed. Other federal agencies, states, and local governments clearly look to MMS to provide leadership and guidance on both policy and technical issues.

2. Generally, the “region” should consist of a single state.

   States differ in the types of beach erosion problems, approaches to solve them, amount of data available, level of state involvement and commitment, etc. It would be an added level of difficulty to try to engage more than one state in the process. The exception will be for borrow sites that straddle state lines, and these sites would have to be handled on a case-by-case basis.

3. Regional management efforts should start in those states that can provide a strong state lead AND have already identified a need for OCS sand resources.

   MMS is limited by the small size of the INTERMAR division. A strong state lead is essential to the success of the planning process.

4. MMS should build on existing geological Task Forces in each state, letting them evolve into a State/MMS Sand Management Task Force.

   MMS has been very successful with their cooperative geological studies and these groups can be the basis for expanded responsibilities of a Sand Management Task Force (SMTF). The relationship between the Sand Management Task Force and the USACE Regional Sediment (RSM) Program will have to be addressed in each region, depending on the stage of development of each. The MMS objectives for cost effectiveness and efficiency, in particular, match closely with those of the RSM.

5. MMS should expand its role in sponsoring and co-sponsoring workshops and developing synthesis documents and guidelines on technical and policy issues for managing offshore sand resources.

   This effort would build on MMS' focus on information transfer and peer-reviewed publications with parallel efforts to generate and disseminate in a timely manner non-peered-reviewed technical documents that represent current approaches, guidelines, policies, findings, etc.

6. MMS should become the clearinghouse for studies and findings on environmental impacts associated with offshore dredging relative to OCS/federal borrow areas and use its web site to better disseminate this knowledge.

   A well-designed and regularly updated web site could achieve many of the MMS objectives, in terms of providing value-added benefits through sharing of information and findings among states. The MMS INTERMAR web site should become the best site for getting the most current, technical and policy information on offshore sand and gravel resources.

7. MMS should continue to play a lead role in the design and funding of long-term monitoring studies.

   Without funds to support long-term monitoring of potential impacts, MMS will not be able to meet its responsibility to ensure that the OCS sand use does not adversely affect the marine and human environments. This lack of funds is a critical gap in the overall program. Monitoring costs need to be shared among the beneficiaries of the sand (state and local government sponsor), the managers of the resource (MMS), and other federal agencies with an interest in the results of a monitoring effort.

   An implementation plan was prepared, with the recommendation that the State of New Jersey be the site of the first Sand Management Task Force (SMTF). Working with the state, the task force should prepare a draft charter at the first meeting. In addition, MMS should identify those states where formation of a SMTF is feasible at this time, and identify potential members in each state. MMS should participate in all of the initial meetings and offer as much support as possible during the initial activities of each task force. At the end of the first year, MMS should evaluate the effectiveness of the SMTFs, individually and as a group, and make recommendations for how the process should be improved. MMS should also evaluate its funding needs to provide sufficient support to SMTFs in terms of staffing, travel, contractor support, and funding of specific studies. Year Two of the project is to assist MMS by investigating the various potential SMTFs, querying potential members, and suggesting the compositions of the various groups for the priority states.

Study Product:

Research Planning, Inc., Baird & Associates Ltd., and Applied Marine Sciences, Inc., 2001. Examination of Regional Management Strategies for Federal Offshore Borrow Areas Along the United States East and Gulf of Mexico Coasts. U.S. Department of the Interior, Minerals Management Service, International Activities and Marine Minerals Division (INTERMAR), Herndon, VA. OCS Report MMS 2001-090, 23 pp. + appendices.

Jacqueline Michel received her Ph.D. in geology from the University of South Carolina in 1980. She is currently the president of Research Planning, Inc. She is a member of the National Academy of Sciences, Ocean Studies Board and is on the Science Advisory Panel to the President's Ocean Policy Commission. Dr. Michel is an expert in oil and chemical spill science, coastal processes, natural resource mapping, and natural resource damage assessment.

U.S. ARMY CORPS' BIOLOGICAL MONITORING PROGRAM ALONG THE NEW JERSEY SHORE

Mr. Mark Burlas
Army Corps of Engineers, New York District

The U.S. Army Corps of Engineers, New York District (USACE) and the State of New Jersey (represented by the New Jersey Department of Environmental Protection, NJDEP) are presently engaged in an erosion control project to protect beaches along the northern coast of the state. The project area encompasses approximately 47 km of exposed, high-energy beaches extending northward from Manasquan Inlet to Highland Beach. Wave heights in the vicinity average 0.3-0.7 m with wave periods of 5.6–9.0 seconds (Nordstrom *et al*. 1982). The area is microtidal with a Mean Spring Low Tide range of 1.62 m (Davies 1964 and Masselink and Short 1993). Beach morphology, measured on a scale ranging from dissipative to reflexive, is intermediate with a longshore trough and bar topography (Wright and Short 1984 and Short 1991). Beach slopes range from 7.30 to 110 (Nordstrom *et al*. 1978). The beachface is punctuated by numerous piers and rock groins and interrupted by an inlet at Shark River. Erosion can be severe with some areas receding as much as 2 m a year (Nordstrom *et al*. 1978). The volume of sand moved by longshore currents averages between 57,000 m3/yr at Manasquan Inlet and 377,000 m3/yr at Sandy Hook (Caldwell 1966). Longshore current direction is predominately to the north (Ashley, Halsey, and Buteux 1986).

A total of 19.39 million cubic meters of sand was placed on the beaches during the project, making this one of the largest such nourishments (in terms of volume) ever constructed. Approximately 6.18 million m3 of this material was placed along the 15.93 km of beach between Asbury Park and Manasquan Inlet, creating a 30 m wide berm 3 m above mean low water (MLW). The area between Manasquan Inlet and Shark River was nourished in 1997, while the remainder was nourished in 1999. The Manasquan Inlet to Shark River section received an additional 300,000 m3 of sand in late May 2000; however, this was after conclusion of the monitoring program.

Concern about ecological impacts of these dredging and filling operations has been focused on potential detrimental effects on infaunal benthos, a major source of forage for commercially important coastal fish and invertebrate species. Previous studies of beach nourishment (e.g., Nelson 1993) concluded that, in most cases, impacts from beach nourishment are minor. Impacts such as short-term reductions in standing stock biomass (an indicator of secondary production) are outweighed by benefits (e.g., medium- to long-term increases in flood protection and recreation), making such projects clearly in the public interest. However, because most previous studies were constructed in beach environments geographically distant from New Jersey (e.g., southeastern U.S. and South Africa), questions have been raised as to the applicability of results reported elsewhere.

Findings from this study are intended not only to assess impacts associated with the immediate dredging and filling operations, but also to evaluate the potential for impacts from subsequent renourishment operations and similar projects in the New York-New Jersey area.

Environmental impacts from beach nourishment are typically confined to the immediate borrow (dredge) and beach (fill) areas and include reduced abundance of infauna, altered infaunal community structure, altered feeding habits among fish, crabs, and other commercially important species (due to changes in the availability of prey items), and increased turbidity. The overall objective of monitoring the Asbury/Manasquan project has been to determine if these impacts are severe and long-term. There are no standard sampling programs for collecting this type of information; however, Cochran (1963), Morrisey *et al*. (1992), and Nelson (1993) provide useful guidelines, Saila *et al*. (1976), Cohen (1988), and Underwood (1992) provide specific advice for applying these principles to environmental impact studies.

During the summer and fall of 1993, the New York District and U.S. Army Engineer Research and Development Center, Waterways Experiment Station (WES) conducted a pilot study of the borrow and beach areas to obtain the information needed to design the environmental monitoring for Reach 1 of the Asbury/Manasquan project (Coastal Ecology Branch 1994). The pilot study characterized longshore variation in the abundance of intertidal infauna, characterized km-scale variation in the abundance of infauna within the borrow areas, and examined the effectiveness of various methods for sampling nearshore ichthyoplankton and juvenile fishes. Based on this information, the report recommended a monitoring plan for this reach of the Asbury/Manasquan project. The District and WES discussed these recommendations with resource agency representatives in March 1994, and the Biological Monitoring Plan (BMP) was developed.

Detection of changes in benthos at both the borrow areas and the beach placement sites is the major focus of the monitoring program. Although the BMP addresses general concerns associated with beach nourishment, certain aspects were tailored to fill specific gaps in knowledge relevant to the specific project area. Northern New Jersey high-energy beaches represent a complex, highly developed, highly altered ecosystem. Much of the shoreline has previously been “hardened” via construction of groins and jetties. Many of the numerous salt ponds scattered behind the former dune lines are now connected to the beach by water control structures. To evaluate the ecological meaning of project-induced changes against this background of pre-existing conditions, several less traditional monitoring components were incorporated into the BMP. Food habits of fishes, particularly bottom-feeders, collected in the surf zone and at offshore borrow areas were being examined to detect potential higher trophic level consequences of the nourishment process. Likewise, ichthyoplankton and juvenile fish assemblages were being characterized to evaluate the importance of northern New Jersey high-energy beaches as nursery areas. In addition, creel surveys of fishermen using jetties, groins, and sandy beaches were being conducted to evaluate effects on recreational fishing. Threatened and endangered species data were also considered (particularly avian and sea turtle occurrences), but are reported separately by the New York District.

An interim report summarizing 1994 sampling and the initial implementation of that plan was submitted to the New York District in June 1995. Preliminary analyses of data derived from the various components of the monitoring program indicated that no major changes in the study plan were necessary. A second year of pre-construction data was collected in 1995 and was the subject of a second interim report submitted in March 1996. Delays in contracting the dredging project afforded an opportunity to collect another full year of baseline data in 1996, which enhanced the overall strength of the baseline portion of the monitoring plan through provision of data to assess interannual variation. Results of the entire pre-construction baseline portion (1994-1996) of the monitoring studies were summarized in 1998 (USACE 1998). Results of the during-construction (1997) and the first year of post-construction (1998) sampling for nourishment of the southernmost reach (Manasquan Inlet to Shark River) were reported in 1999 (Burlas, Ray, and Clarke 1999). The present report summarizes the results of the entire project including both during construction (1999) and post-construction (2000) for nourishment of the northernmost reach of the project area (Shark River to Asbury Park).

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Mark Burlas has 14 years of experience with the U.S. Army Corps of Engineers. As a senior wildlife biologist, he has spent 10 years with the New York District's Planning Division. Mr. Burlas is the technical environmental manager of the multi-year, multi-million dollar Biological Monitoring Program that looked at the effects of beach nourishment to biological resources along the Atlantic Coast of New Jersey. He is also responsible for the oversight and preparation of Civil Works (Shore Protection, Flood Control, Navigation and Ecosystem Restoration Projects) and Military Construction NEPA documents, studies to assess impacts and development of ecological mitigation. In addition, Mr. Burlas served four years active duty as a combat engineer with the 27th Engineer Battalion (Combat) (Airborne) Fort Bragg, North Carolina.

BARRIER SHORELINE RESTORATION BARATARIA BASIN, LOUISIANA FEASIBILITY STUDY

Mr. William Klein
U.S. Army Corps of Engineers, New Orleans District

Click here to see Mr. Klein's slide show.

SESSION 2F

MARINE ACOUSTICS AND SPERM WHALES

Chair: Dr. William Lang, Minerals Management Service
Co-Chair: Ms. Sarah Tsoflias, Minerals Management Service

Date: January 9, 2002

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WHY DO SPERM WHALES CLICK?

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GENERAL INTRODUCTION

Sperm whale (*Physeter macrocephalus*) is an animal of extremes; it is the largest of the tooth whales, and it has the most extensive distribution of any other species of marine mammals (rivaled in this respect only by the killer whale, *Orcinus orca*). Sperm whales range through all oceans of the world from the equator to the edges of the pack ice (Rice 1989).

These whales are the most sexually dimorphic of all cetacean species: physically mature males can reach 18 meters and weigh 50 to 57 tons, while physically mature females are only 10 to 12 meters long and weigh from 18 to 24 tons. They also show a considerable sexual segregation in distribution and social organization. The females and their offspring are mostly found in warm water between 40˚N and 40˚S and live in family units of about a dozen individuals which stay together for at least decades. These permanent units may associate with one another for periods of about a week to form what is commonly called the "nursery group" (Whitehead *et al*. 1991). Males have a less cohesive social organization and are generally found in colder waters. The young males leave the family unit when they are between 6 to 10 years old and form "bachelor" schools which are found in more temperate waters (Best 1979). As they grow older and larger, the males are progressively observed in smaller groups and at higher latitudes. The largest males are found singly or in pairs in polar waters. At least some of the socially mature males migrate back to the tropical waters to mate with the females, but the details of these migrations are not well understood (Best 1979).

Sperm whales are exceptional divers. Norris and Harvey (1972) recorded a dive to 2,500 m, and indirect evidence suggests that adult males may dive to over 3,200 m (Clarke 1977). Watkins *et al*. (1985) reported a group of five sperm whales that remained under water for at least 138 minutes. However, recent studies of undisturbed sperm whales show that they usually dive to about 400 to 800 m for about 40 minutes followed by 10 minutes resting at the surface (Gordon 1987).

The majority of sperm whale's diet consists of meso- and bathypelagic cephalopods, in particular, the deep-sea squid belonging to the families Histioteuthidae, Gonatidae, Onychoteuthidae and Octopoteuthidae. In some regions however, Ommastrephidae, Cranchiidae and Architeuthidae represent, by weight, the bulk of the diet (Kawakami 1980). The importance of fish in sperm whale diet is generally small except in the northeastern part of the North Pacific, New Zealand and Iceland-Greenland. Thus, sperm whale diet varies considerably between regions.

SPERM WHALE VOCAL BEHAVIOR

The head of the sperm whale can make up over a third of the animal's total weight and over a quarter of its total length and thus is clearly disproportionate. Most of the head is involved in sound production and propagation and has been described as the "largest bioacoustical machine" (Cranford 1999). It is therefore easy to imagine the importance of sound for sperm whales.

Sperm whales are highly vocal cetaceans. However, unlike many other species of social toothed-whales, sperm whales do not whistle; they produce only sharp, impulsive, broadband sounds called clicks (Backus and Schevill 1966) that have a frequency range spanning a few hundreds Hz to ~20 kHz with most of the energy between 4 and 10 kHz (Goold and Jones 1995). They seem to be produced by the hard lips called "museau de singe" which are found at the tip of the nose (Figure 2F.1, Norris and Harvey 1972). Once the click is produced, part of its energy passes directly into the surrounding water while the other part passes backwards into the spermaceti organ to be reflected again forward off the frontal sac. The distal sac allows some energy to pass out into the sea while some energy is again reflected back towards the frontal sac. This series of reflections give the typical multi-pulse structure of sperm whale's clicks (Figure 2F.1, Norris and Harvey 1972; Gordon 1991).

Clicks can be produced with a variety of repetition rates, and have been assigned to five main categories. "Usual clicks", the most commonly heard sound, have an interclick interval (ICI) of about 0.5 to 1 second (Backus and Schevill 1966); "creaks" are series of very rapid clicks with up to 220 clicks per second (Gordon 1987); "slow clicks" and "surface clicks" have an ICI of about 5 to 7 seconds (Weilgart and Whitehead 1988; Jaquet *et al.* 2001); and "codas" are short, patterned series of clicks with irregular repetition rates (Watkins and Schevill 1977).

Usual Clicks and Creaks

Usual clicks and creaks are the only sounds which are produced indifferently by male and female sperm whales. Usual clicks have an average duration of about 15 to 24 ms. Recent investigations have suggested that the source level of these clicks can reach 223 db re 1μPa pe RMS and that they have a high directionality (Møhl *et al.* 2000).

The few results presented below come from a study on vocal behavior of male sperm whales off Kaikoura, New Zealand (Jaquet *et al*. 2001). Off Kaikoura, sperm whales were almost always silent at the surface. The first usual click typically occurred 25 seconds (sec) after fluke-up (=24.9 sec, CV=80%, n=373). The time between fluke up and first usual click was very consistent among sightings, with 85% occurring within 10 to 40 sec. The click rate averaged over the first 10 sec of their vocalizations was significantly correlated with water depths (r^2=0.474, p=0.002, n=18, Figure 2F.2, Douglas 2000). However, there was no consistent decrease in interclick intervals during the first five minutes of their descent (Douglas 2000). The last usual click was produced on average 3.7 minutes before surfacing (SE=0.18, n=47).

Creaks were only emitted during the middle part of a dive and were never heard either at the beginning of the dive or when whales were at the surface. The time interval between fluke-up and first creak was very consistent among dives and averaged 7.53 min (CV=33%, n=36). The last creak was produced, on average, 6.67 min (CV=42%, n=20) before surfacing. Clicks within creaks were much shorter than usual clicks ($\bar{x}$=3.59 ms, CV=35%, n=328). Creaks had an average duration of 15.65 sec (CV=93%, n=376). Interclick intervals (ICI) varied considerably both within and between

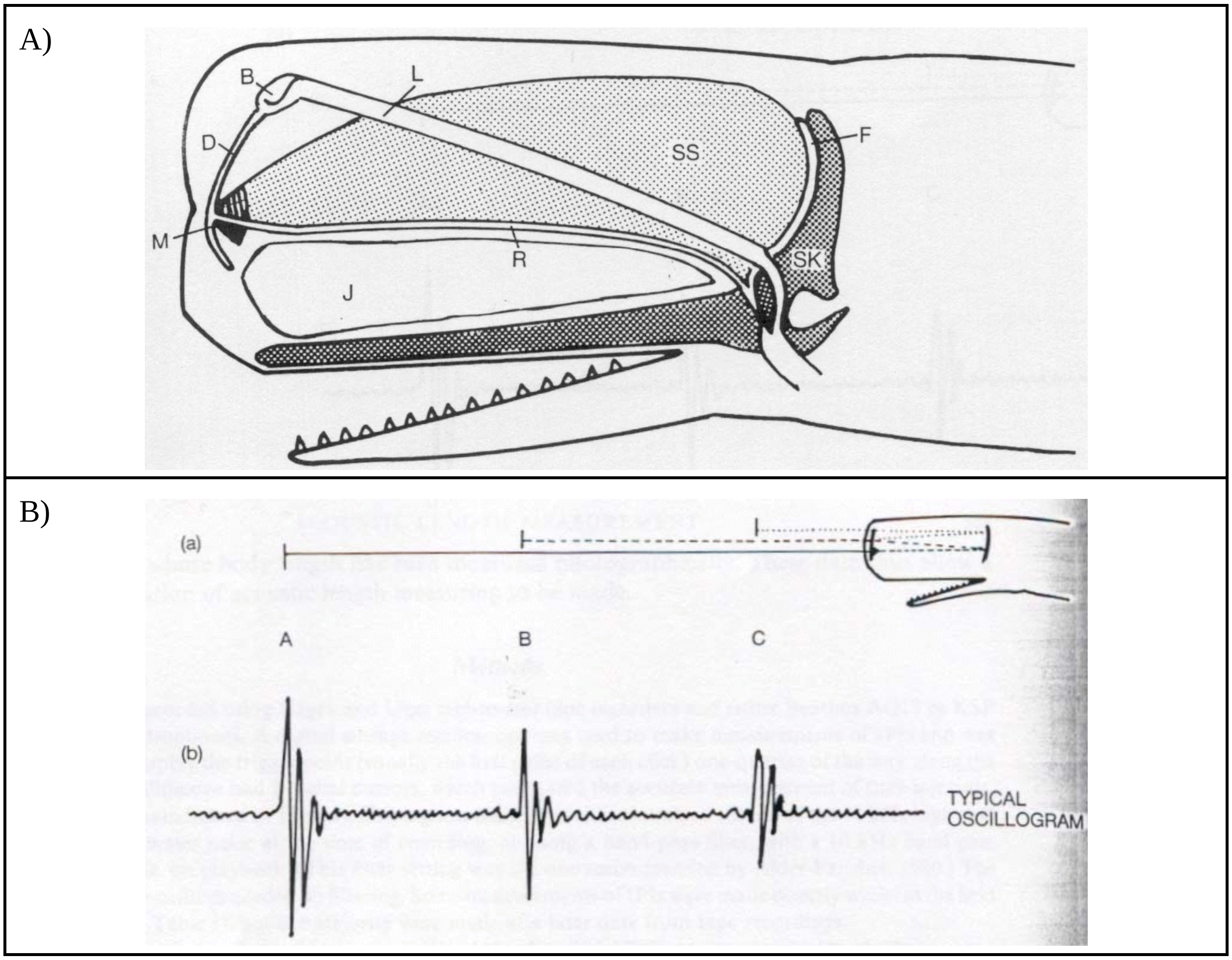

Figure 2F.1. A). Schematic representation of the anatomy of a sperm whale head (after Norris and Harvey 1972; Gordon 1991). B= Blow Hole, D=Distal Sac, F=Frontal Sac, J=Junk, L=Left Nasal Passage, M=Museau de singe, R= Right Nasal Passage, SS= Spermaceti, SK= Skull.
B). Illustration of Norris and Harvey's (1972) proposed method of pulsed click production.

creaks. The shortest ICI measured off Kaikoura was 11.9 ms (n=2103). In general, ICI decreased consistently from the beginning of the creak and then stabilized between 20 and 30 ms (see Figure 2F.3 for a typical example). However, in some cases, ICI kept decreasing until the end of the creak. Creaks were usually followed by a short period of silence (2 to 10 sec approximately), but the exact duration of these silences were difficult to determine as creaks often became very faint toward their end. The number of creaks per minute of dive and the length of a dive were significantly correlated ($r=0.788$, $df=12$, $p<0.001$). Individuals which were performing dives longer than average were also producing proportionally more creaks (Figure 2F.4).

If the primary function of sperm whale usual clicking is for echolocation while foraging, we would expect most of the clicking to occur during foraging dives, and very little clicking to occur at the

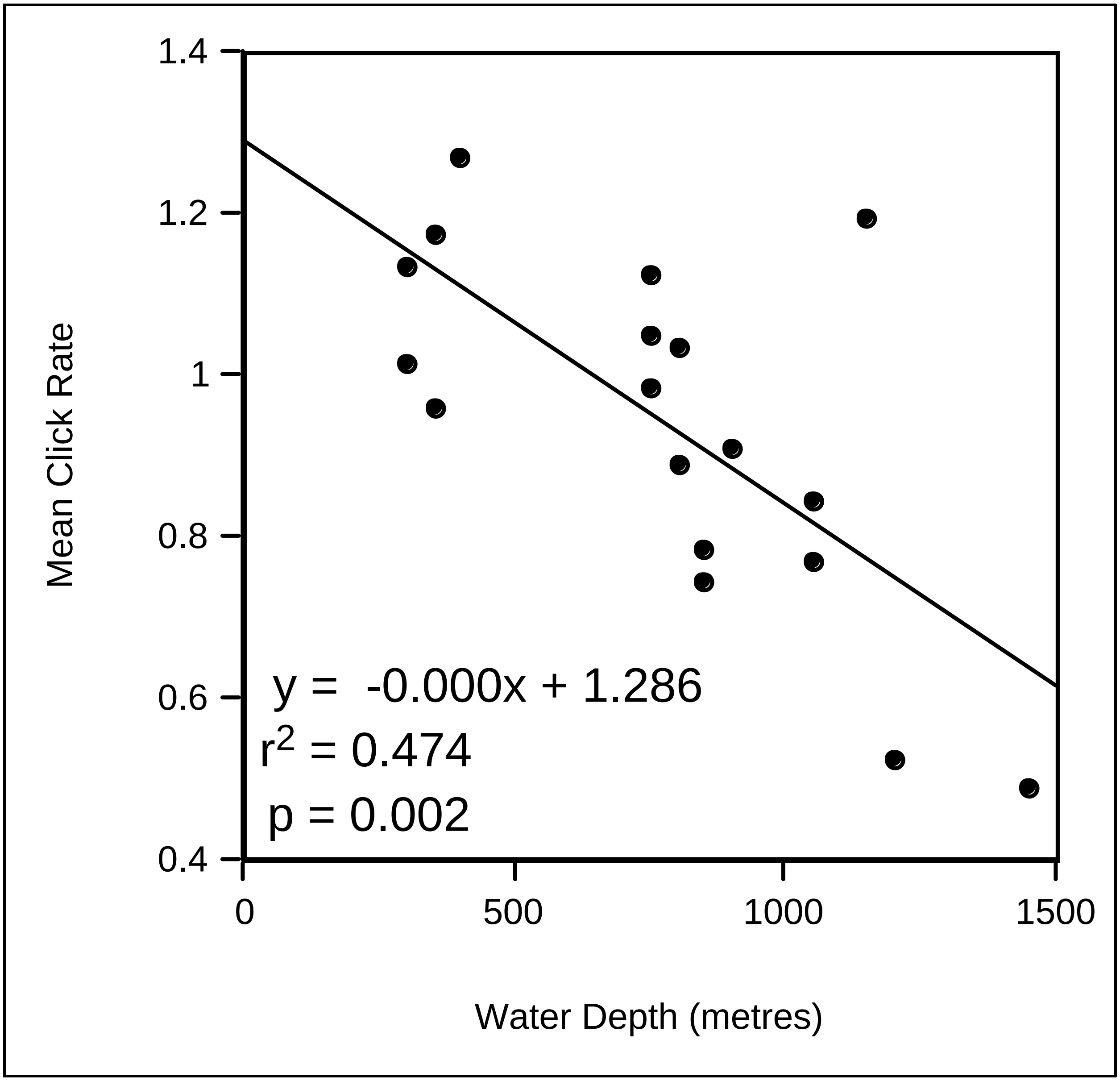

Figure 2F.2. Correlation between mean click rate during the first 10 sec of sperm whale vocalization after fluke-up and water depths at fluke-up (Douglas 2000).

surface. This hypothesis is supported as 97.1% of sperm whale vocalizations were heard during foraging dives. During these dives, sperm whales clicked almost continuously, being silent for only 15.5% of the time between fluke-up and surfacing. The significant correlation between the interclick interval averaged over the first 10 sec of vocalization of a whale dive and the water depth at the fluke-up location, suggests that the first few clicks serve to detect the bottom depth. A consistent ICI of about 1.04 sec during the first few minutes of their dive suggests that sperm whales scan a maximum of 750 m ahead of themselves. These observations are very consistent with long-range echolocation and navigation.

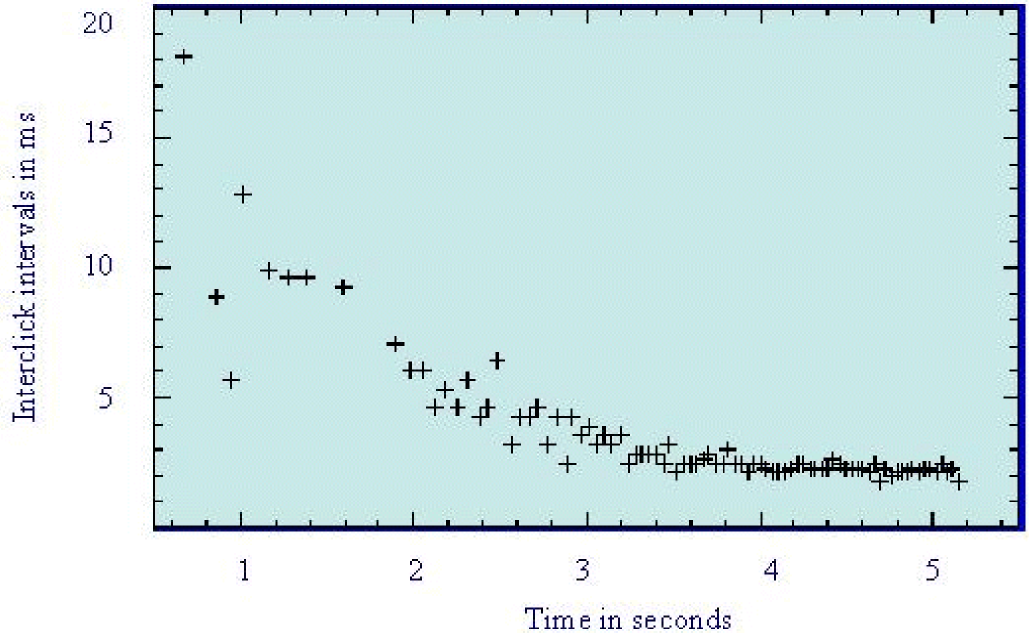

Figure 2F.3. Typical variation in interclick intervals within a creak.

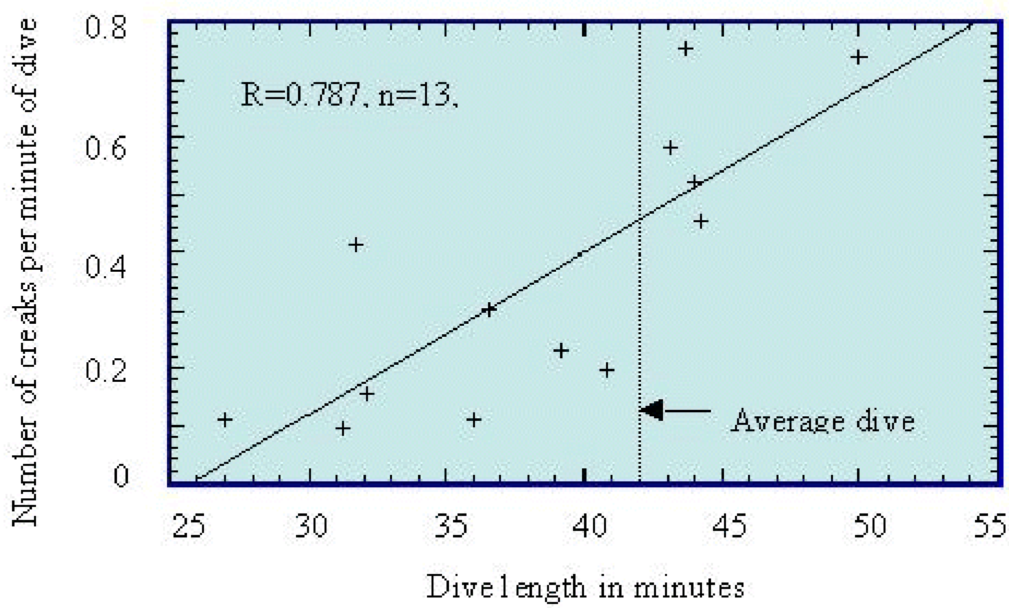

Figure 2F.4. Correlation between the number of creaks per minute of dive and dive length.

Within creaks, ICIs tended to decrease from the beginning to the end of the creak. These results are consistent with Gordon's (1987) findings and with results obtained on bat echolocation behavior (Au 1993). Creaks often started with an ICI of 50 to 60 ms and ended up with an ICI of 15 to 20 ms. These variations in ICI suggest that sperm whales moved about 33 m between the beginning and the end of a creak. The resulting speed estimate (7.4 km/hour: 33m in 16 sec) is slightly higher than the speed of sperm whales averaged over several hours to several days (2.5 to 6.7 km/hour; Gordon 1987; Jaquet and Whitehead 1999), but is plausible. Furthermore, if creaks represent feeding events, one would expect that successful dives (i.e. dives where a large amount of food items are found) would last longer than unsuccessful ones. The significant correlation between the number of creaks per minute of dive and the dive length found in the present study supports this hypothesis. Overall, all the observations regarding creaks are very consistent with short-range echolocation and closing on on prey.

Surface Clicks and Slow Clicks

Surface clicks and slow clicks are exclusively produced by male sperm whales. They are both characterized by interclick interval of 5 to 7 sec and by a metallic echo. However, they are produced in very different contexts.

Surface clicks are produced in short sequence of 3 to 8 clicks, shortly before surfacing, by males at high latitudes. Off Kaikoura, 55% of the dives ended up with a series of surface clicks and 24% of all dives began with a single surface click. Within these short series of surface clicks, the ICI did not vary in any predictable manner, and for most of the dives it fluctuated as the regularly-spaced teeth of a saw (Figure 2F. 5). These surface clicks were produced by every individual and there was no consistent pattern as to when they were emitted (depth, presence of boats in the area, presence of other whales nearby, season, location, etc.). If the main function of these clicks is echolocation, a mean ICI of 5.5 sec suggests a maximum detection range of about 4 km. As the whales were on their way up at a probable depth of 180 to 360 m (assuming an ascent rate of 60 to 120 m/min, Gordon 1987) when producing these clicks, it seems unlikely that they were needed for long-range echolocation. In general the characteristics of surface clicks are not consistent with echolocation, and their function remains a mystery.

Slow clicks are produced exclusively by large mature males on the breeding ground. They are produced in long sequence of 10 to 20 minutes without breaks. Not enough data is currently available on these vocalizations and thus their functions also remain a mystery.

Codas

Codas are short patterned series of clicks (Watkins and Schevill 1977) produced mainly by female and immature sperm whales while socializing at the surface (Whitehead and Weilgart 1991). They can be categorized on the basis of their interclick intervals: regularly spaced, of the +1 type or variable (Weilgart and Whitehead 1993). Codas are seldom produced by males and then only when several males are in close proximity (Pers. Obs.). The most probable primary function of sperm whale codas seems to be the maintenance of social bonds and communication (Weilgart and Whitehead 1993).

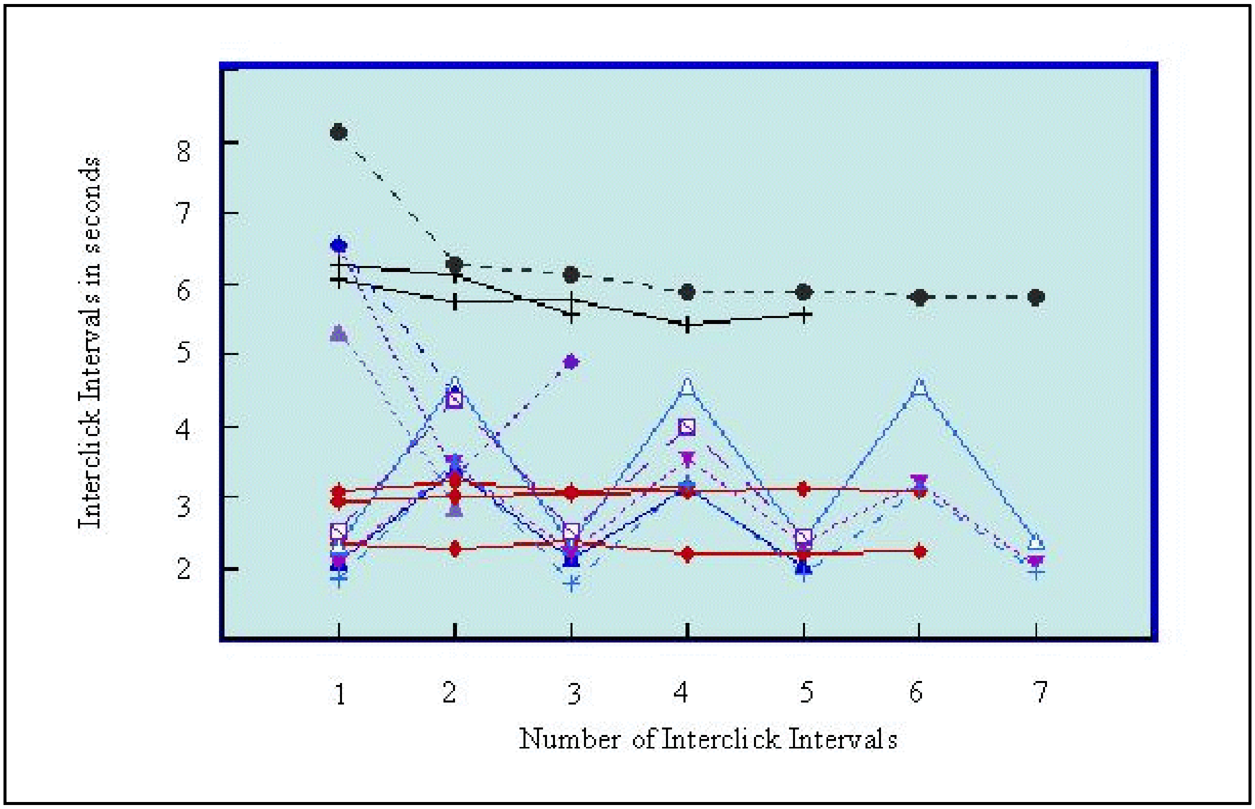

Figure 2F.5. Variation in interclick intervals in surface click sequences.

CONCLUSION AND FURTHER RESEARCH

Sperm whale anatomy (the largest "bioacoustical" machine) suggests that sound production play an important role. This is confirmed by the fact that sperm whales click for 85% of their time underwater and thus for 69.7% in total. They seem to use their sounds to navigate, find their prey, communicate and maintain social bonds between individuals. Furthermore, they also produce sounds (slow clicks and surface clicks) for which we have little understanding. Therefore sound production in sperm whales may have additional functions about which we know nothing yet. To fully understand the impact of man-made noise and seismic industry on sperm whales, it is thus imperative that we gain a better understanding of the characteristics and functions of these vocalizations.

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SPERM WHALES: VULNERABILITY TO ACOUSTIC DISTURBANCE FROM AIR GUN ARRAYS

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INTRODUCTION

From a strictly scientific perspective, all animals are equally special; they are all supremely well adapted, through evolution, to excel at a particular way of life. Sometimes though, it requires a particular perspective to appreciate their particular specializations. Sperm whales on the other hand are overly spectacular animals and their “special nature” is evident to everyone. The sperm whale is truly an animal of superlatives!

- They are the largest of the toothed whales. Males reach lengths of 20m while females grow to 12m.

- They are the most sexually dimorphic of cetaceans. At 44 tones a mature male is over 3 times the weight of a 13.5 ton mature female.

- They are the most accomplished mammalian divers. Dives of over an hour to depths below 2,000m have been recorded.

- Their massive heads, which can account for up to a third of the body length of the males, is the largest sound-producing organ in the animal kingdom. Sperm whales are very vocal, producing loud clicks for most the time they are underwater.

- They have the lowest rate of reproduction of any mammal. Females mature at about nine years of age. Gestation takes about a year and a half, and suckling continues for a few years. Average calving intervals in stable populations are around five years. Calves are cared for communally and the oldest females may contribute to calf care and may have a leadership role when they cease reproducing. Sperm whale populations were decimated by pre-industrial and industrial whaling and have been very slow to recover.

- The have the most highly developed social organization of any of the great whales. Females and their young live together in stable family groups of between 12 and 30 individuals.

- They are extremely wide ranging. Sperm whales are found in deep waters in all the oceans of the world although females and their young are confined to tropical and temperate waters.

- They are very ecologically successful exploiting populations of deep-living fish and squid about which we still know little. Before whaling, sperm whales were numerous consuming more biomass than the world's entire modern fishing fleet.

- Perhaps most intriguingly of all, sperm whales have the largest brains that have ever existed.

Sperm whales are also culturally and historically significant. This point may seem a whimsical one, but for a meeting focusing on marine ecology and the American Petroleum Industry this point should be of some relevance. Sperm whales were the basis of an oil industry before there was the "oil industry." The far-flung and successful Yankee whaling fleet that was so economically important in the early years of American independence, and did much to extend American influence around the world, hunted the world's sperm whale populations to provide oil for lamps and industry and in the process inspired Melville to write *Moby Dick*.

It has been said that the discovery of mineral oil in U.S. saved the world's sperm whales from the unsustainable attentions of the Yankee whalers. Now however, exhaustion of inshore oil reserves and advances in engineering have encouraged the oil industry to push out beyond the edge of the continental shelf and into the sperm whale's habitat. The consequence that these activities, particularly the noise generated during oil exploration and exploitation, may have for the conservation of sperm whales is a matter of increasing concern. Its interesting to note that features of the sperm whale that make them such a fascinating and unique species may also make them vulnerable to offshore activities.

BIOLOGICAL VULNERABILITIES TO ACOUSTIC DISTURBANCE

In essence, sperm whales are deep diving, sexually dimorphic, socially organized animals whose main sensory modality is acoustic. Here, I briefly review how these characteristics may contribute to sperm whale vulnerability.

Deep Diving

We understand very little about what sperm whales do during their deep dives. In particular, we still know virtually nothing about their feeding behavior, the functioning of the ecosystem in which they feed and their role within it. One consequence of this is that it is difficult to identify and interpret any disruption by disturbance or other means of their foraging behavior or to the deep seas ecosystem on which they depend. It should be noted, however, that the ongoing work using D-tag technology, including work on sperm whales in the Gulf of Mexico (GOM), is addressing many of these knowledge gaps. (See Johnson Miller, this volume).

Because they dive to depths of 1,000m or more to feed, there is a large fixed cost, the "travel cost," that a foraging sperm whale must account for during each dive before it can do anything useful, namely start feeding. Consider, for example, a foraging whale that is disturbed so that it spends less time at the surface replenishing oxygen supplies and consequently has a shorter overall dive time. The travel costs to feeding depth are fixed, further reducing the amount of time available for foraging in a shortened dive, so that the proportional reduction in foraging time, which represents the true cost of the disturbance, is rather greater than the proportional change in overall dive length.

The physiological requirements of diving may also mean that a diving whale is constrained in the extent to which it can respond to disturbance. To perform such impressive dives, the whales must use oxygen quite efficiently throughout a dive. For example, diving whales may not be able to increase their swimming speed to escape from a sound source because oxygen requirements will generally increase exponentially as swim speed increases. The natural response of deep-diving air breathers to an alarming stimulus may be to come to the surface where they will be able to breathe, even if this brings them closer to the noise source. There are indications that humpback whales (McCauley *et al*.1998) and deep divers such as sperm and pilot whales surface (Stone 1998) come to the surface in response to seismic air gun activity.

In addition, we should appreciate that a situation that may seem straightforward to an informed human may be a confusing one for a naive diving whale. Consider for example the case of a whale in mid-water when a seismic array starts firing close by. If it is out of the beam directly below the array it may actually hear the echo from the bottom as being louder than the sound arriving directly. (This has often been our experience monitoring whales on the Atlantic Frontier in the United Kingdom.) Moving away from the loudest source of noise may then bring the whale toward the source rather than away from it.

Finally, a very obvious consequence of their long deep diving habit is that searching for sperm whales at the surface visually is not a reliable method for detecting their presence in an area. Indeed, in the case of seismic surveys, it is when sperm whales cannot be seen that they might be in the most hazardous location: directly below the air gun array. This is one of the reasons why supplementing visual observation with acoustic monitoring is necessary for effective mitigation with this species (Gordon *et al*. 2000).

Acoustic Sensitivity

The main sensory modality for all whales and dolphins is sound, but none is more acoustically mediated than the sperm whale. Animals are more likely to be disturbed by noise at frequencies to which they are most sensitive, and acoustic masking of signals is most complete when the frequencies of the signals and noise are similar. There are no audiograms for sperm whales but, based on ear anatomy, Ketten (1997) has suggested that sperm whales are likely to be more sensitive to lower frequencies, at which seismic and industrial noise are dominant, than other odontocetes. Ridgeway and Carder (2001) found best hearing sensitivity between 5 and 20kHz in a neonate sperm whale using ABR responses. This lower frequency specialization is also reflected in the nature of their vocalizations that are broadband with significant energy below 2kHz. While we know something of the nature of sperm whale vocal behavior (e.g. Gordon *et al*.1992; Watkins 1980; Jaquet *et al*. 2001) we understand little in detail about how they may use passive acoustic cues in their daily lives. The ocean is full of passive acoustic information that could potentially be useful for navigation, finding food etc.; indeed, it is certain that hearing evolved to detect such cues rather than an animal's own vocalizations. It is likely, though, that many of these sounds are very quiet and may thus be easily masked by additional noise from anthropogenic sources.

There are some positive consequences of sperm whales' acoustic behavior too. Sperm whales are highly vocal. They can be detected using simple surface hydrophones at ranges of three to five miles, and passive acoustic monitoring can underpin some very powerful techniques for finding and following whales (Whitehead and Gordon 1984) for assessing populations (Leaper *et al*. 1992; Gillespie 1997)and also increase the efficiency of monitoring as part of seismic survey mitigation procedures (Gordon *et al.* 2000).

Social Organisation

The final fundamental feature of sperm whale biology is their complex social organization. Sperm whales are the most social of the great whales, and it seems that social living is important for both the survival of individuals and the well-being of populations. Group organization may be important in calf care, effective foraging, group defense against predators and as a repository of cultural information (Whitehead and Weilgart 2000).

Disruption of the social bonds, which may result from serious disturbance, could thus have a variety of deleterious consequences. Calves may be particularly vulnerable. Calves are routinely are left alone at the surface while their mothers feed many thousands of meters below. Serious disturbance could lead to lost calves and possible increased mortality. The low reproductive rate of sperm whales means that populations will be slow to recover from any increased mortality.

Sexual Dimorphism

The significance of the pronounced sexual dimorphism in this species is that the two different parts of the population, the mature males and the mixed groups, have a very different biology, may live most of their lives in completely different parts of the world, and may have quite different vulnerabilities to anthropogenic disturbance. The mixed social groups comprising females and young that are the majority of the GOM population would seem to be more vulnerable than the less socially mature male groups found at higher latitudes. It may be that higher levels of concern and more stringent mitigation procedures will be appropriate when working in areas populated by mixed groups compared to those inhabited by mature males.

In this section the reasons for being concerned about effects of noise such as that from air gun arrays on sperm whales, based on our knowledge of their biology, have been outlined; in the next we consider information from direct field observations.

FIELD OBSERVATIONS OF EFFECTS OF OIL INDUSTRY NOISE ON SPERM WHALES

There have been no dedicated studies of the effects of oil-related noise on sperm whales. However, a number of field observations have been reported, some of which seem quite contradictory.

During work to assess the impact of a very powerful oceanographic sound source at Heard Island in the southern ocean, Bowles *et al*. (1994) observed that sperm whales stopped clicking when a seismic vessel 370km away could be heard. This effect was noted on several occasions over a two-week period. (The seismic survey vessel was using an array of 8x16l Bolt air guns with an estimated source level of 263dB. At these extreme ranges, the seismic pulses had a duration of c3s, ranged in frequency from 30-500Hz and received levels of 120dB re 1mPa were measured at a range of 1070km.) As sperm whales probably click to echolocate and to find food (see for example, Jaquet, this volume) this is a potentially significant effect.

Mate *et al*. (1994) observed that sperm whales left an area of high abundance off the Louisiana coast of the GOM when a seismic survey started. Sperm whale density was reduced to 1/3 after 2 days; and they were completely absent after five. This appears to be evidence of a fairly dramatic effect, but, as the authors themselves caution, this was a single opportunistic observation, and could have been due to a natural change in distribution unrelated to the seismic survey. Directed surveys like this should be straightforward to perform and observations of this kind should be repeated.

Off New Zealand, a seismic survey was reported to move sperm whales out of an area with a well-established whale watching operation (Liz Slooten pers comm. in IFAW 1996). This was an important effect because, whatever the significance may or not have been for the whales, the consequences for a very profitable locally important economic activity, whale watching, were clear. Also, it is known from the whale watching records that sperm whales were consistently present in this area and their vacating the region was a most unusual occurrence.

Other observations suggest rather less substantial responses however. During surveys of sperm whales in the GOM, Rankin and Evans (1998) observed some changes in behavior and orientation but not the degree of habitat exclusion reported by Mate *et al.* (1994).

Work in the Atlantic Frontier region, off the west coast of Scotland by the Hebridean Whale and Dolphin Trust HWDT (funded by Shell UK) is reported by Swift *et al.* (1999). This involved monitoring sperm whales acoustically in part of the Rockall Trough before, during, and after a seismic survey was conducted in the area. They found that during the seismic survey period there were slightly more whale encounters when guns were off than when they were on. However, far from being excluded from the area, sperm whales appeared to move into it over the course of the survey.

Seismic vessels working in U.K. waters often carry trained marine mammal observers and their observations are recorded on standard sheets and collated by the U.K. Joint Nature Conservation Committee. Analysis of these data by Stone (1998) revealed that there were more sperm whale sightings when guns were active than when they were silent. This may have been because sperm whales tend to surface in response to loud noise. Analysis of the whales' relative headings showed a tendency to avoid the seismic vessel. These data are more akin to opportunistic observations than dedicated surveys, making their interpretation difficult. However, while they indicate some response, they are not consistent with large-scale exclusion from seismic survey areas.

Field observations paint a very mixed picture of the vulnerability of sperm whales to air gun emissions, ranging from extreme sensitivity to apparent near indifference. How can we make sense of these contrasting responses? The first point to make is that none of the observations summaries above have resulted from dedicated, properly controlled and replicated studies, and this inevitably makes observations difficult to interpret. They have also relied on rather crude measures of disturbance: habitat exclusion, gross changes in movements or vocal behavior. Dissimilar sensitivities of different components of the population such as mature males, mixed groups and calves may be a factor accounting for different responses, as may differences in the animal's experience of exposure to seismic surveys. The whales that seemed so little affected by seismic surveys on the Atlantic frontier lived in an area that has been subject to intense exploration over the last few decades. Animals may have become habituated and show few overt signs of disturbance, although more subtle behavioral changes could also occur. In addition, more sensitive animals may already have left the area so that only animals which for whatever reason are less disturbed by air guns were observed.

CONCLUSION

Sperm whales are impressive animals that are an important component of the deep-sea ecosystem as well as being of great public interest. They are recognized as endangered species under the United States Endangered Species Protection Act. Their biology differs in many ways from that of other great whales and some of these unique characteristics may make them particularly vulnerable to the effects of noise. Field observations of disturbance by seismic air guns are equivocal, however, with some indicating great sensitivity and others a degree of tolerance. Where existing information on environmental effects supports a range of interpretations, as is the case here, the precautionary approach will be to base management on the most pessimistic understanding of the data. In this case then, managers should proceed on the assumption that sperm whales are a most vulnerable species. More directed dedicated research projects should resolve current uncertainties and may justify less restrictive management measures.

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Dr. Jonathan Gordon has been studying the behavior of whales and dolphins offshore for 30 years, with a particular interest in sperm whales. His interest in sperm whales led to a practical interest in underwater acoustics, how marine mammals use sound, developing acoustic techniques to study them, and the potential problems of man-made underwater noise for marine mammals. Dr. Gordon has worked on studies to measure disturbance in sperm whales and on use of acoustic monitoring for seismic survey mitigation. He currently acts as a consultant and honorary lecturer at the Sea Mammal Research Unit at the University of St. Andrews, Scotland.

A NEPA ASSESSMENT OF GEOLOGICAL AND GEOPHYSICAL ACTIVITIES IN THE GULF OF MEXICO

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This presentation summarizes work completed to date on the development of a Programmatic Environmental Assessment (EA) entitled "Geological and Geophysical (G&G) Exploration for Mineral Resources on the Gulf of Mexico Outer Continental Shelf." This project is being overseen by the MMS Gulf of Mexico OCS Region, with review and comments being provided from all MMS OCS Regions and Headquarters. The document is being prepared pursuant to the requirements of the National Environmental Policy Act (NEPA). While G&G activities have been previously evaluated (e.g., USGS EIS [1976], MMS Programmatic EA [1984]), there have been advances in technology, expansion of G&G operations into deeper waters, and improving knowledge of and concerns for acoustic impacts to marine life (sensitive resources) since the last assessment was completed.

Over the past 18 months, preliminary versions of the EA have undergone extensive MMS review. Further, the project has seen a certain degree of evolution, with new tasks added, alternatives expanded and revised, appendices expanded, and the document made more lay reader-friendly. The Draft EA is to be released for agency review in February 2002.

The objectives of the EA have been to 1) determine what impacts G&G activities have on the marine, coastal, or human environments of the Gulf of Mexico (GOM); 2) identify potentially significant impacts for further NEPA analysis; 3) evaluate the range of alternatives; and 4) consider current mitigation measures (current regulations, lease stipulations). The EA has focused on activities and resources for which the potential for significant impacts exist. Primary issues of concern include seismic impacts on marine mammals, turtles, and fish. Other issues have been identified through a systematic consideration of impact agents and potentially affected resources for all G&G activities.

Characterization of G&G activities indicated that there are several types of G&G activity occurring in the Gulf. Seismic data acquisition is the most prevalent G&G activity pertinent to exploration operations; however, other techniques are also employed and have been considered in the EA. Types of G&G activity characterized in the analysis include: 1) deep-tow side scan sonar surveys, 2) electromagnetic surveys, 3) geological/geochemical sampling (i.e., bottom sampling, heat flow measurements, shallow coring), 4) remote sensing (i.e., radar imaging, aeromagnetic surveys, gravity surveys, gravity gradiometry, marine magnetic surveys), and 5) seismic surveys. This last category includes various seismic exploration and development techniques, including streamer surveys (2D, 3D), ocean bottom cable surveys, vertical cable surveys, high resolution surveys, time lapse (4D) surveys, and other variations (e.g., multi-ship, undershooting).

Airgun characteristics and sound source levels for systems being used in the GOM were determined. Typical systems had outputs ranging from 218-240 dB re 1 μPa-m (zero to peak). Seismic airgun arrays are designed to produce low frequency output (i.e., 10 Hz to ~200 Hz, peaks ~50-60 Hz, with limited higher frequency components). Seismic sources are also repetitive, transitory; and intermittent, as seismic vessels make a series of passes through offshore lease blocks (i.e., period between exposure ranges from hours to days). Seismic survey vessels move at 3.0-4.5 knots, with airguns firing every 8-16 seconds. There is also a definitive directional component to the airgun array pulse, with most of the energy directed downward towards the seafloor and sound attenuated in the horizontal direction. In terms of levels of activity, the majority of seismic activity has occurred in the Western and Central Gulf, with only limited G&G operations in the Eastern Gulf.

A preliminary screening was completed prior to the formal impact assessment. A total of 12 resource categories were evaluated. Results of the analysis indicate that most G&G activities have negligible or no impact on most Gulf resources; however, seismic operations are potentially adverse to several resources - marine mammals, turtles, fish, commercial and recreational fisheries, coastal and marine birds, and benthic communities. The impacts of G&G activities on each of these resources (or activities) was evaluated in detail.

The impact analysis considered direct and indirect impacts from four separate alternatives, including:

- Alternative 1 - Proposed Action
- Alternative 2 - Implementation of Additional Mitigation Measures
- Alternative 3 - Implementation of a Suite of Mitigation Measures
- Alternative 4 - Restrict G&G Surveying Operations

Under Alternative 1 (Proposed Action), the status quo would be maintained. Under this alternative, all of the existing suite of G&G activities would continue, as would all of the existing mitigation measures (i.e., lease stipulations, protective measures).

Under Alternative 2 (Implementation of Additional Mitigation Measures), depth and geographic restrictions are established. All seismic surveys in OCS waters east of 88˚ W Long and all seismic surveys in water depths >200 m west of 88˚ W Long in the GOM would include either ramp-up procedures (Alternative 2A), visual monitoring (Alternative 2B), and/or passive acoustic monitoring (Alternative 2C). These measures are intended to ensure that species of concern are not present within a predetermined impact zone.

Under Alternative 3 (Implementation of a Suite of Mitigation Measures), the same depth and geographic limits evident under Alternative 2 would be maintained. Further, this alternative includes a requirement for gear deployment and ramp-up during daylight hours and the use of trained marine mammal observers (including potential for vessel crew to be used in this capacity) trained as whale spotters. Continuous seismic survey operations will be allowed under this alternative, except when whales are spotted within the impact zone, or when whales are spotted outside the impact zone but are likely to be affected by continued seismic operations (i.e., ahead of the vessel). Either case prompts system shutdown, with start-up to be allowed only during daylight hours when the impact zone can be visually cleared of marine mammals.

Under Alternative 4 (Restrict G&G Seismic Surveying Operations), there would be a prohibition of simultaneous surveys by more than one G&G survey vessel in those portions of the Gulf most frequented by sperm whales.

As an integral part of the impact assessment process, significance criteria were developed which were resource specific, based on consultation with and guidance from agencies and recent environmental impact assessments. Three separate impact classification levels were established - significant adverse, adverse but not significant, and negligible. Impacts from G&G activities on coastal and marine birds and benthic communities were determined to be negligible. Results of the impact analysis on the remaining resources are outlined below, by resource. Hearing sensitivities, impact agents, and significance criteria are also provided.

Sea Turtles

- Hearing data on sea turtles are limited, with only two studies documenting the effects of airguns on turtles
- Impact agents: seismic noise, vessel traffic
- Significance criteria: death or life-threatening injury; long-term or permanent displacement from critical habitat, nesting beaches, migratory routes; and/or destruction or adverse modification of critical habitat
- Impact determination: adverse but not significant (i.e., Alternatives 1, 2, 3, and 4)

Fish

- Sound detection is generally well understood, but the effects of intense sound are poorly understood
- Impact agent: seismic noise, airgun pressure (immediately adjacent to the airgun)
- Significance criteria: death or life-threatening injury to a listed species, or to a non-listed species in sufficient numbers to adversely affect the population or ecological functioning of the fish community; long term displacement from preferred areas; destruction or adverse modification of habitat
- Impact determination: adverse but not significant (Alternatives 1, 2, 3, and 4)

Commercial and Recreational Fisheries

- Concerns center on behavioral changes which may make target species more difficult to catch and temporary areal preclusion
- Impact agents: seismic noise, areal preclusion
- Impact determination: adverse but not significant (Alternatives 1, 2, 3, and 4)

Marine Mammals

- There are 29 species reported in the Gulf: 7 baleen whale species, 21 toothed whale species, and 1 sirenian species; hearing sensitivity is generally inferred from vocalization characteristics, with few direct studies of hearing completed; considerable variability in vocalization (and inferred hearing capability) exists between species and species groups between species and species groups

- A significant adverse impact on marine mammals is one that is likely to cause - exceedance of potential biological removal (PBR) levels for listed species or strategic stocks; or displacement of any listed species or strategic stock from critical habitat; or long term or permanent displacement of any species from preferred feeding, breeding, or nursery habitat (other than critical habitat); or substantial or chronic disruption of behavioral patterns to an extent that may adversely affect a species or stock through effects on annual rates of recruitment or survival
- An "Impact Zone" was estimated, based on the potential for behavior changes, hearing loss, discomfort, hearing impairment (TTS), and masking from exposure to high sound levels at 180 dB. The maximum output of a seismic array in the GOM of 240 dB re 1 μPa, zero to peak. Other factors act to attenuate the sound, particularly horizontally from the array, including the array effect (-20 dB). Conversion was also made from zero to peak to rms (-3 to -10 dB), for comparative purposes with other noise sources being reviewed and evaluated by NMFS. The distance from the array to the 180 dB (rms) isopleth was calculated at between 100 m and 293 m radial distance in surface and near surface waters; greater distances to the 180 dB isopleth were calculated for sound directed vertical to the array. Variance in the distance calculations reflects different assumptions regarding zero to peak to rms conversion. The 180 dB (rms) level generally conforms to NMFS interim criteria for single impulse sound.

Summary of Impact Determinations

- Marine mammals: select species appear most susceptible to G&G seismic surveys: sperm, Bryde's, and beaked whales, due to deep diving habits (sperm and beaked whales) and perceived sensitivity to low frequency sound. Impacts were determined to be adverse but not significant, due to the fact that seismic sources produce repetitive, intermittent, and transitory sounds and marine mammals have the ability to avoid a sound source once it is detected
- Remaining mammal species with lower susceptibility
- Sea turtles, fish, and commercial and recreational fisheries: adverse but not significant from seismic; same for areal preclusion (fisheries only)
- Coastal and marine birds and benthic communities: negligible from coastal vessel and aircraft traffic (birds) and geological/geochemical activities (benthic communities)

Brian J. Balcom, senior scientist with Continental Shelf Associates, Inc., is a benthic ecologist with nearly 25 years of experience in biological baseline studies and assessments of the potential effects of man's activities on the marine environment. With CSA since 1981, Mr. Balcom has provided technical expertise and management oversight on numerous multidisciplinary assessments of proposed activities in federal and state waters (e.g., nearshore and offshore oil and gas operations ranging from exploration through abandonment, remediation, and monitoring). He has recent international experience assessing impacts of offshore oil and gas operations in the Arabian Gulf, Caribbean waters, and north Pacific, as well as onshore operations in the Middle East and South

America. Mr. Balcom has also prepared assessments pertinent to noise effects (e.g., from offshore operations, sonars, explosives) on marine mammals and sea turtles, with an emphasis on endangered and threatened species. Mr. Balcom earned his B.S. and M.S. degrees in biological sciences (emphasis: marine) from the University of Southern California, and has post-graduate experience in environmental engineering and environmental law.

ACOUSTIC BACKSCATTER INTENSITY AS A PROXY FOR PLANKTON AND MICRONEKTON BIOMASS IN SPERM WHALE HABITATS IN THE NE GULF OF MEXICO

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A 300 kHz acoustic Doppler current profiler (ADCP) was hull-mounted on the NOAA Ship *Gordon Gunter* from July to September 2001 in support of NOAA's Sperm Whale and Acoustic Monitoring Program (SWAMP) and follow on ichthyoplankton survey (SEAMAP). During this three-month summer period, the ADCP recorded near-surface current velocity and acoustic backscatter intensity (ABI) data. Previous ABI data collection during the GulfCet II program had showed that the ABI signal can be used as a proxy for zooplankton and micronekton biomass (Ressler 2001) and that regions of sperm whale abundance were correlated with regions where ABI was locally high (Wormuth *et al*. 2000). ADCP data collection during summer 2001 allowed us to continue and extend our analysis of ABI in sperm whale habitats of the NE Gulf of Mexico (GOM).

SWAMP fieldwork aboard the *Gordon Gunter* was done in three legs (Figure 2F.6) spanning the period 18 July to 22 August 2001 (see Table 2F.1). In general, the ADCP recorded data continuously throughout each of these three legs, although the formation of Tropical Storm Barry over the eastern GOM during the second leg forced the ship into port for several days 3-6 August 2001. Echo intensity was recorded in 4 m vertical slices (bins), with the first bin centered 7 m from the instrument (12 m from the surface, since the ADCP was hull-mounted at a depth of 5 m below the sea surface). The deepest usable bin (deepest bin before percent good return signal dropped < 80%) was centered 71 m from the instrument (76 m below the surface). For the present analysis, we compared 11 four-meter-thick bins (16-56 m below the surface). Only the ADCP data collected during times when the ship transited the continental slope (water depths > 200 m) were included in our analysis, since sperm whales appear to prefer deepwater habitats (water depths > 300 m).

To analyze the ADCP signal, the binary raw data were converted into ASCII format using the instrument manufacturer's program BBLIST (available from the RDI website). Then, programs written for PV-Wave that were originally created by S.F. DiMarco and R.L. Scott for analysis of ADCP data collected during the DeSoto Canyon Eddy Intrusion Study (see Scott *et al*. 2001) were used to correct the data for spherical spreading loss to estimate the relative backscatter coefficient, or S_v, in units of decibels. Preliminary graphs of backscatter intensity versus time for each of the depth bins 16-56 m were created to compare ABI at various depths below the surface. Data were then separated into day and night periods, using times of local sunrise and sunset as tabulated by the

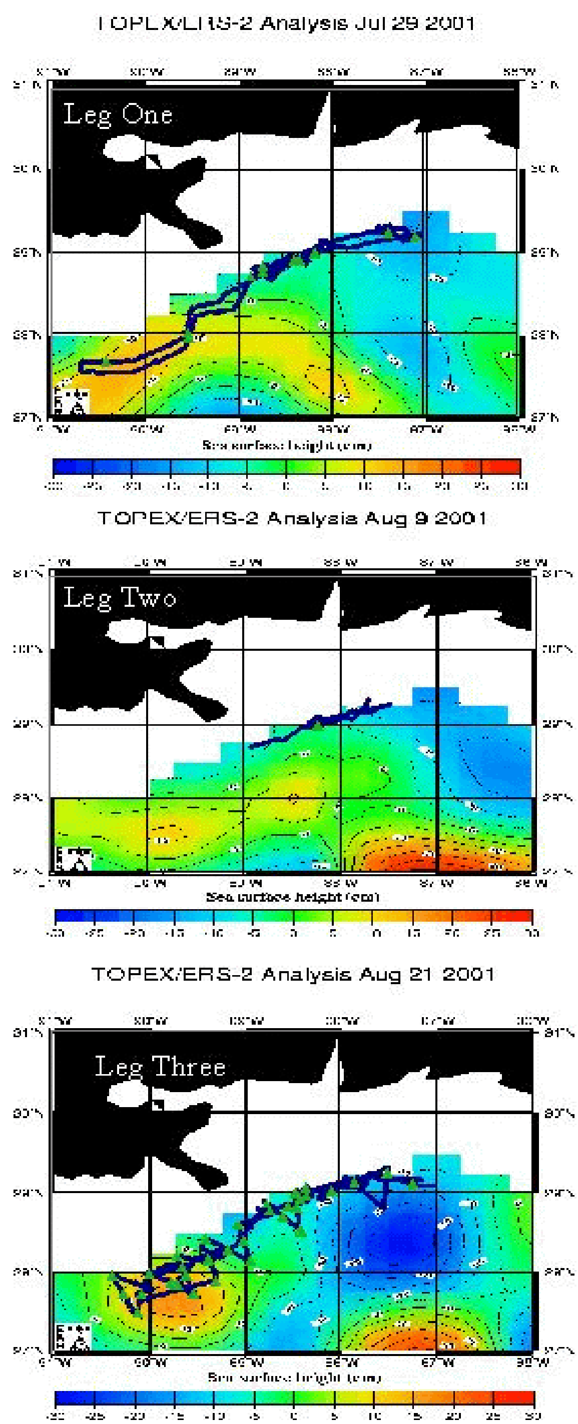

Figure 2F.6. Ship tracks for the three legs of SWAMP fieldwork, superimposed on sea surface height (SSH) fields composited by optimal interpolation from tandem TOPEX-Poseidon and ERS-2 altimetry (*http://www-ccar.colorado.edu/~realtime/gom-historical.ssh/*). Since sperm whales appear to prefer water depths > 200 m, SSH has been masked for water depth < 200 m.

Table 2F.1. Average ABI for three hydrographic regimes sampled day/night for the three legs of the SWAMP fieldwork. ABI was obtained using the visual data analysis software program PV-Wave.

		Warm Filament	**Confluence**	**Cyclone**
Leg 1 (July 18-29)	**Day ABI** & Standard Error (hours usable data)	-104 (± 0.032) 13 hrs.	-102 (± 0.062) 90 hrs.	-101 (± 0.061) 26 hrs.
	Night ABI & Standard Error (hours usable data)	-102 (± 0.053) 9 hrs.	-100 (± 0.074) 62 hrs.	-98 (± 0.078) 18 hrs.
	location (longitude)	west of 89.5° W	88° - 89.5° W	east of 88° W
	depth of 15°C isotherm (n = CTDs + XBTs)	271m (n = 3)	188m (n = 9)	182m (n=1)
Leg 2 (Aug 1-2 & 7-9)	**Day ABI** & Standard Error (hours usable data)		-103 (± 0.051) 42 hrs.	
	Night ABI & Standard Error (hours usable data)		-100 (± 0.058) 20 hrs.	
	location (longitude)		87.5° - 89° W	
	depth of 15°C isotherm (n = CTDs + XBTs)		170m (n = 1)	
Leg 3 (Aug 10-22)	**Day ABI** & Standard Error (hours usable data)	-109 (± 0.041) 26 hrs.	-105 (± 0.048) 65 hrs.	-105 (± 0.054) 26 hrs.
	Night ABI & Standard Error (hours usable data)	-105 (± 0.060) 18 hrs.	-100 (± 0.077) 36 hrs.	-98 (± 0.064) 18 hrs.
	location (longitude)	west of 89.5° W	88° - 89.5° W	east of 88° W
	depth of 15°C isotherm (n = CTDs + XBTs)	250m (n = 14)	209m (n = 21)	166m (n = 5)

U.S. Naval Observatory (*http://usno.navy.mil*), and separate daytime versus nighttime averages in ABI were computed. Twilight times during dusk and dawn (approximately one hour of acoustic data each) were not included in these averages. These averages document that ABI was higher at night than during the day, as Scott *et al.* (2001) had reported. This lower-during-daytime, higher-during-nighttime periodicity is caused by the diel vertical migration of zooplankton and micronekton out of (daytime), and then back into (nighttime), near surface waters.

Backscatter intensity data were analyzed to look for differences among the three hydrographic regimes that were present in summer 2001 along the continental margin of the NE Gulf. Altimetry data showed that a warm filament was located just off the shelf-slope break in the western part of the field area, while a cyclone was present there in the eastern part of the field area. A zone of off-margin confluence flow was set up between these two hydrographic regimes. Preliminary analysis indicates that the region of the cyclone has higher average ABI, while the region of the warm filament has the lowest average ABI (Table 2F.1). For each of the three legs of the SWAMP fieldwork, between-bin correlation coefficients were calculated for every other depth bin, 16-56 m. Correlation coefficients were robust between adjacent bins but these decreased as the vertical separation between bins increased.

Analysis of ADCP data from the SWAMP fieldwork is ongoing. Programs in PV-Wave will be developed to perform empirical orthogonal function (EOF) analysis of the data in order to better interpret spatial and temporal variability in ABI.

Following the SWAMP fieldwork, ichthyoplankton sampling in support of the NOAA-SEAMAP program was conducted within the region 91.5W to 86.5W from 8-17 September. During this SEAMAP cruise, the ADCP was run continuously to gain additional across-margin ABI data from the NE Gulf but only that portion of the ABI data collected in water depths > 200 m will be analyzed in this project to describe the deepwater oceanographic environment of sperm whale sightings. Nine Bongo net tows were fished obliquely to 200 m during the SEAMAP cruise in deepwater between 91.5 W and 86.5W (Pamela Bond, communication). The wet displacement volume of these nine tows has been measured, and these data will be used to compute the linear regression between ABI and plankton biomass, following the methodology outlined by Scott *et al.* (2001). Then, by combining SWAMP and SEAMAP data, the regions where sperm whales were seen by marine mammal observers will be examined to determine whether these regions had significantly higher average ABI.

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Doug Biggs is professor and chair of the six-person biological oceanography faculty at Texas A&M University. In addition to being part of the project team for the Sperm Whales and Acoustic Monitoring Program (SWAMP), Biggs has been a co-PI on MMS-sponsored GulfCet2 and NEGOM-COH projects and on the ongoing MMS-sponsored DGoMB project.

Steve DiMarco is an associate research scientist at Texas A&M University. Originally trained in physics (B.A., M.S., and Ph.D.), he has worked on physical oceanographic problems related to the Gulf of Mexico since 1993. His principal research interests include the physical oceanography of the continental shelves and slopes, particularly of the Gulf of Mexico, the general circulation of the southwest Indian Ocean, and the cross-shelf exchange processes.

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SPERM WHALE MOVEMENTS IN THE GULF OF MEXICO FROM AN ARGOS SATELLITE-MONITORED RADIO TAG

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As part of the Minerals Management Service (MMS), Office of Naval Research, and National Marine Fisheries Service co-sponsored Sperm Whale Acoustic Monitoring Program (SWAMP), satellite-monitored radio tags (S-tags) were deployed during leg 2 of the summer 2001 cruise off the Mississippi River delta region. Within the overall SWAMP effort, S-tags will provide longer-term information on surfacing locations of tagged sperm whales while digital tags (D-tags) provide short-term behavioral information. The two tags complement each other in providing information on Gulf of Mexico (GOM) sperm whales and responses to the presence of seismic surveys.

Field efforts to tag whales in July 2001 were limited due to bad weather and high sea states. One sperm whale tagged off the Mississippi/Louisiana coast in July 2001 was tracked for 137 days, showing a preference for waters 1,000 meters deep during the first 95 days. It subsequently traveled west across the upper GOM and south into the Gulf of Campeche, Mexico. Analyses included the distances of locations from shore, depths of waters traversed, and numbers of dives the tagged whale completed while in the tagging (foraging) area, migrating and in Mexican waters (a possible reproductive area).

In 2002, research conducted under SWAMP will be continued and expanded under a new research program, Sperm Whale Seismic Study (SWSS), managed by the Texas A&M Research Foundation.

A three-week cruise is proposed for June-July 2002 to survey for sperm whales off the Texas coast and Mississippi River delta and to place up to 20 S-tags on sperm whales.

Dr. Bruce Mate has studied marine mammals for 33 years, concentrating on habitat identification and migration patterns of endangered whales during the last decade. He has served as a scientific advisor to the Marine Mammal Commission and the Minerals Management Service Outer Continental Shelf program. Dr. Mate pioneered the development of satellite-monitored radio tags for large whales. He is currently at Hatfield Marine Science Center at Oregon State University.

SPERM WHALE DIVING AND VOCALIZATION PATTERNS FROM DIGITAL ACOUSTIC RECORDING TAGS AND ASSESSING THE RESPONSES OF WHALES TO SEISMIC EXPLORATION

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We present a description of a new tag device (D-tag) for observing the sub-surface behavior of sperm whales and how D-tag can be used to quantify the responses of whales to underwater sound. D-tag is a synchronous motion and audio recording tag that is attached to whales using suction cups. The current version of D-tag contains 1.6 Gbytes of memory, and accurately records the pitch, roll, and heading (to within ±2°) and depth (±0.3m) of the whale at a high-rate as well as audio received on the tag. By linking the whale-orientation data from the tag with visual observations conducted from the support research vessel, we are able to create an accurate 3-D track of the diving sperm whale. This position information is critical to measure the response of whales to underwater sounds. Tag attachment is aided by a pneumatic passive-pump linked to the suction cups that also function to release the tag after the programmed attachment duration.

To date we have attached D-tag to 15 sperm whales in the northern Gulf of Mexico (GOM) and the Mediterranean with attachment duration ranging from <1 to >9 hours. We have recorded at least one complete deep foraging dive from seven animals with a total of 33 deep dives. With this data set, we have begun to describe the underwater behavior of deep-diving sperm whales with a level of detail never before possible. We find that depth transitions and animal roll are closely linked, that clicking behavior of diving whales follows consistent patterns from steady clicking to creaks to pauses, and that sperm whales appear to increase overall movement during creaks, suggesting the whales use creaks in the final stage of chasing prey. Sperm whales also exchange coda-style clicks, which are associated with more complex movement by the whale. This behavior often results in joining between whales. On the tag we also detect echoes of the whale's clicks from the sea-surface and ocean-bottom, and the whale's diving behavior suggests that the whale makes use of these echoes to position itself in the water column. These data strongly confirm the view that underwater sound is critical in the day-to-day life of sperm whales.

Use of D-tag in association with visual and acoustic observations from a research vessel provides an excellent means to assess possible effects of seismic exploration on sperm whales. In one D-tag deployment in the northern GOM on 28 July 2001, we documented that the tagged whale moved away from an operating seismic vessel once the seismic pulses were received at the tag at roughly 137 dB re 1mPa. Such avoidance reactions have been documented in the past, but their biological significance remains unclear. We have used data collected from D-tag to build an energetic model of foraging and energetic expense to provide a measure of the biological significance of such reactions. The model is based upon the idea that disturbance from noise may increase energetic expenditures and/or decrease foraging effectiveness, and that such effects reduce the amount of energy that sperm whales can dedicate to growth and reproduction, which are critical for the health of an animal population.

Because creaks indicate the final pursuit phase of foraging (see above), they provide a useful metric for the rate of feeding in sperm whales. For example, in the avoidance event documented by D-tag on 28 July 2001, the whale's creak-rate decreased substantially after it moved away from the seismic vessel, suggesting that the disturbance affected its feeding rate. We also suggest that more information is urgently needed on the behavior and distribution of the squid prey of sperm whales. Combining D-tag data with measured body-size, we have been able to quantify the magnitude of drag and buoyancy forces acting on the sperm whale. This is made possible by the fact that sperm whales often glide on the ascent-portion of deep dives, and the amount of deceleration in the glide period is controlled by the twin forces of buoyancy and drag. We can therefore use D-tag data to estimate the work required by the whale to travel through the water, which is a useful measure of the whale's relative energetic expenditure.

D-tag has also revealed certain behaviors of sperm whales in the northern GOM that may predispose them to more severe effects of disturbance. One of the sperm whales tagged near De Soto canyon, nicknamed "Deep-Dan," foraged along the sea-floor at over 900m depth, the deepest of any sperm whale recorded in the Gulf to date. Foraging along the bottom may be a risk factor for disturbance because the requirement of such animals to dive to the bottom to feed significantly increases the energetic outlay for foraging. Because the whale forages on the bottom, it may be tied to localized food resources that it has learned to find and capture. As a result, if this whale moves away from its preferred feeding area to avoid a loud noise source, it may have a much greater impact on foraging rates than sperm whales that feed on more widely dispersed squid in the middle of the water column. We feel that D-tag is an ideal tool to continue to study the behavior of sperm whales, to identify risk factors for disturbance, and to study the reactions of sperm whales to controlled exposures of sound in a carefully designed experiment. D-tag is an ideal tool not only to document detailed responses to sounds at levels measured at the whale, but also to estimate the biological significance of such responses.

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PASSIVE ACOUSTIC MONITORING OF SPERM WHALES IN THE GULF OF MEXICO, WITH A MODEL OF ACOUSTIC DETECTION DISTANCE

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INTRODUCTION

Surveys of cetaceans have traditionally been performed visually (*e.g.*, Hiby and Hammond 1989; Barlow 1995; Davis *et al.* 1998). Visual surveys can suffer from a number of impediments, not least that the species surveyed usually spend the large majority of their time underwater, where they are visually undetectable. In addition, visual survey accuracy is hampered by variability in wind and wave conditions, by changes in atmospheric visibility, by sun angle, by variability in observer ability, and so on, and furthermore visual surveys are restricted to the daylight hours. Because of these difficulties, surveys in recent years have started to use passive acoustic methods (Norris *et al.* 1996; Clark and Fristrup 1997; Barlow and Taylor 1998; Stafford *et al.* 1999; Akamatsu *et al.* 2001). ("Passive" refers to the use of only those sounds made by the target animals, rather than active sonar signals emitted by the surveyor.) Acoustic methods work well because sound is transmitted quite effectively in sea water, and because many cetacean species are acoustically active much of the time – indeed, it is the principal information-gathering and -communicating sense used by cetaceans. Passive acoustic monitoring can be done around the clock, making good use of valuable ship time, and it can detect animals that may escape visual detection by staying underwater while a survey ship is passing nearby. Acoustic methods have impediments as well, of course, most notably variability in background noise and variability in animals' vocalization behavior, but these are mainly independent of those for visual surveys, and thus visual and acoustic methods can be used complementarily.

Sperm whales (*Physeter macrocephalus*) make excellent subjects for acoustic surveys. They are highly vocally active (Jaquet *et al.* 2001, this volume), making them easily detected acoustically, particularly during long dives when they are visually undetectable. Their sounds, wideband clicks that usually occur in certain timing patterns (Jaquet *et al.* 2001), are distinctive and can be easily distinguished, in most cases, from other marine sounds. Their sounds are also easily localized, as the clicks have a sharp onset and offset and so provide good material for determining the time-of-arrival differences used in many acoustic localization methods.

If acoustic methods are to be used for population studies, a key question is that of acoustic detection distance: at what distance is a given species audible? The answer depends on many factors, leading to the need for a statistical model that calculates some kind of mean detection distance, averaged over the relevant factors. Several researchers have previously estimated acoustic detection distance of sperm whales. Leaper *et al.* (1992) conducted a field audibility test in the Azores and estimated a mean distance of 9.1 km. They also used successive bearings to estimate a distance of 6.5 km. Norris *et al.* (1996), as part of the GULFCET surveys in the Gulf of Mexico (GOM), used a simple acoustical model that assumed spherical spreading and deduced a detection distance of 11.1 km. Barlow and Taylor (1998), working in the northeast Pacific, used successive bearings to calculate a detection distance of 7.0 km. Acoustic transmission distances vary from location to location and also vary over time, so it is not surprising that different researchers found different answers.

In this paper, we first describe the acoustic monitoring methods used on cruises in the GOM. We also develop a method for estimating the acoustic detectability of sperm whales. Improvements over previous estimation methods include (1) the use of a more realistic acoustic model to estimate propagation loss, (2) a statistical model of whale diving behavior, and (3) a statistical model of whale sound production that includes variable-loudness calls.

METHODS: ACOUSTIC MONITORING

In July-August 2000, a MMS-sponsored pilot cruise for the Sperm Whale Acoustic Monitoring Program (SWAMP) was conducted in the GOM to investigate methods for censusing sperm whales and assessing impacts of anthropogenic noise. Goals of the cruises included development of techniques to assess impacts of anthropogenic noise and census sperm whales, and integration of visual and acoustic surveys. Goals of the acoustics team included detection, localization, and tracking of sperm whales; observation of diving behavior; studying the effects of diving on sperm whale behavior; and development of methods for sperm whale population monitoring.

The research vessel, the R/V *Gordon Gunter*, towed hydrophone array(s) containing two and/or five hydrophones during daylight hours, and sometimes at night as well. Sounds from these hydrophones were conditioned and recorded in the acoustics lab on board the ship.

Acoustics operators monitored the sounds in real time using several software platforms. Ishmael was used in real time for sound viewing, recording, localization, and automatic call (click) recognition. WhalTrak was used in tandem with Ishmael to plot ship tracks and whale bearings. RainbowClick was used for automatic click detection and whale bearing determination. MATLAB was used for many types of analysis, both in near-real-time aboard ship and in post-analysis in the laboratory.

METHODS: ACOUSTIC DETECTION DISTANCE

Acoustic population monitoring is a key application of passive acoustics. As discussed above, acoustic detection distance is an important element of acoustic population monitoring. Here we investigate the question of sperm whale acoustic detection distance.

Whale Detection Model

Under what conditions can a whale be heard? A whale is just detectable when

$$l_s - t(r, d_r, d_s) = n - g \tag{1}$$

where

l_s	=	source level of whale, dB
$t(r,d_r,d_s)$	=	transmission loss (dB) as a function of range r, depth of receiver d_r, and depth of source d_s
n	=	noise level, dB
g	=	processing gain and detection gain, dB

How were these values obtained? We address each in turn:

Whale source level l_s: The equation above requires only that background noise level and source level be measured relative to the same reference level. To do this, we simply measured the signal-to-noise (SNR) level of the received clicks. Next, we used an acoustic propagation model, as described below, to calculate the transmission loss between the source whale and the receiving hydrophone, then added it to the SNR of received signal to obtain l_s.

Noise level n: The background noise level *is* the reference level, so n is 0 dB.

Processing and detection gain g: In the absence of beamforming (Johnson and Dudgeon 1993), the processing gain is 0 dB. Detection gain is a measure of what the received sound level must be relative to background noise for the signal to be detectable. It was measured by determining finding whale clicks that were just detectable, then measuring their SNR.

Transmission loss t: Transmission loss is calculated using an acoustic propagation model. The model used here was Oases, a model based on the technique of wavenumber integration. It produced the acoustic transmission loss, in decibels, as a function of discrete depth and range. It required extensive information about the ocean environment to perform accurately. The principal types of information needed included these:

- Sound speed profile (SSP). This was measured at sea using a conductivity-temperature-depth instrument lowered from the research vessel.

- Bathymetry. Most propagation models need as input the bathymetry between the whale and the hydrophone. Smith and Sandwell (1997) provided global bathymetry data at a resolution of 3-10 km.

- Sediment characteristics. From data obtained in ocean drilling projects (*e.g.,* http://www-odp.tamu.edu/database), sediment types and thicknesses were estimated. From these, approximate values of the sediment characteristics needed by Oases were determined using Jensen and Kuperman (1983), which provided average values of these characteristics by sediment type.

- Depth of hydrophone. This was obtained from a sensor on the hydrophone array. It varied with ship speed and other factors, and was 60 m during the test described below.

- Depth of whale. This was averaged using the statistical model described below.

Using this information, the acoustic propagation model was run. It produced an array containing the transmission loss values as a function of depth and range.

Detection Distance Model

Given the above detectability function, how is the *detection distance* – the average distance at which a whale is detectable – calculated?

We used a probabilistic model: Assume that whales are diving, and that their loudness varies with depth. Define the following probability density functions (PDFs):

$p(d_s)$	=	probability that whale is at depth d_s
$p(d_s,l_s)$	=	probability that whale at depth d_s makes a sound louder than l_s

These functions can be derived from tagging data: a depth tag could provide data that can be used to calculate $p(d_s)$, and an acoustic recording tag (Tyack and Johnson, this volume) could provide data that can be used to calculate $p(d_s,l_s)$. At the time of this analysis, these data were not available; instead estimates of these distributions were used to show how the detection distance model works.

Given these probability functions, the probability of detecting a whale at range r is given by

$$D(r) = \int p(d_s)\, p(d_s, d_l)\; dd_s \qquad (2)$$

$$= \int p(d_s) p(d_s, n - g + t(r, d_s, d_r))\; dd_s \qquad (3)$$

RESULTS: ACOUSTIC MONITORING

The hardware/software setup described above was highly effective for locating whales. Most times that whales were detected, they were heard before they were seen. While monitoring a pod of diving whales, the acoustic operator would frequently hear the whales go silent, often indicating that a surfacing was imminent; the operator could then inform the visual team of the bearing and sometimes distance to the whales.

Acoustic tracking was not as effective when whales were very near to the ship – within, say, 1 km. Most likely, this was because the whales' angle to the hydrophone array would change rapidly as the whales dove and surfaced, making it difficult to get precise bearings to the whales. Also, because of the left/right ambiguity of the hydrophone array, it was sometimes difficult to know which side of the ship the whales were on. (This was much less of a problem when the whales were farther away, since the side of the ship they were on changed only occasionally and could be disambiguated by slight changes of ship heading.)

Passive acoustic tracking was perhaps most useful when the research team wished to stay with a group of whales overnight. This happened when other research teams aboard, including the tagging and behavior teams, either needed to stay with the same group of animals or to get an early start the next day. Using passive acoustic monitoring, it was not difficult for the acoustic operator to guide the ship to stay in proximity to the moving pod of whales.

RESULTS: ACOUSTIC DETECTION DISTANCE

Using the parameters described above, the transmission loss between the whale and the hydrophones was as shown in Figure 2F.7.

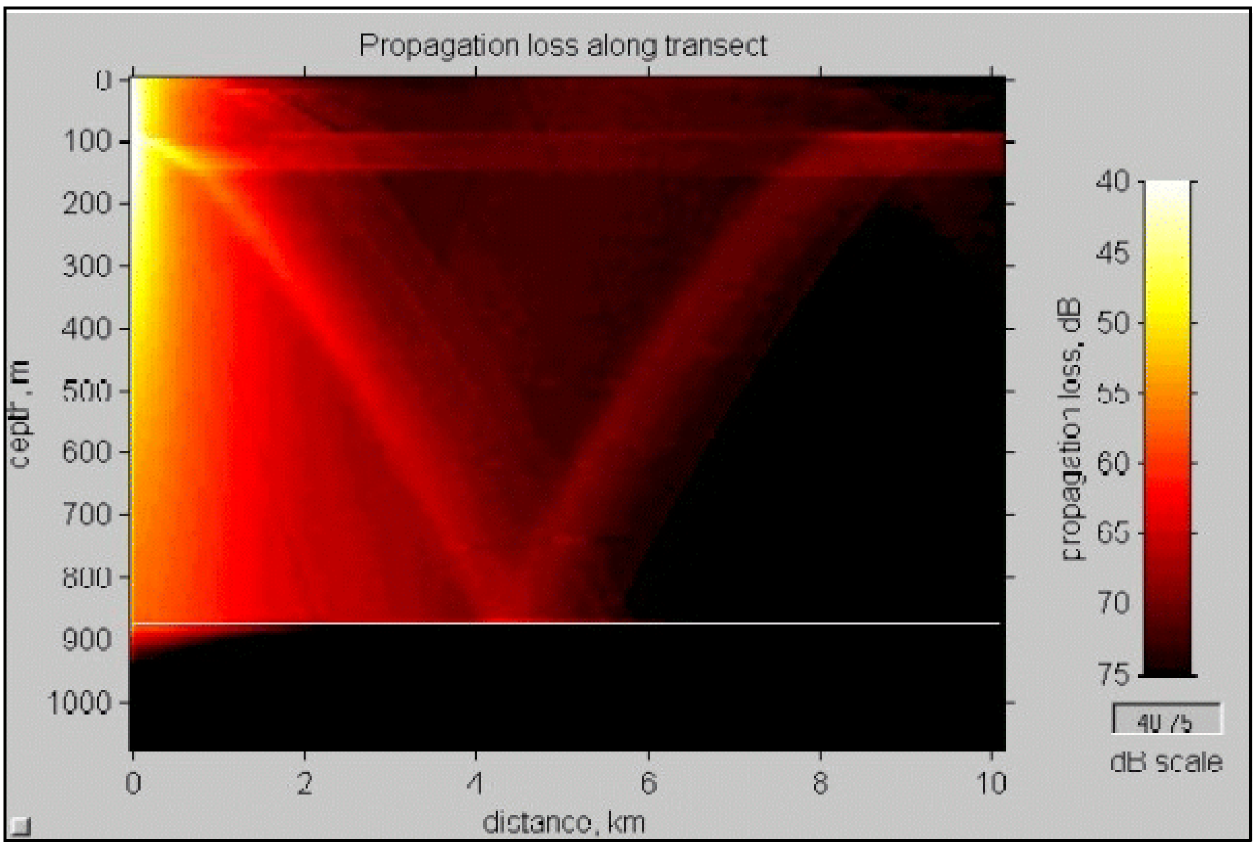

Figure 2F.7. The transmission loss between the whale and the hydrophones.

The model of whale detectability described above requires a number of parameters. These were as follows:

> Beamforming was not used, so the beamforming processing gain was 0 dB. Clicks were just audible when they were 7 dB above the average background noise level, giving a combined value for *g* of 0+7 = 7 dB.

The SNR of received sperm whale clicks was measured to be 35 dB. The transmission loss was calculated using Oases to be 54 dB. The source level estimate was then 35+54-7 = 82 dB relative to background noise level.

A simplified whale diving depth probability function was used: whales were assumed to be at the surface (14% of the time), feeding at depth (70%), or transiting between surface and feeding depth (16%). The whale depth-loudness joint PDF was even simpler: whales were assumed to be silent at the surface, and making sounds of constant loudness while diving. (The latter assumption was based on anecdotally observed behavior in the field while whales were foraging.)

Using these parameters, whales were detectable when they were in the white region of Figure 2F.8.

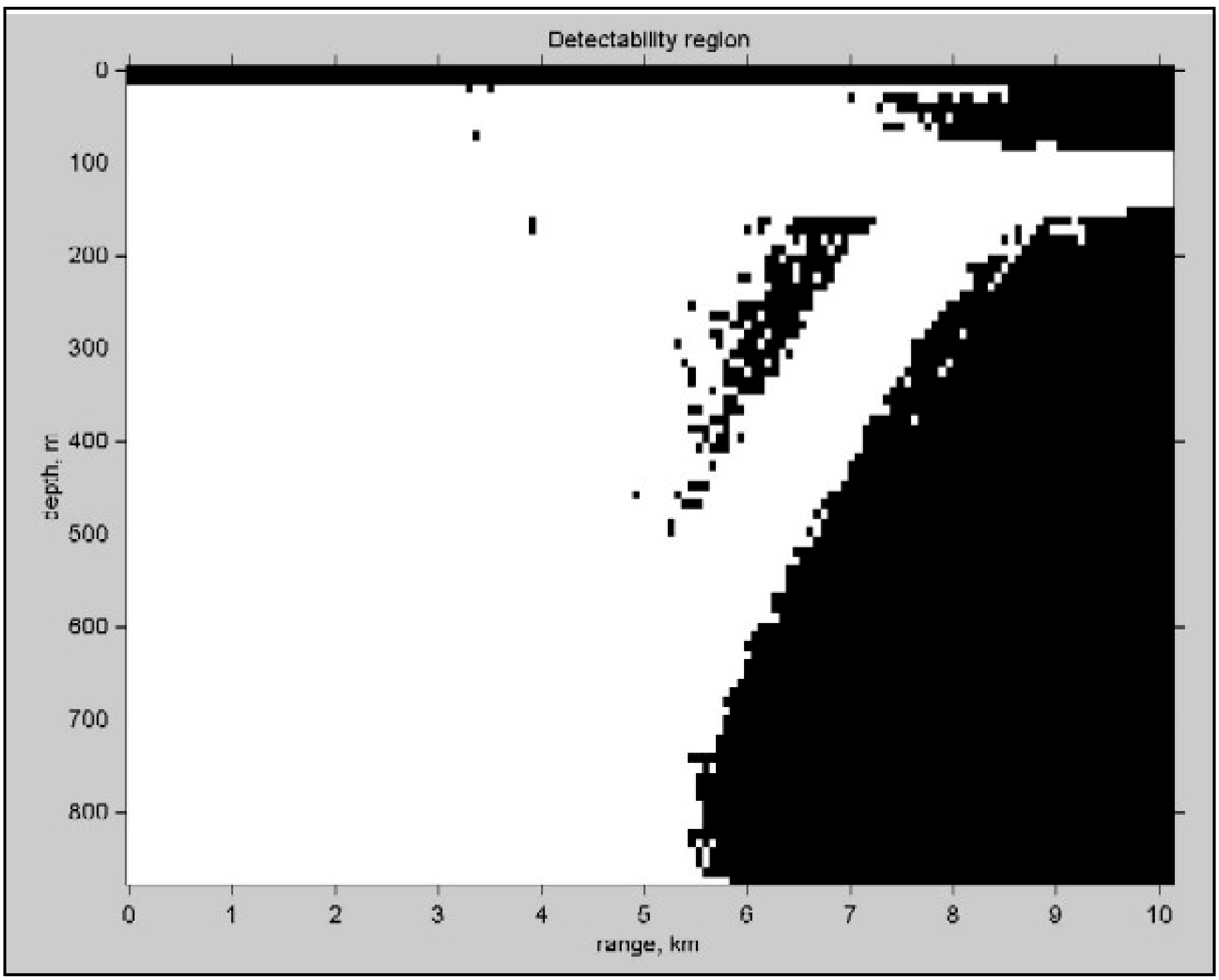

Figure 1F.8. Whales were detectable when they were in the white region.

From Figure 2F.9, and using the detectability model described above, the acoustic detectability of sperm whales as a function of distance can be estimated.

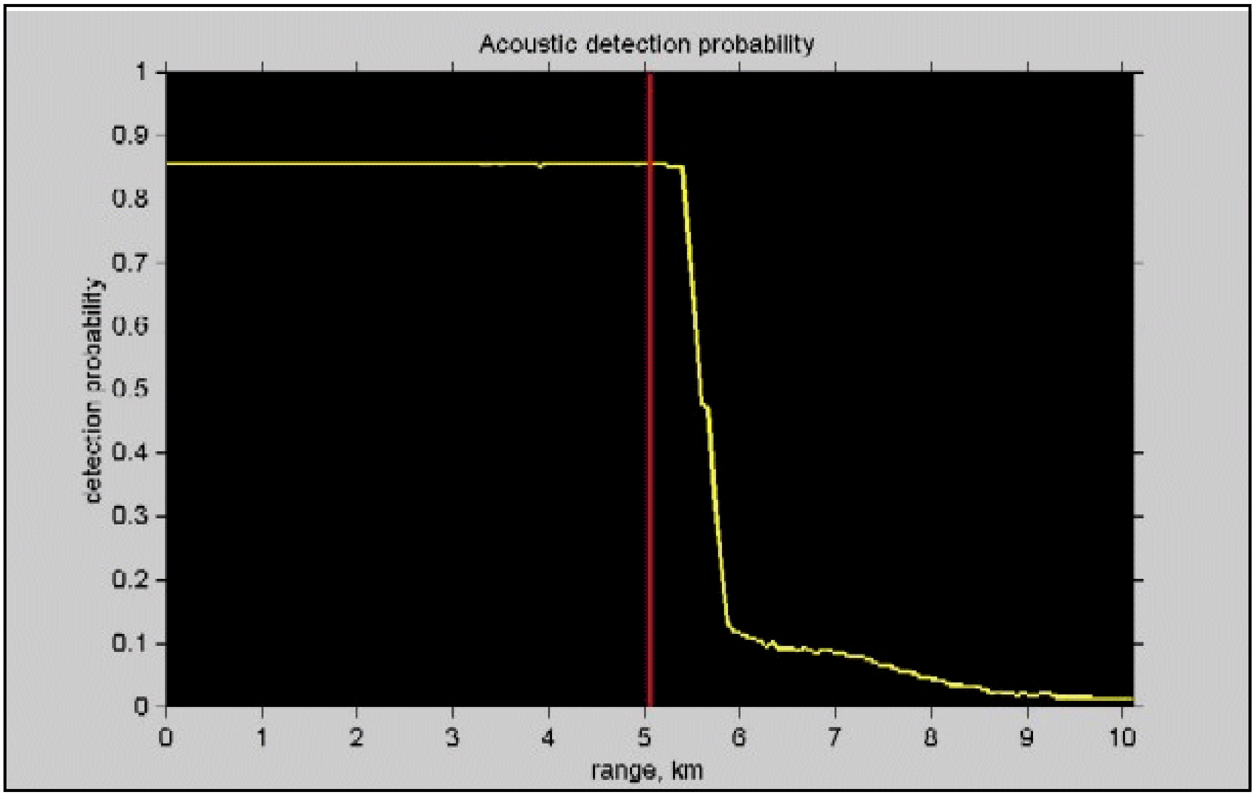

Figure 2F.9. Estimating the acoustic detectability of sperm whales as a function of distance.

The line here at just over 5 km is the "strip width," the distance such that equally many whales will be seen beyond that distance as will be missed closer than that distance. (In other words, the area above the curve to the left of the line equals the area under the curve to the right of the line.) It can be thought of as the acoustic detection distance under the prevailing environmental conditions. For estimating population sizes, it is a critical value for determining how much area a ship's trackline covers.

DISCUSSION

Acoustic localization and tracking worked quite effectively during these pilot cruises, and will probably be used on future sperm whale research cruises in the GOM (Sperm Whale Seismic Study, initiated June 2002) and elsewhere. As mentioned above, acoustic methods are beginning to be used much more widely in cetacean research, a trend that can only be encouraged given our experience on these cruises.

The detection distance here, about 5 km, is significantly less than that estimated by Norris *et al.* (1996). They primarily used a simple propagation model, so the more highly developed model used here (Oases) is likely to be more accurate. In addition, the environmental conditions used here are likely to be different from the ones they encountered, so the detection distance would likely be different in any case.

The statistical model described here uses many parameters. What does the model's accuracy depend most highly on? It depends on quality of the probability functions – the whales' diving depth profile, and the whales' relative loudness as a function of depth. Both of these can be calculated from acoustic tag data, and will be in future work. Accuracy also depends on accurate determination of source level; this determination, as well as the detection distance calculation, depend on the accuracy of acoustic propagation model. This in turn depends on quality of environmental data, which were fair to good in this case; improvements will be made by obtaining information from better databases, and by making more frequent measurements of the sound speed profile while at sea.

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DEPTH-DEPENDENT BEHAVIORAL AND SPECTRAL FEATURES OF DIVING SPERM WHALES (*PHYSETER MACROCEPHALUS*) IN THE GULF OF MEXICO

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By measuring the relative arrival times of direct, surface, and bottom-reflected acoustic paths on a towed hydrophone array, three-dimensional dive trajectories of three vocalizing sperm whales in the Gulf of Mexico (GOM) have been obtained between 200 and 700 m depth. The inter-click intervals display a pattern consistent with that expected for bottom echolocation. Individual click frequency spectra show diffuse local maxima at 2 and 10 kHz that shift frequencies by up to 50% during the 500 m depth change. These features are consistent with those expected from small resonating air sacs inside the animal that do not change dimension with depth. This last requirement indicates that the hypothetical resonator (Fletcher 1992) is connected to compressible air cavities.

We present here detailed quantitative evidence of echolocation behavior from three diving sperm whales in the GOM, and identify depth-dependent features in their vocalization spectra that are consistent with simple resonator models of air-filled swim bladders (Love 1978; Andreeva 1964). To obtain these results we used the passive acoustic localization technique of measuring multiple acoustic reflections off the ocean surface and bottom(Cato 1998; Aubauer *et al.* 2000). This method is a variant of standard acoustic methods for tracking whales(Watkins and Schevell 1972; Spiesberger and Fristrup 1990; Wahlberg *et al*. 2001; Whitney 1968; McGehee 1997; Mohl *et al*. 2000).

On the evening of 3 July 2000, between 22:00 and 23:30 Central Daylight Time, a fortuitous set of circumstances converged that allowed acoustic three-dimensional tracking of three diving sperm whales in the GOM. During this time the National Oceanic and Atmospheric Administration ship *Gordon Gunter* was cruising slowly among a group of diving animals, recording their sounds on a hydrophone array deployed at an unknown depth and tilt behind the ship.* The sexes of the animals

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*Data presented here were recorded between 27.8875 N, 89.4823 W and 27.9197 N, 89.4822 W, in water whose depth varied from 930 to 953 m. Data were recorded on a five-element hydrophone array built by Sonatech, Inc., with two meter element spacing, and 75 m of trailing cable behind the last element. The array was deployed from a cable 147 m behind the *Gunter*. Sound signals captured by the array hydrophones were routed through a Mackie 1604-VLZ PRO Mic/Line preamp mixer, and then passed through a Avens Model 4228 8 Dual Channel Variable Frequency Filter to cut the substantial flow noise below 1 kHz. Signals were then recorded onto a TASCAM DA-78HR digital recording system.

were unknown, but were likely female and/or immature male. Due to a combination of very calm ocean conditions on the sea surface and a flat bottom bathymetry, each click was received on each hydrophone via multiple paths, including the direct path, surface reflection, bottom return, and a combined bottom and surface return. The use of a second array element allowed estimation of arrival angles of the direct and surface-reflected paths. Thus, five independent variables could be measured from each click, and both the whale position and array position could be derived simultaneously. Detection of bottom returns was the essential requirement for this localization procedure to work.*

An observed relationship between the whales' inter-click interval (ICI) and its elevation above the ocean floor is plotted in Figure 2F.10.

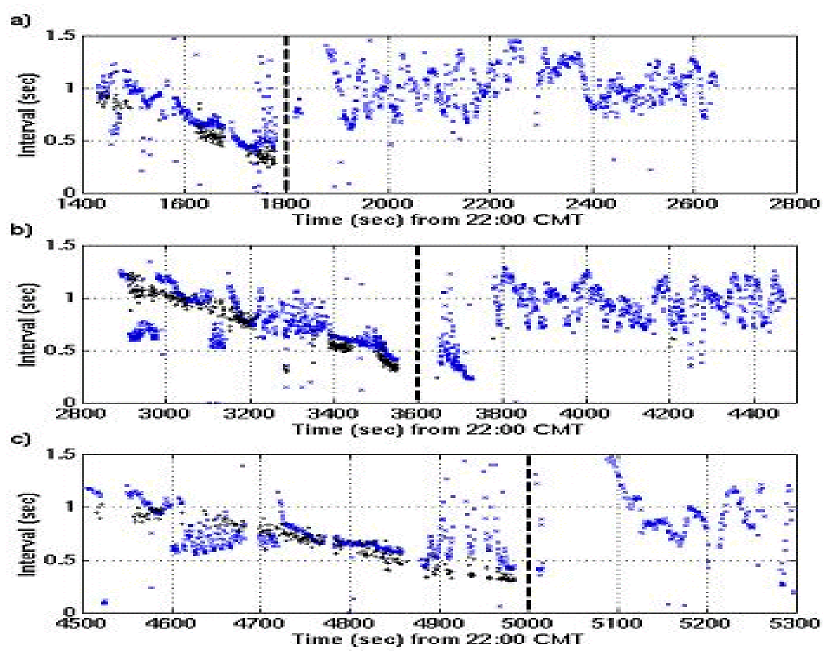

Figure 2F.10. Relationship between inter-click interval (crosses) and two way acoustic travel-time between three whales and the ocean floor (circles). Each subplot (a-c) corresponds to a different dive profile from a different animal. The travel times shown in subplot (b) were computed using the depths displayed in Figure 2F.10. The dashed vertical lines indicate the times at which the bottom bounces disappear, and 3-D localization becomes impossible. Note the sudden change in ICI that occurs after the bottom bounces vanish.

The black circles represent the time required for an acoustic pulse to travel from the whale to the ocean floor and back (assuming vertical travel), and the blue crosses represent the ICI. The close

*Details of the 3D localization have been submitted in a paper to the Journal of the Acoustical Society of America.

correspondence between the two measures during the descending phase suggests that these whales waited to receive the bottom return from their previous clicks before generating the next sound, a form of depth-sounding. This temporal pattern is characteristic of echolocation in other animals such as dolphins and bats. Once the bottom arrivals vanish, the ICI becomes irregular, although occasional bouts of rapidly-decreasing ICI appear. These click bouts, followed by silence, are suggestive of hunting behavior. This behavioral dichotomy has also been observed in Mediterranean sperm whales (Zimmer *et al*. unpub.; Teloni *et al*. 2000). The use of sperm whale clicks for bottom ranging has been proposed by Goold and Jones (1995), and these data, along with other recent measurements (Zimmer *et al*. unpub.; Jaquet *et al*. 2001) (see also N. Jaquet and M. Johnson, and P. Miller, this volume), provide quantitative support for this hypothesis.

The frequency spectra of sperm whale clicks* have been well documented in previous literature (e.g., (Goold and Jones 1995; Watkins 1980)). Three frequency maxima are generally visible: 1 kHz, 2 kHz, and a diffuse region near 10 kHz. The first two regions seem representative of female sperm whale clicks, but the last region has not been previously discussed in the literature (Goold and Jones 1995). In the data discussed here, the 2 and 10 kHz regions were observed to shift toward higher frequencies during the first 10 min of a dive, with a 25% shift for the 2 kHz region and a nearly 50% shift for the 10 kHz region. An examination of the spectra at later times shows no further shifts in the frequency maxima.

A straightforward explanation for the observed frequency shifts during a dive is that an air-filled resonator inside the animal experiences increased radiation impedance, and possibly compression, from the increasing water pressure. The fundamental resonance frequency for a spherical air cavity is provided by the following expression (Love 1978; Andreeva 1964; Minnaert 1933; Fletcher 1992):

$$f_{resonance} = \frac{1}{2\pi a}\sqrt{\frac{3\gamma P_{water} + X}{\rho_{water}}} \qquad (1)$$

Here, a is the cavity radius, g is the ratio of specific heats for an ideal gas, P_{water} is the external water pressure, and r_{water} is the water density. The quantity X depends on the characteristics of material surrounding the cavity. If the material is water, Equation (1) represents a freely-oscillating bubble, and $X=0$. If the material is an infinite elastic solid, $X=4\mu$, where μ is the real part of the shear modulus(Andreeva 1964). A widely-accepted model of a fish swimbladder (Love 1978) assumes that the air cavity is surrounded by a thin membrane capable of sustaining surface tension, embedded in a viscous fluid. The derivation yields a result of $X=2s(\gamma-1)/a$, where s is the surface tension of the tissue at the air/shell interface.

The 10 kHz click spectra from the three dives have been arranged in Figure 2F.11 as a function of dive depth, averaged in 5 meter layers.

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*Each spectrum was computed by conducting a 2048 point FFT on 512 points(10.67 ms) of data that included a sperm whale click, where the data were windowed with a Hanning window and zero-padded on both ends. To minimize noise contamination, each data segment was selected to start 10-50 points before the direct arrival began, which enabled the entire signal to fit within the 512 point window. This procedure typically required manual selection of the start times. The duration of a direct arrival was generally less than 12 ms, so a 512-point window was sufficient to sample the entire signal and not include any of the surface reflection arrival. Click spectra were averaged over two second intervals.

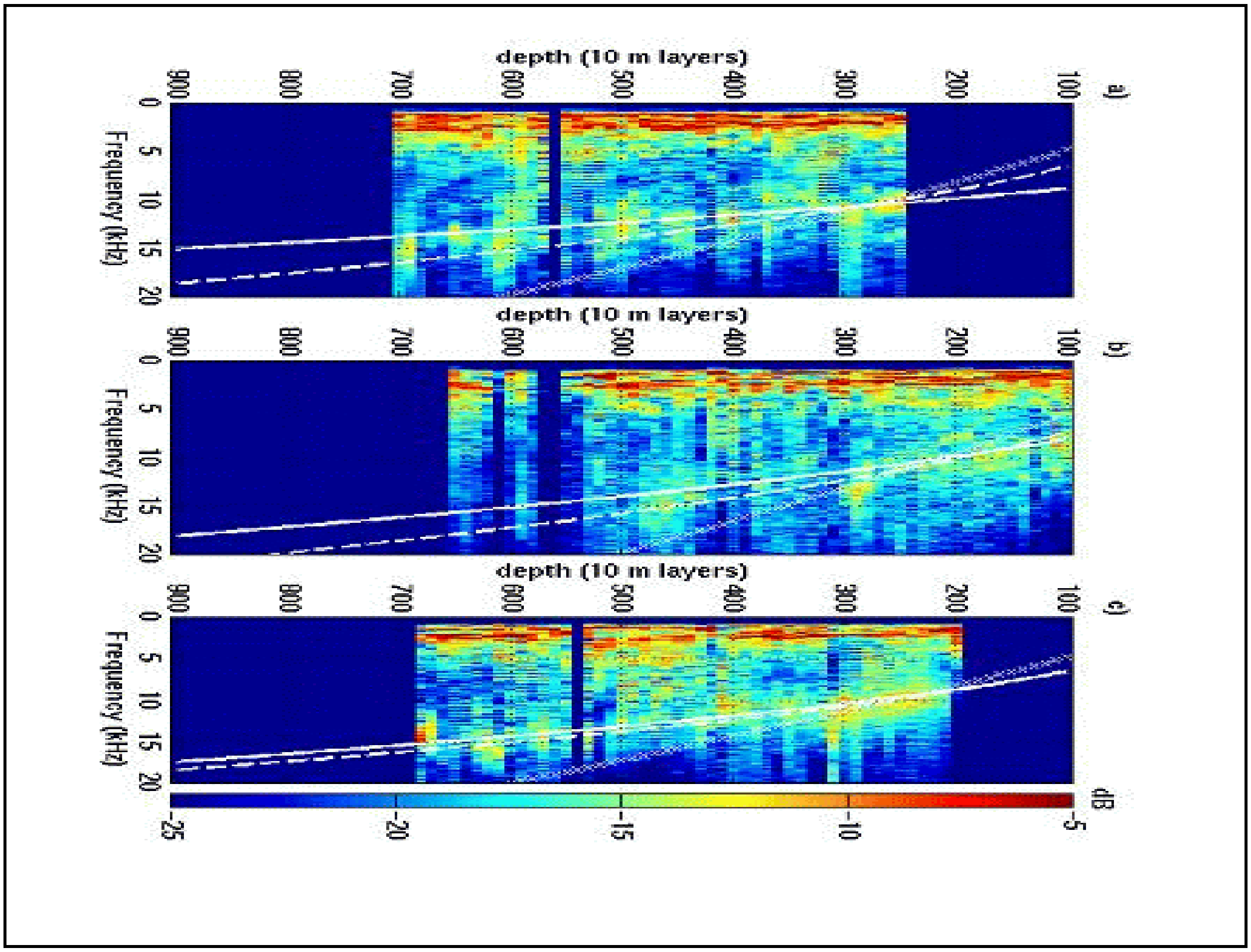

Figure 2F.11. Comparison of click spectra vs. animal depth for (a) first whale, (b) second whale, and (c) third whale, for the 10 kHz band. Spectra have been depth-averaged over 10 m intervals. Dashed lines represent predictions of the simple incompressible bubble model described in Equation (1), solid lines display the predictions of the fitted elastic and viscous swim bladder models, and the 'x' symbols represent predictions of the compressible resonator model.

Predictions from the air-filled resonator models overlie the images. All curves were fit by selecting a point at 250 m depth, the shallowest depth for which data were available for all three animals. An additional data point at 650 m depth was selected to fix the additional free parameter of the elastic and viscous models, which yield identical curves. Because the external pressure increases roughly 1 atm for every 11 m increase in depth, Equation (1) predicts that the resonant frequency of a fixed size bubble would increase roughly with the square root of depth, as represented by the dashed lines. In addition, if the cavity is assumed to be compressible, the bubble model predicts a nearly linear relationship between resonant frequency and pressure. Figure 2F.11 indicates that a resonator of fixed dimensions fits the data best. Thus, if the observed frequency shifts are indeed due to a simple depth-dependent resonance, the resonating cavity would need to be connected to another, compressible cavity, to allow the resonator dimensions to remain fixed.

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MODELING AND MEASURING THE ACOUSTIC ENVIRONMENT OF THE GULF OF MEXICO[*]

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The Littoral Acoustic Demonstration Center (LADC), a joint undertaking of scientists from the University of New Orleans, the University of Southern Mississippi, and the Naval Research Laboratory-Stennis Space Center (NRL-Stennis), received funding from the Office of Naval Research (ONR) in June 2001 to perform acoustic measurements and modeling in the northern Gulf of Mexico (GOM), with special attention initially to marine mammal and oil industry-related sources and the ambient noise baseline. Ultimately one goal is the development of a littoral mobile acoustic test range (MATR) based on a small number of sensors. Scientists from the Navy Meteorology and Oceanography Command and the Naval Oceanographic Office (NAVOCEANO) are providing technical guidance.

Four research areas have been identified for LADC: (1) Ambient Noise, (2) Marine Mammals, (3) Acoustic Tomography, and (4) Autonomous Underwater Vehicle (AUV) Synthetic Aperture Sonar. The first three are discussed briefly in this paper.

The ambient noise portion consists of (1) measuring and characterizing the ambient noise baseline within the northeastern GOM, (2) measuring and modeling noise propagation upslope and the effects of fronts and eddies on propagation, (3) measuring and modeling the transmission loss as a function of frequency up to 5000 Hz, and (4) determining optimum placements for a small number of single

[*]Research supported by ONR, Program Officer Melbourne Briscoe.

acoustic sensors and sparse oceanographic measurements, when used with computer modeling, for characterization of a littoral environment to produce a MATR.

For marine mammals the goals are to (1) investigate detection, classification, identification, and tracking using bottom-moored single hydrophones, (2) coordinate with scientists making surface visual observations, surface acoustic measurements, and on-whale acoustic tag measurements concurrent with LADC bottom measurements, and (3) evaluate, and modify if necessary, automatic detection and characterization computer codes when applied to marine mammal signals received on bottom mounted hydrophones.

In connection with acoustic tomography in the GOM, the following are being or will be done: (1) feasibility modeling and measurements for acoustic tomography of subsurface water properties in the northeastern GOM, (2) a pilot experiment for a single slice through the Desoto Canyon to establish proof of concept, (3) characterization of eddy loops moving into the Desoto Canyon, and (4) coupling acoustic tomographic measurements and models to satellite altimetry and infrared observations to provide an integrated image of deep water properties not measured by satellites alone.

During the summer of 2001, Minerals Management Service and National Marine Fisheries Service, with other government scientists and those from several academic institutions, conducted a major marine mammal set of experiments (SWAMP) to study sperm whales in the northeastern GOM from 16 July through 21 August. Even though LADC funding (not affiliated with SWAMP) was not received until June 2001, LADC scientists realized that it might be possible to have the three bottom-moored hydrophones funded by the ONR grant ready in time to make ambient noise measurements while the SWAMP exercise was being conducted. This was an excellent opportunity to have marine mammal “groundtruth” while the bottom-moored hydrophones were recording, since SWAMP included surface visual observations, surface towed array acoustic measurements, digital acoustic and motion-sensing recording tags mounted on whales, and even a whale tag sending locations to satellites.

One problem faced by the group was that the hydrophone packages to be used, Environmental Acoustic Recoding System (EARS) buoys, from NAVOCEANO, were designed to measure up to 1,000 Hz, and for recording a significant portion of the lower frequency part of sperm whale vocalizations, measurements to about 5,500 Hz were needed. Much to their credit, NAVOCEANO scientists and engineers were able to modify the EARS design and build three buoys for purchase by LADC in time for deployment concurrent with the start of the SWAMP exercise. Measurements for both commenced 17 July 2001. At the time of deployment, the batteries for the redesigned EARS had only been tested for 30 days, but in fact they lasted for the full duration of SWAMP. The buoys each recorded 72 gigabytes (Gb) of acoustic data for a total of 216 Gb of data. The hydrophones were each moored 50m from the bottom and a cable, instrumented to make oceanographic measurements, extended upwards almost to the surface. See Figure 2F.12. The oceanographic measurements are needed for accurate propagation modeling. Arrangements are being made to exchange data or results with SWAMP participants.

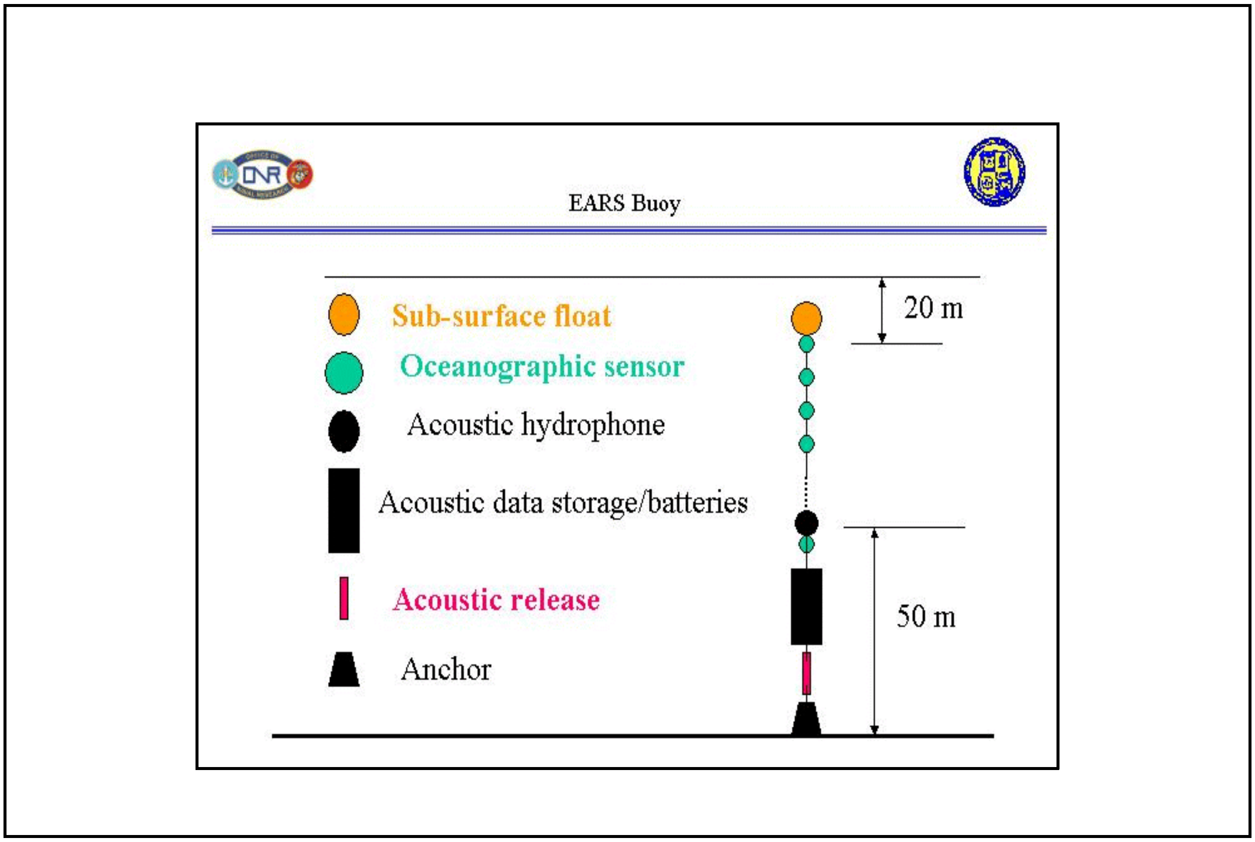

Figure 2F.12. Bottom-moored instrumented cable deployment. Acoustic portion is EARS buoy.

The issue of buoy placement was resolved by considering the location of frequent sperm whale sightings and the LADC objective of measuring noise propagation up the continental slope. Figure 2F.12 shows the location of oil platforms (black dots) and whale sightings (blue and gray whale symbols). The largest cluster of sightings is along the 1,000m depth isobath at about 28º 15' N latitude and 88º 50' W longitude. There the isobath is roughly southwest to northeast. A 43 km downslope line was chosen to instrument which started at the 200 m contour and which extended beyond the 1,000m contour in the middle of the whale sightings. An 80km cross track line was chosen for oceanographic study centered at the terminus of the downslope track and in the southwest to northeast direction. See Figure 2F.13.

To decide how far to instrument up the slope, propagation studies were made using archival sound speed profiles. Figures 2F.14 and 2F.15 show the upslope transmission loss for sources at 500m and 950m depths, respectively. Even though there was interest in propagation up to the 200m contour, the transmission loss was so great this far up the slope that a decision was made to instrument only up to the 600m contour. Therefore the EARS buoys with the oceanographic sensor string were moored in 600m, 800m, and 1000m water depths along the downslope track. The total separation was 25km. The buoy placement is shown in Figure 2F.16.

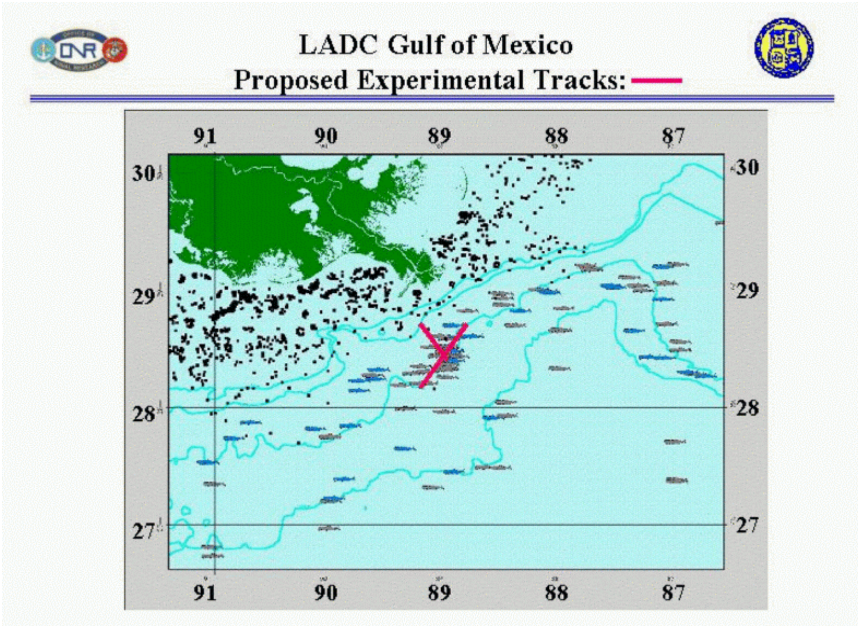

Figure 2F.13. Ship track locations for oceanographic sensing in red. Oil platforms are black dots and whale sightings are blue and gray whale symbols. Louisiana coast is green at upper left.

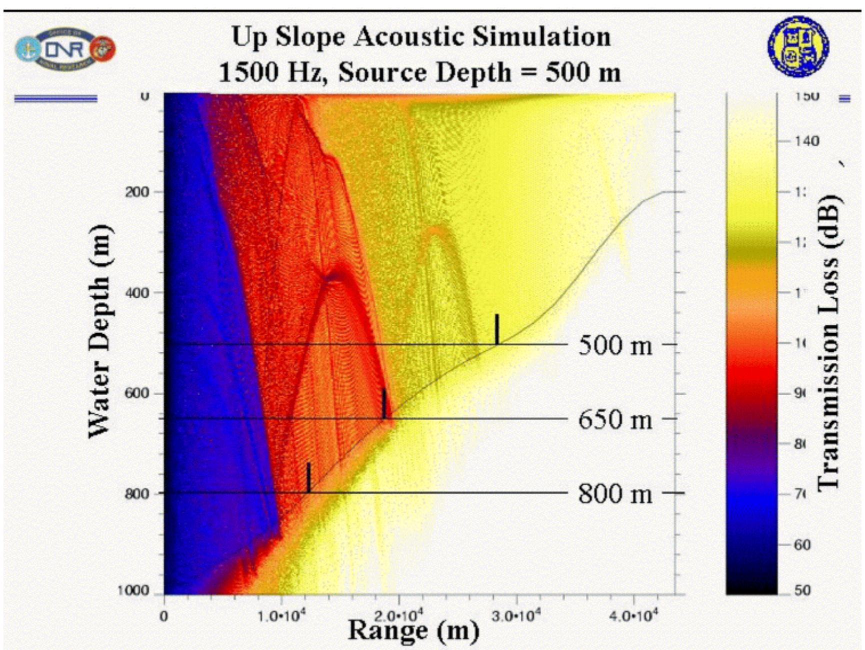

Figure 2F.14. Upslope transmission loss for source depth of 500 m. Bathymetry is for downslope track in Figure 2F.13.

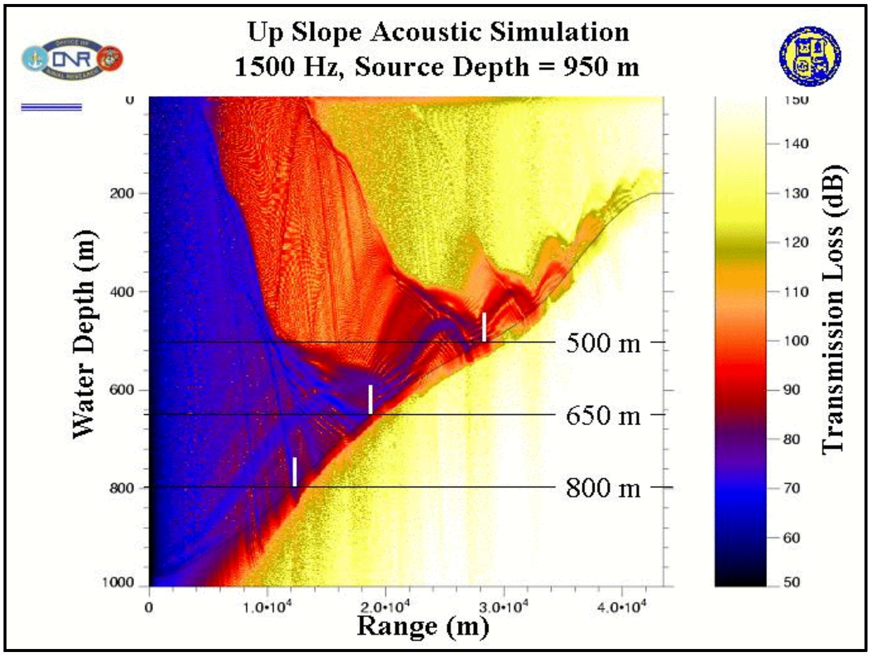

Figure 2F.15. Upslope transmission loss for source depth of 950 m. Bathymetry as in Figure 2F.14.

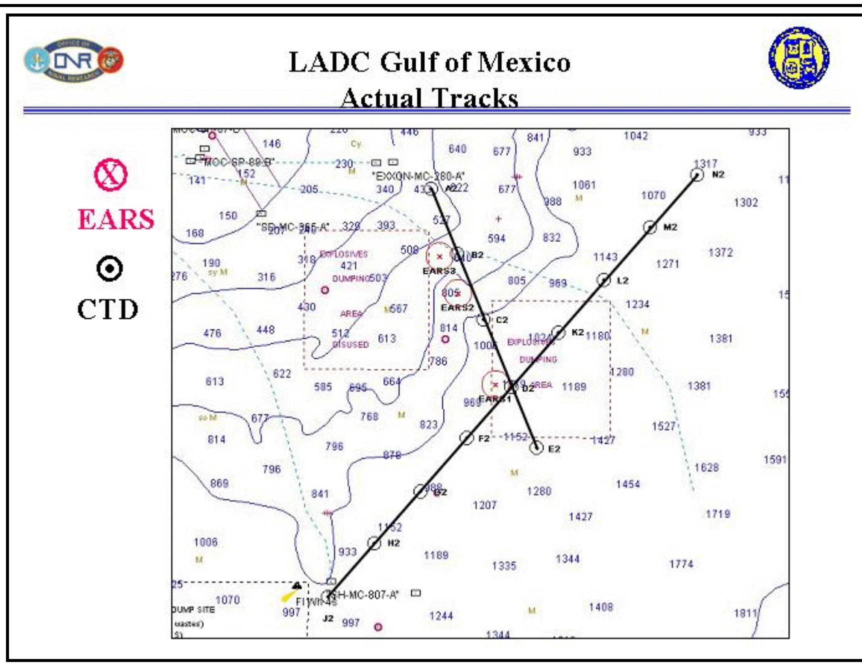

Figure 2F.16. Ship tracks for oceanographic surveys in black, mooring placement at magenta circles, and CTD casts at black circles.

In addition to the oceanographic measurements made continuously at each mooring, CTD and XBT measurements were made along the downslope and cross-slope tracks during the deployment cruise (Leg 1, 16 to 19 July), on a mid-experiment cruise (Leg 2, 7 to 10 Aug), and on the retrieval cruise (Leg 3, 29Aug to 1Sept). The survey tracks and the locations of the CTD casts are given in Figure 2F.16. During and just after Leg 1, the NAVOEANO ship USNS BRUCE HEEZEN was in the area making oceanographic measurements. Also on the mid-experiment cruise, a chirp sonar survey was conducted to determine bottom properties. The chirp sonar survey tracks are shown in Figure 2F.17. Because one of the EARS buoys could not be retrieved on the third cruise, a fourth cruise was conducted (Leg 4, 2 to 3 November) for its recovery. These oceanographic and bottom measurements, together with those made at the moorings, increase significantly the quality of the acoustic propagation modeling which can be done.

In between Leg 1 and Leg 2, a strong tropical storm, Barry, passed over the area. The sound speed profiles (water depth versus sound speed) at the CTD sites along the downslope track are shown in Figure 2F.18 for Leg 1. The profiles differ at each site. After the mixing caused by the passage of Barry, the downslope profiles from Leg 2, shown in Figure 2F.19, are all similar. Figure 2F.20 shows the sound speed profiles at site A (the shallowest CTD site on the downslope track) for Legs 1, 2, and 3. The Leg 1 profile has distinctive breaks due to layering. These are smoothed out by the passage of Barry, as shown in the Leg 2 profile. By the time of Leg 3, the profile shows that the layering is being restored.

The chirp sonar survey produced high quality results for bottom property determination. See Figure 2F.21. The bathymetry and layered structure are already visible. The data are being inverted to give the sound speed profile and density in the bottom.

Figure 2F.22 shows a 349s sample of the recorded acoustic data from one of the EARS buoys, in the upper left plot of relative voltage versus time. The relative Fourier power spectrum of the segment versus frequency is shown in the upper right part of the figure. The lower portion of the figure shows the sonogram for these data. Frequency is on the vertical axis and time is on the horizontal. Each vertical slice is the Fourier spectrum calculated by a short-time Fourier transform centered on the time given on the horizontal axis. The power level along the vertical slice is given by the color. Acoustic data analysis is now underway. Ambient noise in general and marine mammal vocalizations in particular will be analyzed. Ambient noise characterization will emphasize statistical analysis. Propagation studies will be done using whatever source information is available for comparison to the EARS measurements. Source classification, identification, and tracking are all of interest, as mentioned previously.

LADC is having built a mid-frequency acoustic source system capable of output levels up to 178 to 200 dB over a frequency range from 800 Hz to 5000 Hz. LADC will rebuild or have newly built a system that will operate from 40 Hz to 600 Hz. These will make possible controlled source propagation measurements and the acoustic tomography pilot study planned for summer 2002.

LADC is also having built a 16-channel autonomous receiving array with variable array length capability to 1,000m. This will allow water-column spanning measurements to verify predictions

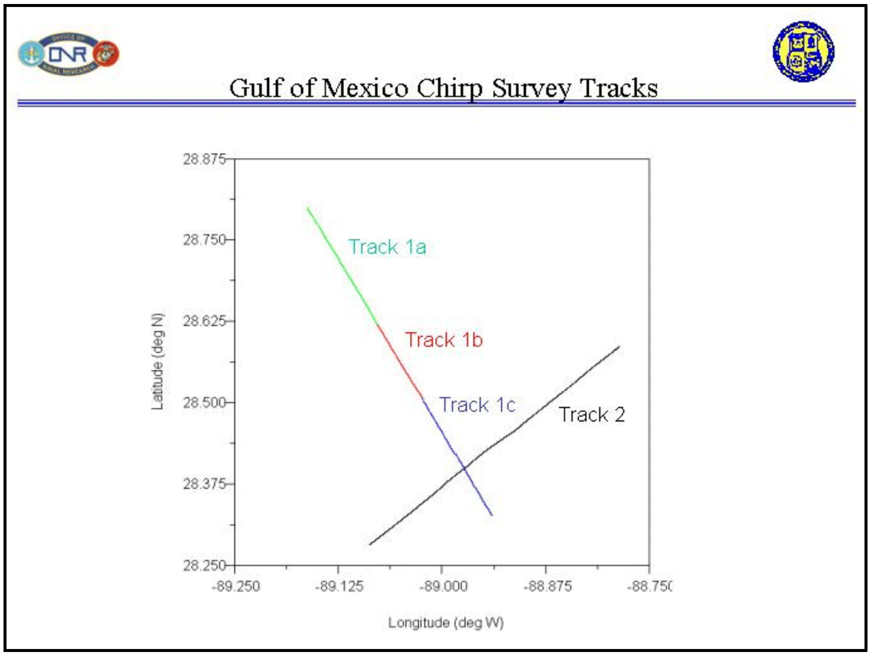

Figure 2F.17. Chirp sonar survey tracks.

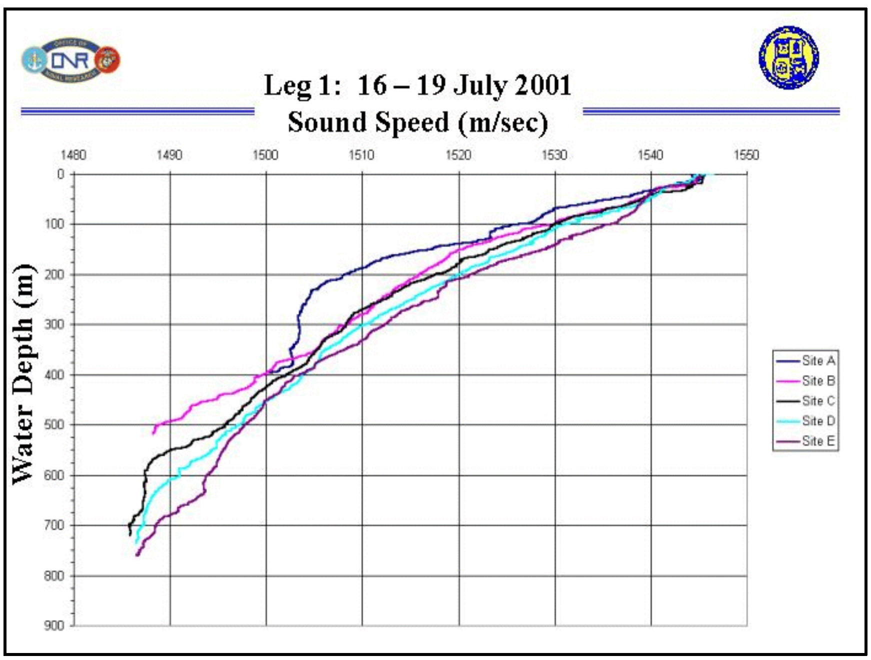

Figure 2F.18. Sound speed profiles at the CTD sites along the downslope track for Leg 1 cruise, before tropical storm Barry. A is shallowest and E is deepest.

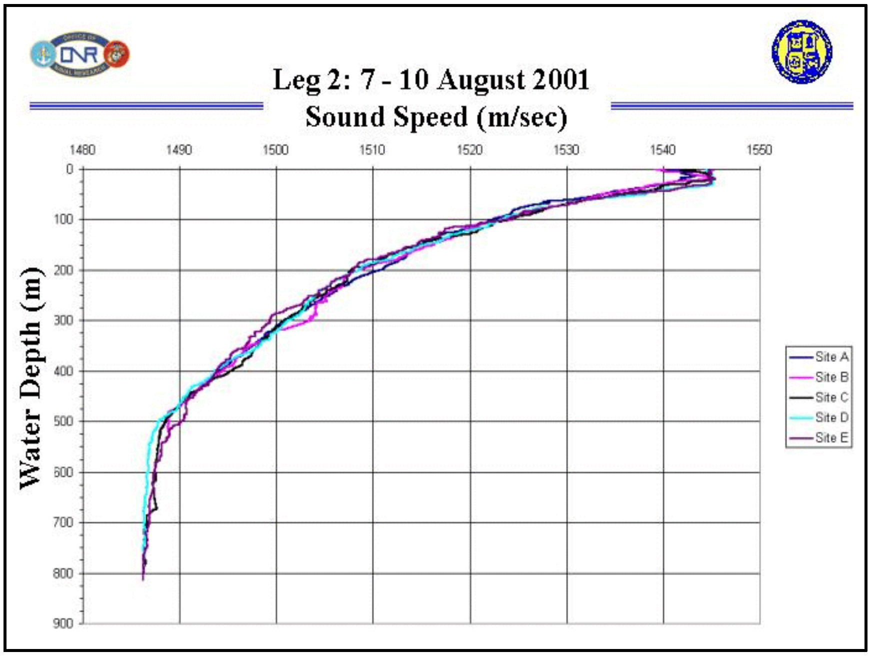

Figure 2F.19. Sound speed profiles at the CTD sites along the downslope track for Leg 2 cruise, after tropical storm Barry.

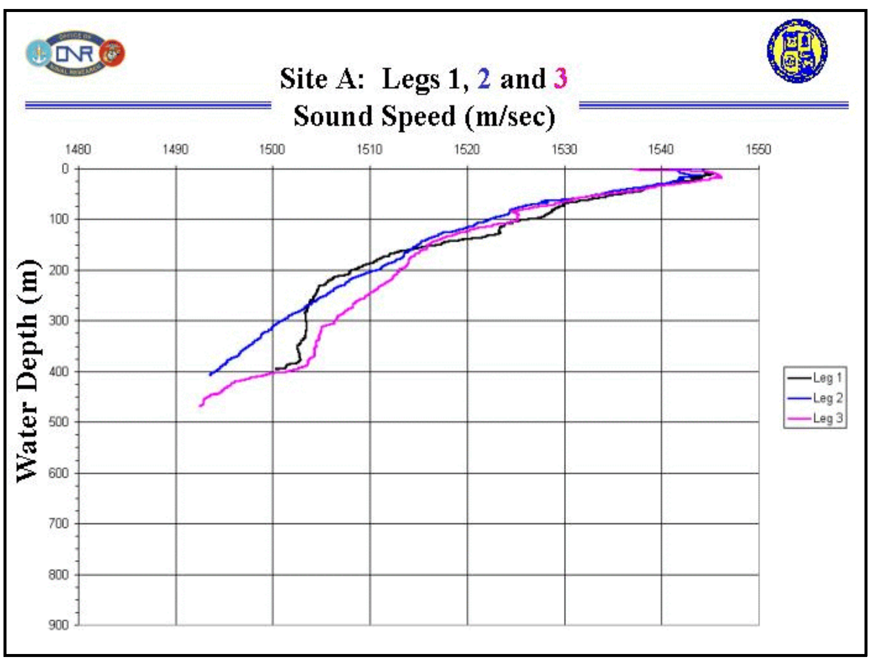

Figure 2F.20. Sound speed profiles at site A for Legs 1, 2, and 3. Leg 3 is from 29 August to 1 September.

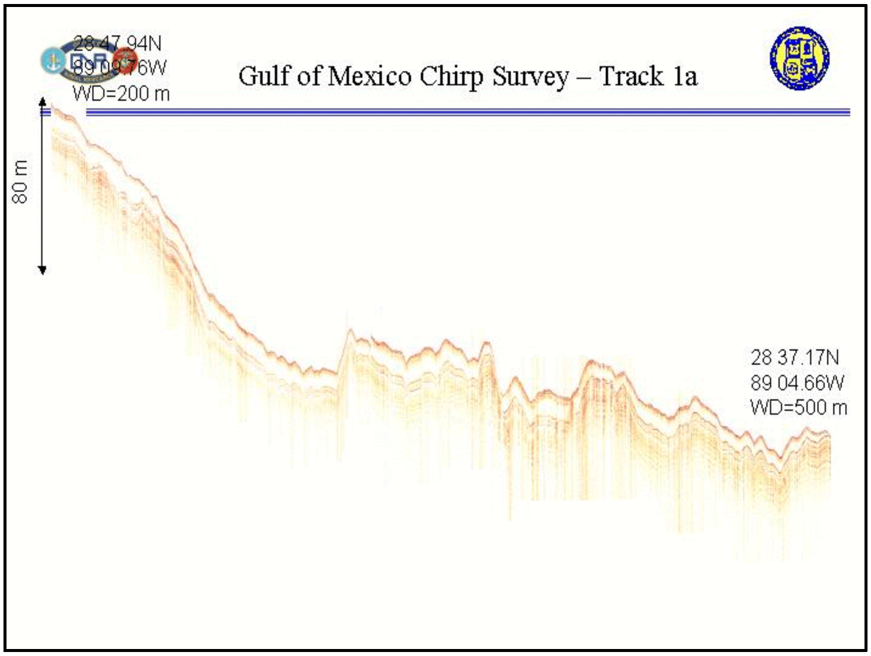

Figure 2F.21. Track 1a of chirp sonar survey, showing the bottom and subbottom layering.

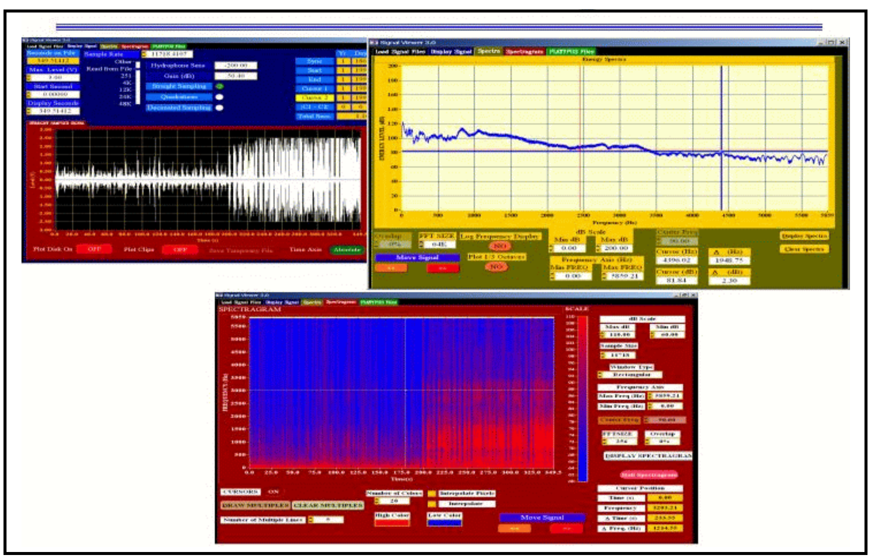

Figure 2F.22. Upper left: 349 seconds of the recorded acoustic data of relative voltage versus time from one of the EARS buoys. Upper right: relative Fourier power spectrum of the segment versus frequency. Bottom: sonogram for these data. Frequency is on the vertical axis and time is on the horizontal. Each vertical slice is the Fourier spectrum calculated by a short-time Fourier transform centered on the time given on the horizontal axis. The power level along the vertical slice is given by the color.

based on EARS buoy measurements and computer modeling. It can also be used for the tomography pilot study and for more detailed measurements of marine mammal vocalizations to compare to single hydrophone measurements.

LADC will collaborate in future marine mammal exercises in the GOM and, if possible, with SACLANTCEN marine mammal exercises in the Mediterranean.

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The authors wish to acknowledge with gratitude helpful discussions with Bruce Northridge and other scientists of the Naval Meteorology and Oceanography Command and Craig Peterson, Mike Wild, Martha Head, Bob Joyce, and other scientists of the Naval Oceanographic Office. They also greatly appreciate the assistance of the following, who served as scientific crew on some of the cruises or helped prepare the research vessel: Jim Showalter, Glenn Messer, Winston Anyanwu, Eddie Beasancon, Mark Snyder, Charles Thompson, Michael McCord, James Larue, and Harry Borden. Finally, they are deeply indebted to the scientists of NAVOCEANO who redesigned and built in such a short time the EARS buoys for the deployments described in this work.

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Ralph R. Goodman received bachelor degrees in mathematics (1950) and physics (1951), a masters degree in physics (1952), and a Ph.D. in theoretical physics (1958) from the University of Michigan. His specialties in physics are solid-state physics and underwater acoustics. He has served as a professor of physics at Colorado State University, associate director of the Naval Research Laboratory, director of the Naval Ocean Research and Development Activity, director of NATO's SACLANT Research Centre, director of NCPA, and a professor of Acoustics at Pennsylvania State University. He is currently a research professor at the University of Southern Mississippi. Dr. Goodman is a fellow of the Acoustical Society of America and past associate editor of the Journal of the Acoustical Society of America. He has numerous awards and publications.

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SESSION 1G

DEEPWATER PHYSICAL OCEANOGRAPHY

Chair: Dr. Alexis Lugo-Fernandez, Minerals Management Service
Co-Chair: Dr. Carole Current, Minerals Management Service

Date: January 10, 2002

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ENERGETIC MID-WATER COLUMN CURRENT EVENTS OF THE NORTHERN GULF OF MEXICO: OBSERVATIONS AND MODEL PERSPECTIVES

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INTRODUCTION

There are four major classes of energetic currents in the Gulf of Mexico (GOM) which are of primary concern to offshore petroleum operators. These are: 1) currents resulting from energetic, episodic atmospheric events, 2) currents associated with the Loop Current and related eddies, 3) vertically coherent currents below 1,000 m (e.g. those believed to be associated with topographic Rossby waves), and 4) high-speed sub-surface intensified currents.

High-speed subsurface intensified currents, also known as jets, typically have temporal durations on the order of a few hours to one day, have subsurface speed maxima that can exceed 4 knots (200 cm/s), have peak speeds that occur between 150-350 m below the surface, and have little or no surface expression of the subsurface energetics. Offshore operators design drilling and production systems to account for forces exerted by currents at all depths; therefore frequency, persistence, and speed characteristics of jets are important design criteria.

OBJECTIVES

Begun in 1999, the MMS-sponsored "Study of subsurface high-speed current jets in the deep water region of the Gulf of Mexico" seeks to address the last class of currents. The study objectives are to characterize the subsurface jets that occur in the GOM and to describe the physical mechanisms responsible for their generation.

There are several activities to achieve these goals. (1) Identify and acquire data sets believed to contain subsurface jets.(2) Characterize each identified jet and jet environment (through collection of ancillary data such as satellite, meteorological, and CTD data). (3) Examine relationships between jets' occurrence and potential forcing mechanisms. (4) Identify and analyze jets found in numerical model output. (5) Attempt to identify physical mechanisms responsible for jet generation. (6) Meet with MMS and industry representatives. (7) Synthesize results into reports. An additional activity, to prepare a climatology of jet events, has been dropped due to the paucity of robust events found in the data base.

DATA AND APPROACHES

The short temporal character and confined, relatively narrow vertical extent of jets provide a challenge to researchers attempting to investigate them. Because of the coarse vertical coverage of moorings instrumented with conventional single point current meters (usually hundreds of meters), practically all current meter data collected prior to 1990 are useless to investigate jets. The advent of acoustic Doppler current profilers (ADCP), gave investigators the opportunity to collect high spatial resolution vertical profiles (order several meters) of current velocity over vertical ranges of tens to hundreds of meters. However, a single ADCP looking vertically through the water column does not provide any indication of the horizontal scale and structure of these jets. This can only be accomplished with a closely-spaced (at most 5-10 km) array of vertically looking ADCPs. Unfortunately, there have been no deployments of multiple ADCPs in the GOM in the depth range of the water column where jets are likely to occur. Therefore, there is virtually no direct observational data with which to quantitatively investigate the horizontal scales of jets.

We have examined all available current meter records obtained from academic, government, and industry sources. Presently, the Texas A&M University GOM deep water current meter archive has over 8-million instrument-hours of quality-controlled current meter data.

FINDINGS

Studies of Observations

To date, we have identified a total of 10 candidate cases of subsurface jets in our data inventory. Table 1G.1 summarizes the locations, dates, and maximum speeds of the five jets contained in non-proprietary current meter records.

Table 1G.1. Summary of subsurface jets.

No.	Lease Block	Date	LON °W	LAT °N	J-Dep m	Speed cm/s	T-Dep m
1.	GC200	30 APR 1994	90.749	27.767	210	60	600
2.	VK956	10 FEB 1997	88.094	29.045	275	105	1200
3.	MC628	10 APR 1997	89.366	28.332	325	80	760
4.	DC977	28 SEP 1998	87.494	28.003	Unk	25	1300
5.	EW913	16 AUG 1999	90.399	28.066	160	210	500

J-Dep = depth of jet core
Speed = maximum speed during jet
T-Dep = total water depth

The locations of the jets summarized in Table 1 are shown in Figure 1G.1 and indicated by filled stars. As seen, these jets are confined basically to the slope region of the north-central GOM. This is expected due to the high density of observations associated with offshore operations in that region. Locations of proprietary data containing jets are roughly within the same region.

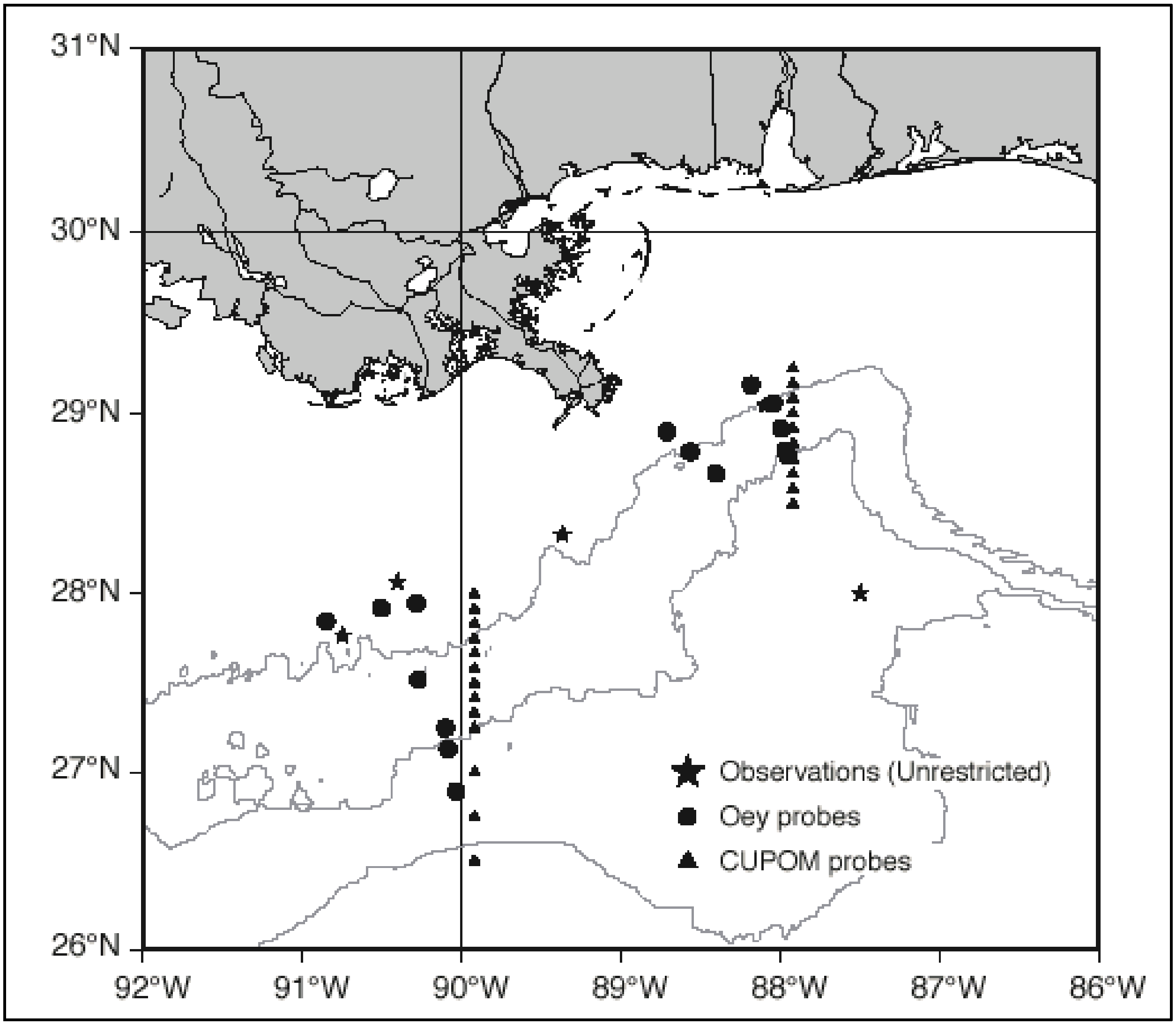

Figure 1G.1. Map of north-central GOM showing locations of candidate jets from public data (stars) and virtual mooring locations of CUPOM model (triangles) and PROFS model (circles). Bathymetric lines shown are for 1,000, 2,000, and 3,000 m isobaths.

Figure 1G.2 shows speed contours during a representative subsurface jet event which occurred in lease block GC200 (data courtesy Marathon Oil Company). The ADCP data during this deployment were taken at five-minute intervals and binned into eight-meter bins. This particular jet is seen to be propagating upward in time with peak speeds greater than 50 cm/s at about 210 m depth, although most candidate jets in our inventory do not seem to have vertically propagating characteristics. The

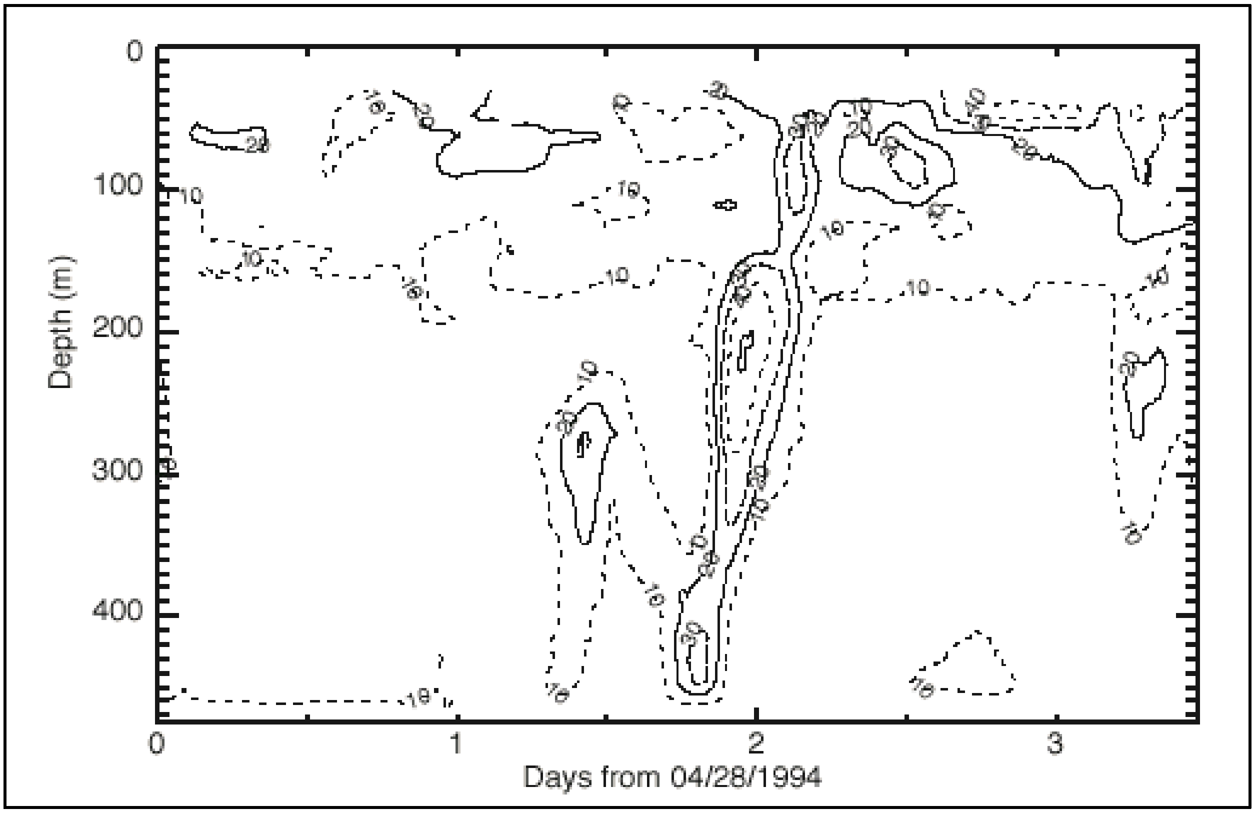

Figure 1G.2. Speed contours (cm/s) versus depth and time for a representative subsurface jet found in lease block GC200 during April 1994. This jet appears to be propagating upward. Measurements made with a 75-kHz suspended ADCP configured for 8-m bins and 4-min sampling. Data have been temporally smoothed with a 25-point boxcar filter. Contour intervals and styles are: 10 (dot), 20 (solid), 30 (dashed), 40 (dot), 50 (solid). (Data courtesy Marathon Oil Company)

jet lasts on the order of 8 hours. The raw speeds have been smoothed with a 25-point boxcar filter to stabilize the contouring.

Four of the five jets summarized in Table 1G.1 (numbers 1, 2, 3, and 5) show the development of a subsurface speed maximum over time ranges from 6 to 24 hours. The jet found at lease block DC977 (number 4) consists of an inertial wave packet caused by Hurricane Georges which propagated downward to at least 500 m depth. The depth of the speed maximum is unknown because the water column was not instrumented between 100 and 500 m. The inertial oscillations at 500 m occurred without any surface expression and several days after the hurricane's passage.

STUDIES OF MODEL OUTPUT

We have obtained the model outputs of two versions of the Princeton Ocean Model for the Gulf of Mexico: the Princeton Regional Ocean Forecasting System (PROFS) model (data courtesy L. Oey, Princeton University) and the University of Colorado Princeton Ocean Model (CUPOM) (data courtesy L. Kantha, University of Colorado) (Kantha *et al.* 1999). We have designed virtual current meter arrays to investigate the time and space scales and frequency of occurrence of subsurface jets from models. The purpose of a virtual current array is to simulate the deployment of a current meter array into the model domain.

Figure 1G.1 shows the locations of the virtual moorings from each model. The PROFS virtual array locations were chosen to be in the vicinity of the jet candidates summarized in Table 1. The PROFS arrays, which are depicted as filled circles in Figure 1G.1, were in two general locations: one centered at 88°W and the other just west of 90°W. The locations were chosen to investigate across- and along-slope variability during jet occurrences. Both the CUPOM and PROFS models can assimilate satellite altimeter data. We have obtained PROFS model output with and without this assimilation. We will investigate the available three years of both assimilated and non-assimilated runs. Hourly CUPOM output with assimilation are available at longitude lines near 90°W and 88°W with full vertical resolution (23 sigma-levels) and are depicted as triangles in Figure 1G.1. A non-assimilated run of the CUPOM outputs is not available.

An example of the cross-slope variability of a jet found in the CUPOM model is shown in the sequence of plots of Figure 1G.3. The panels of Figure 1G.3 show speed contours versus depth and time (hours from 0000 1 January 1993). The center panel is from the location 90°W, 27.5°N; the jet core is centered at 150 m and hour 5,500. Note that north of this location the speed maxima diminishes and then disappears in the top panel. South of the central panel the speed maxima again diminishes before being lost in the northern edge of a large anticyclone (bottom panel). The panels of Figure 1G.3 are arranged with north at the top of the page and south at the bottom. The transverse (cross-jet) scale of this jet event is approximately 46 km.

MECHANISMS

We continue to pursue the theoretical investigation of candidate mechanisms of the jets found in observations and in the CUPOM and PROFS outputs. These mechanisms include internal solitons such as those observed in the Andaman Sea (Osborne and Burch 1980); the combined effects of transient surface winds and deep flow over an undulating sea bed (Rhines 1977); reversed geostrophic flow (Onken 1990); and the interaction of an anticyclone with the continental slope or other eddies.

CONCLUSIONS

Only ten candidate cases of subsurface jets are present in the observational record. The number of available data sets capable of resolving the vertical structure of a subsurface jet are also few. In the coming year we will focus on hypothesis testing of causal mechanisms using the available model products and provide field sampling criteria based on each causal mechanism. It is recommended that offshore drilling and production platforms be instrumented with ADCPs to improve the chances of capturing a jet event.

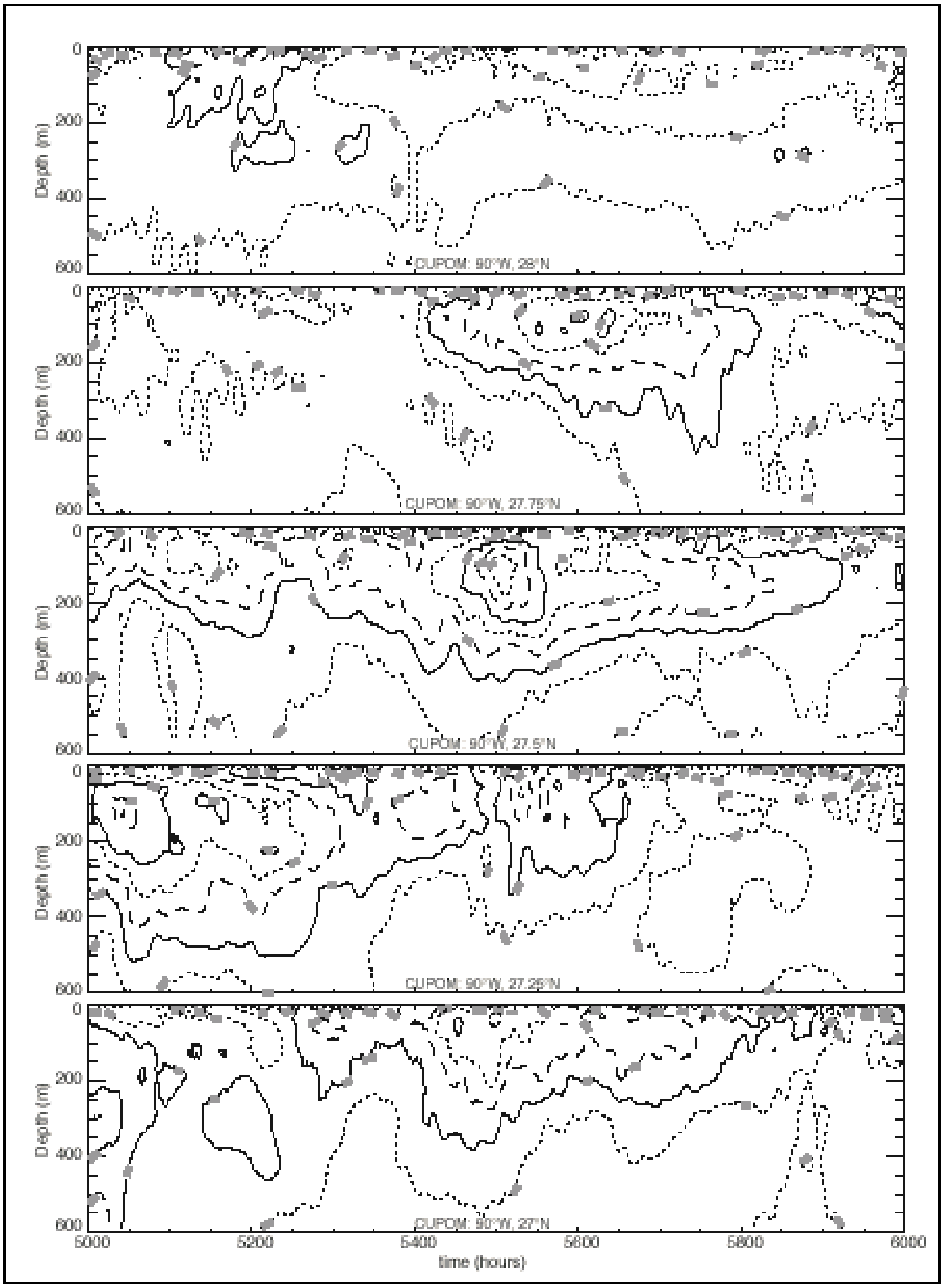

Figure 1G.3. Contours of current speed versus depth and time during a sub-surface event seen in the CUPOM output at five locations along 90˚W. Panels are arranged with northern-most location at top of page, southern-most at bottom. See Figure 1G.1 for geographical locations of CUPOM output. Contour interval and styles are: 10 (dot), 20 (solid), 30 (dash), 40 (dot), and 50 (solid).

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DEEP CIRCULATION IN THE GULF OF MEXICO: COMPARING MODELS AND OBSERVATIONS

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ABSTRACT

A new set of mooring data in Yucatan Passage has been obtained by a joint effort between the oil industry, the Naval Oceanographic Office, and a group of oceanographers at CICESE, Ensenada, Mexico. Preliminary results of this work are beginning to confirm results obtained with high-resolution numerical models. Among these are the evidence of strong deep return flow to the south when the Loop Current front is advancing, the unexpected shape of the velocity contours, and the surprisingly large variability in total transport through Yucatan and the Florida Straits. An essential restriction is that the models employ forcing from winds over the full open Atlantic Ocean. In some features the models are in good agreement. One major disagreement is in the mean deep flow in the interior of the Gulf – whether it is cyclonic or anti-cyclonic—at depths of ~ 1,500 to 2,000m. Present observations are not adequate to resolve the disagreement.

INTRODUCTION

This work is collaboration among E. Chassignet, University of Miami, T. Ezer, Princeton, and me. In addition, Dr. S. Welsh, L.S.U., has provided results of her work with the MOM version of the Bryan-Cox model for additional comparisons. Quite recently the results of the mooring program by the Ensenada group have begun to appear, and A. Badan has been most helpful in providing us with pre-publication results from several manuscripts.

RESULTS

Figure 1G.4 is from the work of Bunge *et al.* (2002). They measured flow in Yucatan channel with an array of moored current meters. This picture shows data from the first nine-month setting. The fine line shows the total transport in the lower layer (below the 5.75 isotherm, at about 800m); the heavy line is the time rate of change of the area enclosed by the Loop Current frontal boundary (from satellite IR). Note that the flow back to the south initially is greater than 5 Sv. The plot begins shortly after a ring separation that occurred in October.

The important feature here is the remarkably high coherence between the two curves. This coherence had been postulated much earlier (by Maul and others) but this confirmation is new. The phase delay of about one week is not yet explained. The numerical models had shown this deep southerly flow, but we did not know whether to believe it. We now know that the flow to the south is real.

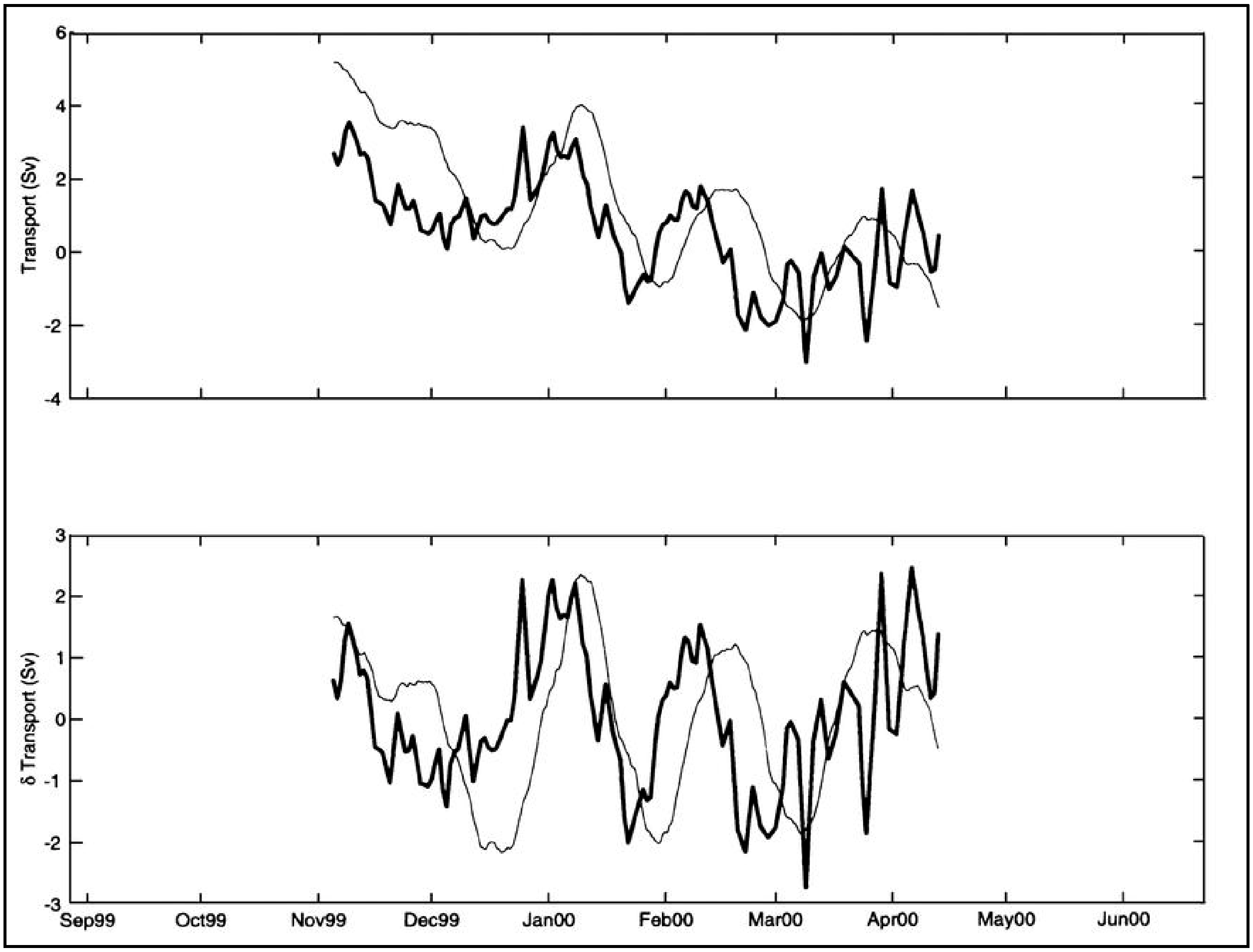

Figure 1G.4. Deep volume transport to the south in Yucatan Channel (fine line) and time rate of change of Loop Current area from Bunge *et al.* (2002). Note that southerly flow is positive. Tick marks on x axis are monthly, beginning in September 1999 through June 2000.

The models agree with the observations that the flow to the south takes place on both the eastern and western sides of the channel, but they disagree over the relative amounts. The Ensenada group also has made several hydrographic sections across Yucatan over the past few years, with an acoustic Doppler current meter attached to the CTD wire. Figure 1G.5 is copied from a paper in press by Ochoa *et al.* (2002) and shows the velocity observations from one section, repeated on the return leg. I have cross-hatched the areas of flow to the south.

The flow back toward the Caribbean is strongest in this section, with flows of up to 20 cm/sec on either side. Although the net flow is only 20-22 Sv, the observed transports to the north were 38 and 33, with flows back to the south of 15 and 13 Sv, a remarkable result. For comparison, Figure 1G.6 shows a snapshot of velocity in Yucatan from the Princeton model, chosen to maximize the agreement.

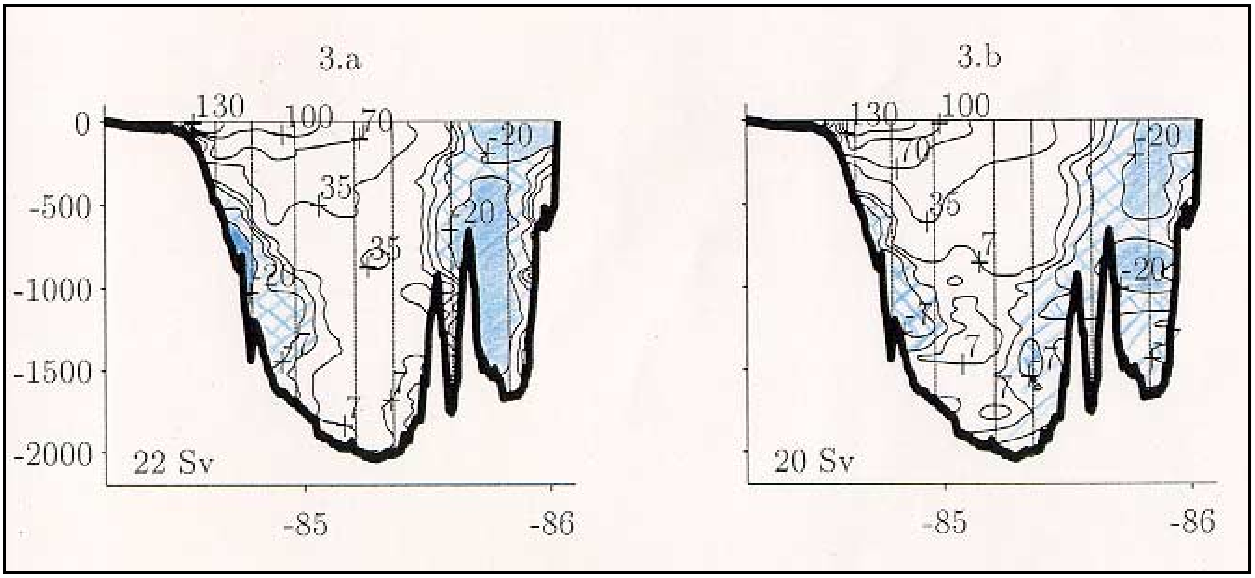

Figure 1G.5. Repeat cross sections of velocity (ADCP) 30 Jan – 2 Feb 1999 in Yucatan Channel (Ochoa *et al.* 2002). Transports shown in the lower left corner are the net flow. X axis is longitude.

The flow in Yucatan in the Princeton model favors a concentration of strong deep flow to the south on the Mexican side of the channel. By contrast, the MICOM favors stronger deep flow on the Cuban side.

One feature the new observations have confirmed is that the net transport through Yucatan fluctuates a great deal more than had previously been suspected. Figure 1G.7 is from the results of the MICOM and shows 1,800 days of results. There is remarkable variability, from ~17 to 34 Sv. The deep flow also fluctuates similarly.

One feature of the model output that is still puzzling is the disagreement in the mean deep flow. At depths below the main thermocline, the Princeton model shows a mean cyclonic circulation around the edges, which is consistent with deep topographic rectification. This flow is toward the east along the continental slope north of Mexico, to the west along the slope south of the U.S. The MICOM results, by contrast, show almost no mean flow along the slope north of Mexico. The mean flow along the slope south of the U.S. is to the east, with return flow confined to the northern half of the basin. Deep flow in the Bryan-Cox model of Dr. S. Welsh agrees with the Princeton Model. There is some evidence of deep mean flow from the 800-m RAFOS floats of a previous NOPP program. (Some results are given at a web site of the FSU analysis group, *www.ocean.fsu.edu/~natassa/GoMoms/main.html*) Their results have been corrected for a serious bias caused by wind-driven motions at the sea surface when the RAFOS floats pop up every week. Although these results are based on a small number of total days of observations, they tend to support, however weakly, the MICOM mean flows.

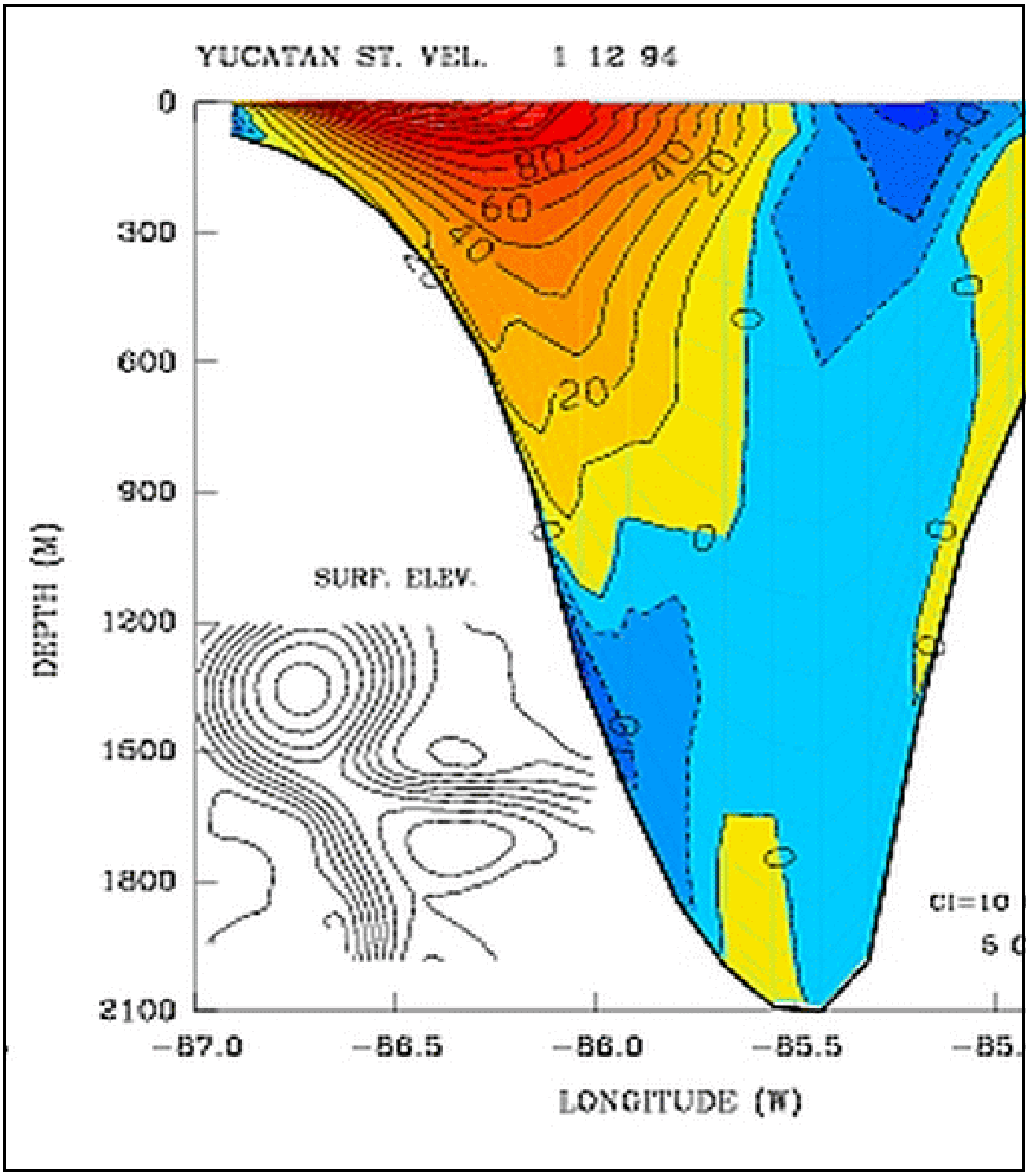

Figure 1G.6. Velocity snapshot in Yucatan from the Princeton Model. The configuration of the Loop Current is shown in lower right.

In Figures 1G.5 and 1G.6, the shape of the "zero contours" is startling, from the point of view of classical geostrophic method assumptions. A standard method would have been to assume zero velocity along a carefully selected density surface, which would be roughly horizontal. The zero velocity surfaces in Figures 1G.5 and 1G.6, by contrast, tend to be nearly vertical.

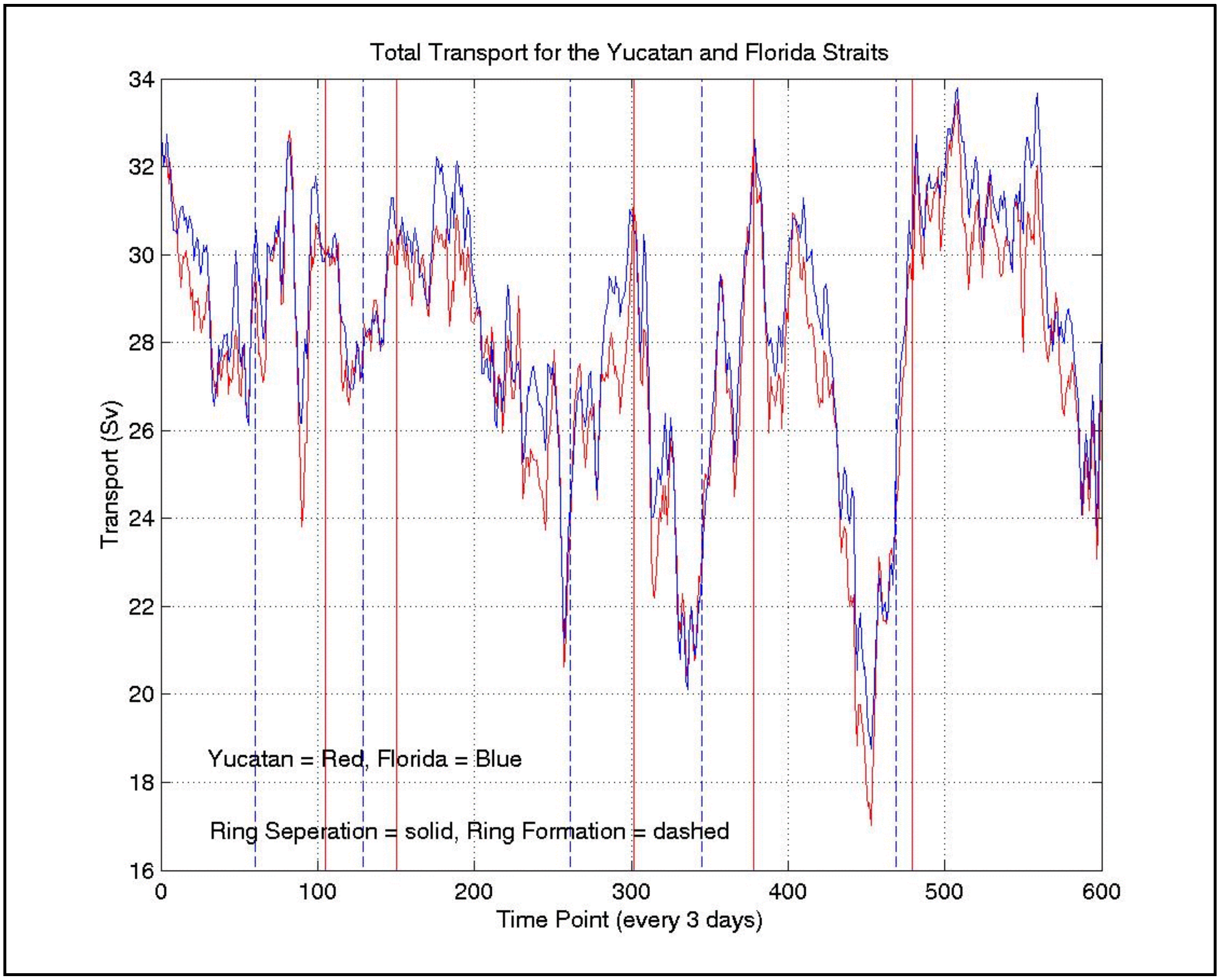

Figure 1G.7. MICOM model output; 1,800 days of total transport in Yucatan Straits and in the Key West-Havana section.

ACKNOWLEDGMENTS

In addition to the other PIs of the program, I am grateful to Professor Georges Weatherly, FSU, for information about the NOPP float results; and to Jane Jimeian, Christopher J. DeHaan, and Natassa Romanou for substantial help with the data and analysis.

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PRINCETON REGIONAL OCEAN FORECAST SYSTEM (PROFS): GULF OF MEXICO AND THE CARIBBEAN SEA: MEAN CIRCULATION, EDDY ENERGY, AND SMALL-SCALE EDDIES

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INTRODUCTION

We present here a model study of the Loop Current (LC), Loop Current Eddies (LCEs) and parasite eddies (PEs) in the Gulf of Mexico (GOM), and also of transports in the Caribbean Sea. Figure 1G.8 shows the domain of interest. A series of 'coarse-' (CGE: D=2~10km) and fine-grid (FGE: D=1~5km; embedded GOM and Cayman Sea region) experiments, with and without satellite data assimilations, with and without remote forcing, and with and without surface forcing (winds and heat fluxes) were conducted to examine the model's response, and also to provide information on model dynamics. Some comparisons of the results with observations have been completed. The results were also analyzed to show the existence, and to understand the behaviors of, topographic Rossby waves (TRWs) in the Gulf. All model experiments were conducted for at least eight years,

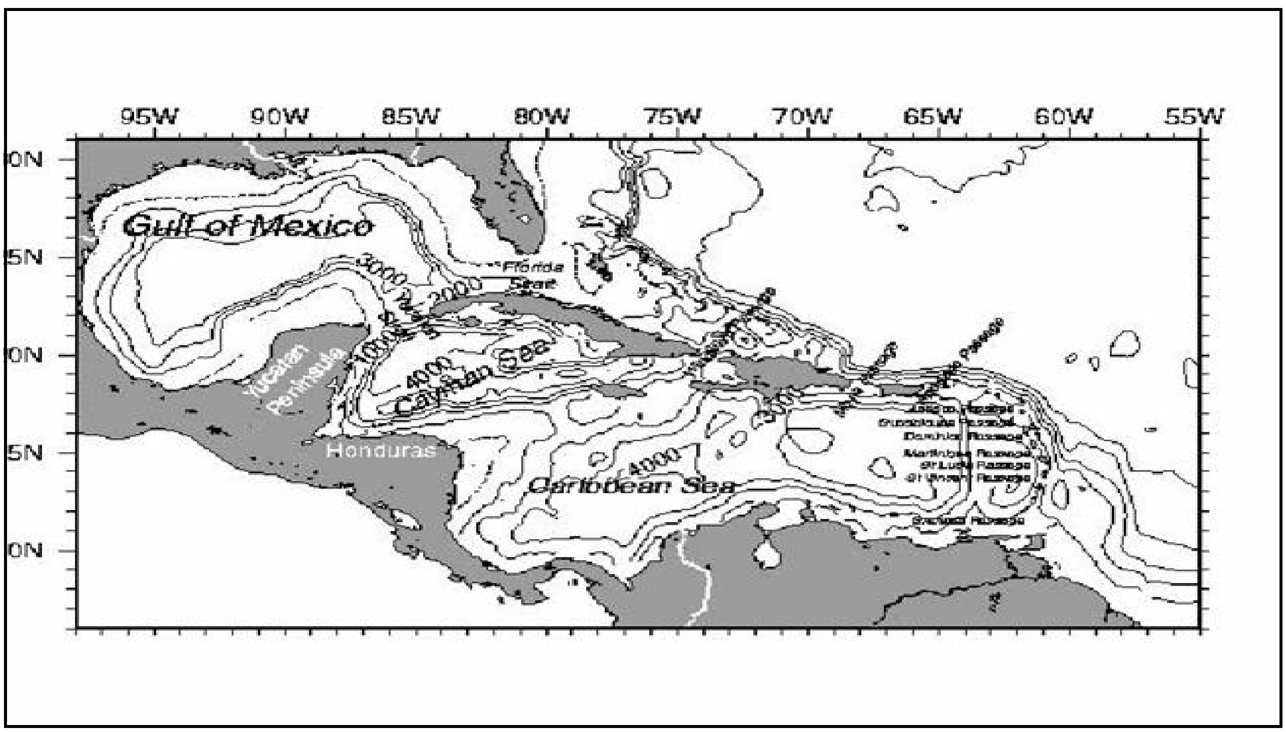

Figure 1G.8. Map of the modeled regions of the Gulf of Mexico and the Caribbean Sea. Isobaths are in meters.

spun up to quasi-equilibriums in ~ 2 years from initial conditions based on T/S climatology and the corresponding geostrophically-balanced velocities.

RESULTS

Of the model-generated total transport through the Yucatan Straits (»27Sv), approximately 23 Sv is accounted for by the large-scale (Svedrup's + thermohaline) forcing across the 55ºW in the Atlantic, while the remaining 4 Sv is locally forced (i.e. west of 55ºW in the Caribbean), primarily by wind and wind stress curl. Interestingly, satellite sea-surface height (SSH) assimilation contributes an additional 2Sv, perhaps through some kind of eddy-generated rectified currents (JEBAR).

In general, the model's SSH variance improves with improved forcing and, perhaps not surprisingly, the experiment with data-assimilation reproduces the satellite SSH variance.

The model-generated eddy variability constitutes the main source of SSH variance and eddy kinetic energy (EKE) in the Gulf, accounting for about 80% of the total variance. Local winds (i.e. within Gulf) adds about 7% and remote winds about 13%.

Modeled LCE-shedding is visually correlated with and in general preceded by deep outflow through the Yucatan Straits. This finding is consistent with Oey (1996), who used a coarser grid ((D=20km) and a regional Gulf and Cayman Sea-only domain. It suggests that the phenomenon is 'local' (but dependent on the free interaction between the Gulf and the Cayman Sea as pointed out in Oey 1996). The finding is also consistent with recent data from DEEPSTAR.

Data-assimilated modeled LC and LCEs in general mimic those deduced from satellite. Moreover, data assimilation tends also to generate small-scale eddies (~ 100-200km), which in general occur less frequently in experiments without assimilation (top two panels). It appears therefore that assimilation 'excites' motions at smaller scales. The small-scale features look superficially good, but we caution that little is known if these are dynamically consistent with the model, or are mere artifacts of assimilation (see below).

The fine-grid experiments (FGEs), with grid-sizes » 1-2km in the northern Gulf, »5km over the LC and »10km in the southwestern Gulf, are able to resolve small-scale eddies (bottom two panels). These eddies *are* dynamically consistent entities of the model, though we have yet to analyze their generation mechanism.

The FGEs illustrate the importance of parasite or satellite cyclones in eddy cascade process in which larger LCEs break down into smaller eddies. In fact, cyclones draw their energy from parent warm eddies, which are then sliced into smaller anticyclones.

Figures 1G.9 shows this nonlinear process starting with Figure 1G.9a when a LCE "W1" and one of its parasite cyclones "C1" enter the LATEX slope and rise. (The Eulerian trajectories are colored with (*the negative of*) relative vorticity divided by the local Coriolis parameter, such that green-orange with red arrow head is anticyclonic and blue-purple with white arrow head is cyclonic. The white solid vectors are daily-averaged windstresses at the selected locations). Further west against the Mexican slope, a warm eddy, "W2," is in the process of being sliced into "W2a" and "W2b." About one month later, in Figure 1G.9b, this slicing is complete, while "C1" has intensified. Another parasite cyclone "C2" now also appears. Figure 1G.9c shows the process 15 days later when "C1" slices into "W1" and Figure 1G.9d when the process is complete, and a sextet of three anticyclones and three cyclones can be seen. We should mention also that eddies are not only sliced, but they are also sometimes spliced—in an apparent inverse cascade process.

The baroclinic Rossby radius is » 20-30 km, so that with the coarsest grid size being a fraction of this, or about 5km over the LATEX slope and rise, we think that our results represent a well-resolved simulation (Oey 1998). Abundance of eddies with scales of 50-200km were found during LATEX C observations (Hamilton *et al.* 2000).

The above eddy-formation process is a natural dynamic by-product of the model. The challenge is then to formulate an assimilation scheme that retains as much as possible the model's dynamics, yet at the same time depicts the observed. We believe that one has a better chance of accomplishing this task with a model that resolves the observed features. With assimilation, one may obtain deceptively realistic small-scale features at coarser resolution (D>5km; Figure 1G.10), but the solution may be an artifact of non-physical sources and sinks produced by assimilation.

Small-scale eddies weaken mean shelfbreak currents—a result in better conformity with that observed along the shelfbreak. The general near-surface circulation is anticyclonic. This is consistent with a generally southward Svedrup transport in the Gulf's interior, and the 'shelfbreak' jet can be interpreted as a continuation of the western boundary current—the 'Fofonoff mode' (c.f. Oey 1996).

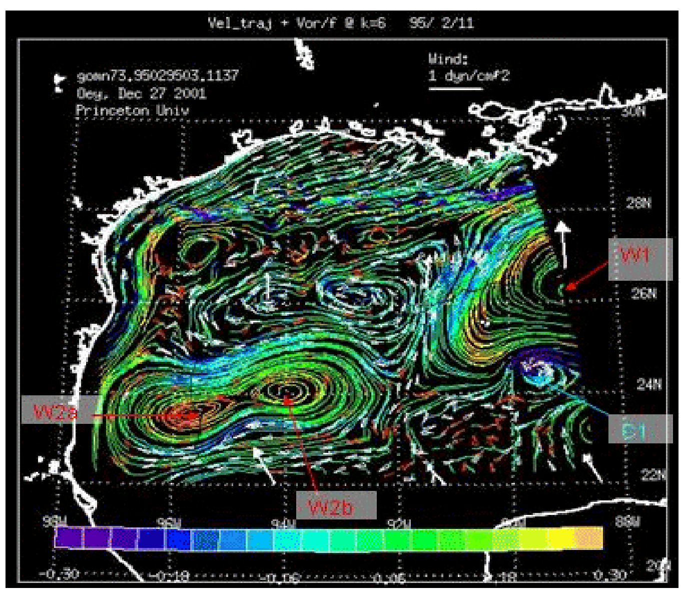

Figure 1G.9a. Evolution of eddies in the western Gulf of Mexico from the Fine Grid experiment (see text).

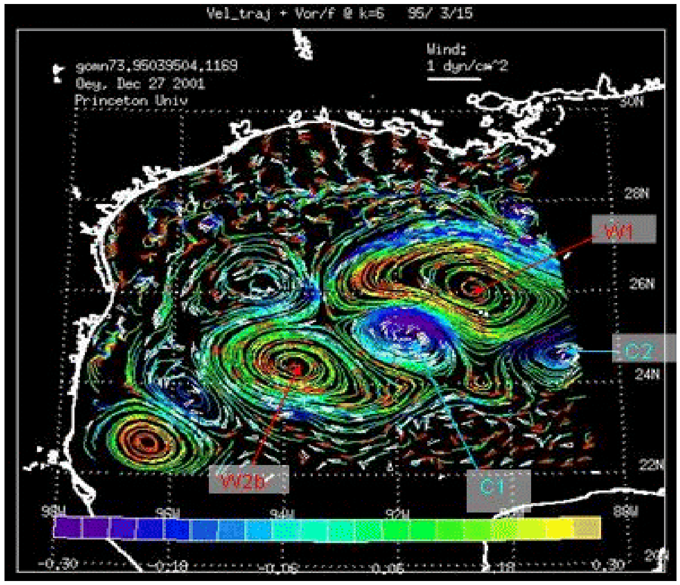

Figure 1G.9b. Evolution (continued) of eddies in the western Gulf of Mexico from the Fine Grid experiment (see text).

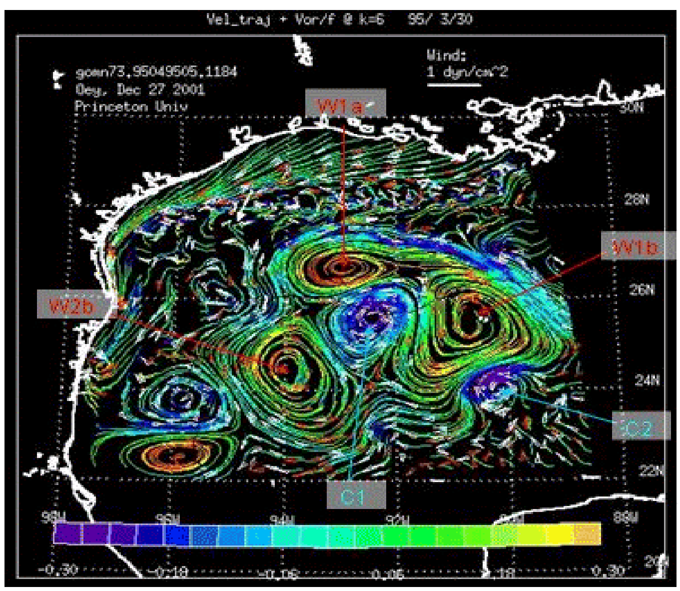

Figure 1G.9c. Evolution (continued) of eddies in the western Gulf of Mexico from the Fine Grid experiment (see text).

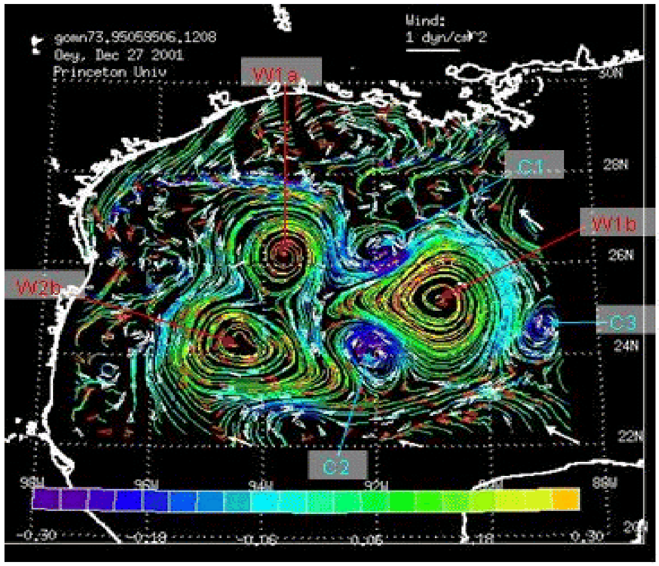

Figure 1G.9d. Evolution (continued) of eddies in the western Gulf of Mexico from the Fine Grid experiment (see text).

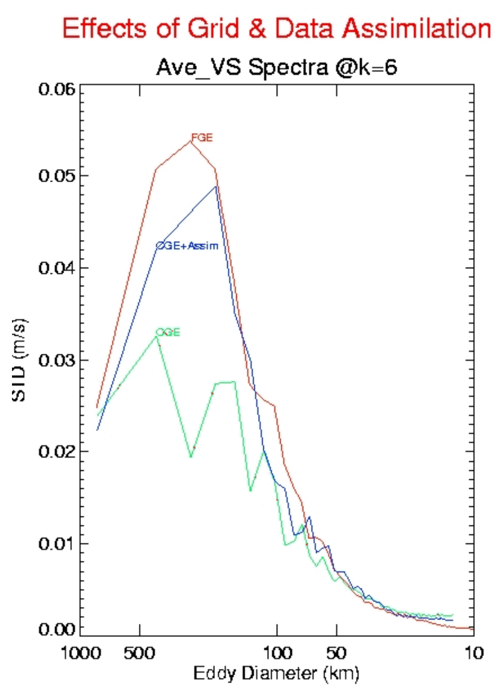

Figure 1G.10. Average velocity spectra at sigma level 6 as a function of spatial scale for the indicated model grids.

The deep circulation is cyclonic, a robust feature that is present in both the CGEs and FGEs. The simulation suggests that this deep flow is forced by cyclones constantly being generated underneath, and generally to the north and east of the LC (against the Florida slope; Figures 1G.11a and 1G.11b). The forced disturbances circle cyclonically around the deep basin, probably as trapped wave.

The deep fluctuations are caused by small-scale eddies (diameters ~ 100km), most of which are cyclones. As LC enters the Gulf, strong cyclonic shears develop (V/f » 0.7) along its western edge, and intensify over the deep waters into cyclones or cyclonic meanders that propagate clockwise around the LC (Figures 1G.12a and 1G.12b and Figures 1G.13a and 1G.13b).

The cyclonic perturbations around the LC (and also LCEs) produce TRWs that propagate predominantly along the 3,000m isobath across the central Gulf—a process that was discussed extensively during last year's ITM and QRB. Figures 1G.14a, 1G.14b, 1G.14c, and 1G.14d shows an example of this generation and propagation episode starting from (a) quiet period, (b) generation period when the northern edge of the LCE just passes the 3,000m isobath, (c) propagation along the 3,000m-isobath, and (d) high-energy period around the 90-91°W on the 3,000m isobath when TRW arrives. The path coincides well with a ray-tracing model also discussed during the last QRB (Oey and Lee 2001, submitted).

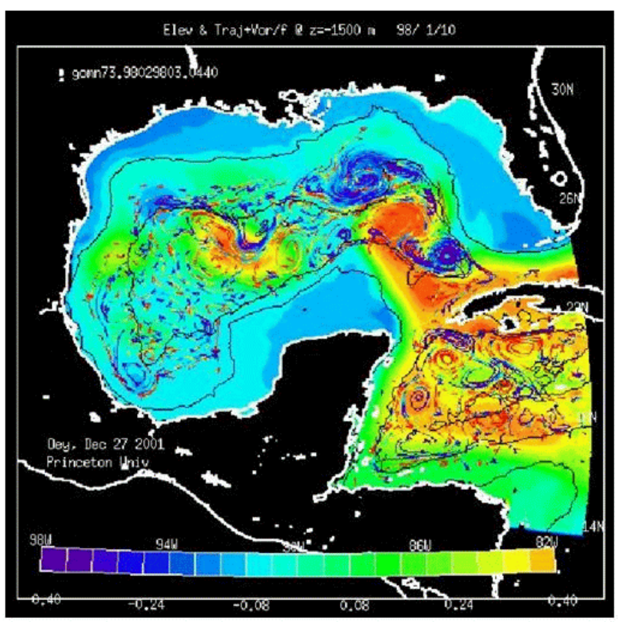

Figure 1G.11a. SSH and deep circulation at 1,500 m from the FGE.

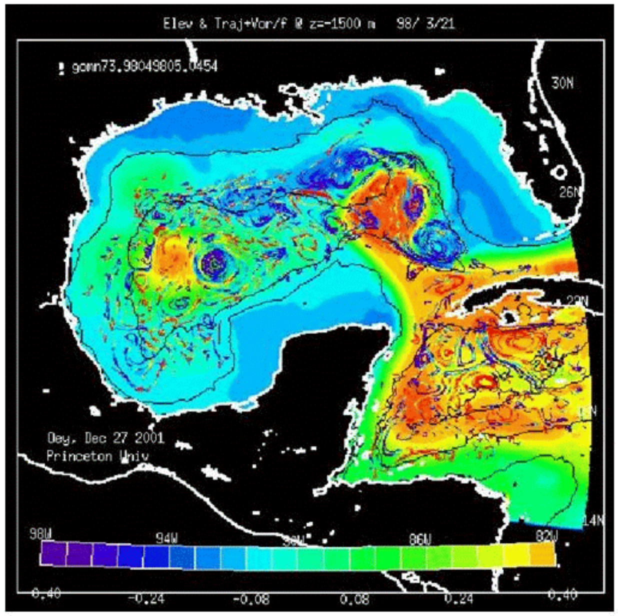

Figure 1G.11b. As Figure 1G.11a but 70 days later.

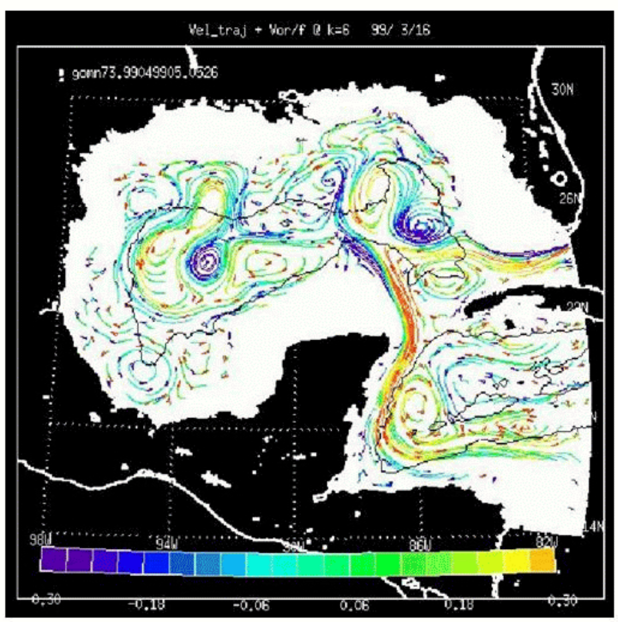

Figure 1G.12a. Upper layer trajectories from the FGE for the indicated time.

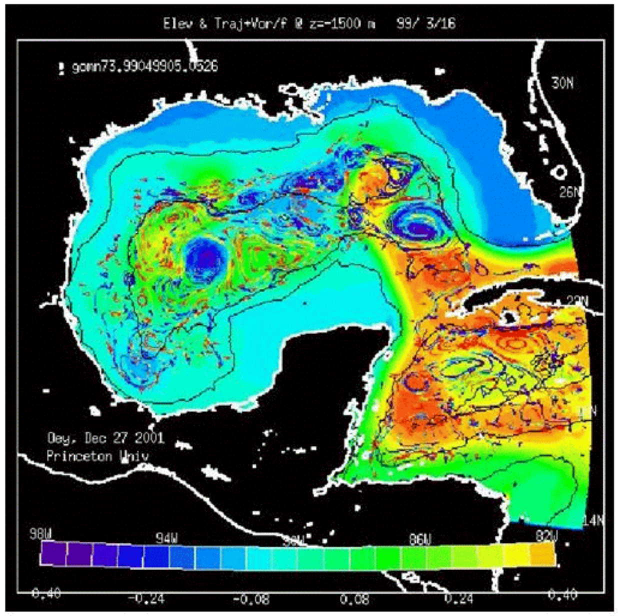

Figure 1G.12b. SSH and trajectories at 1,500 m for the same time as Figure 1G.12a.

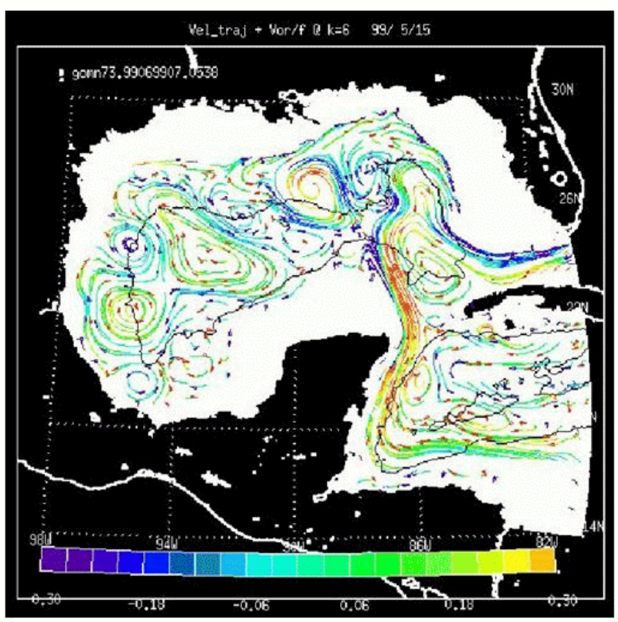

Figure 1G.13a. Upper layer trajectories from the FGE at 60 days later than Figure 1G.12a.

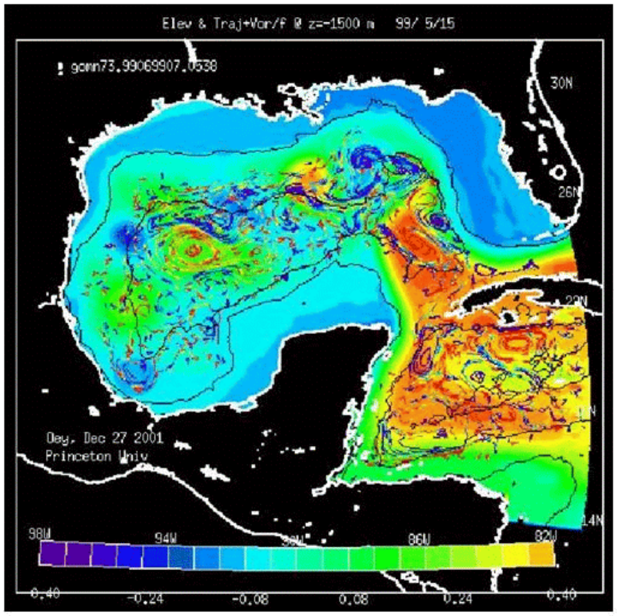

Figure 1G.13b. SSH and trajectories at 1,500 m for the same time as Figure 1G.13a.

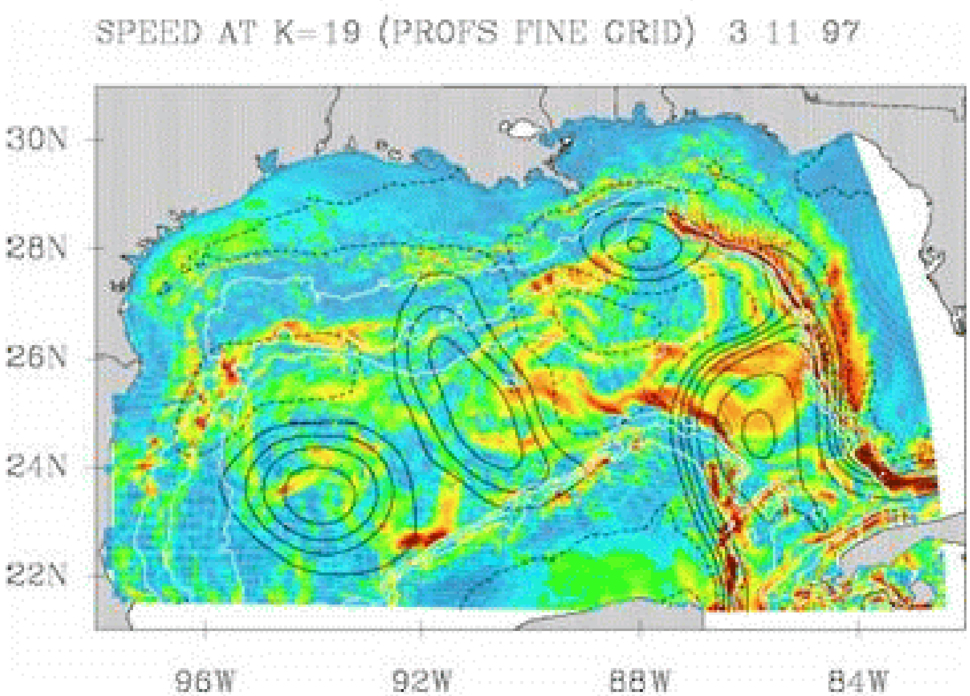

Figure 1G.14a. Generation and propagation of deep TRWs (a) upper panel – quiet period.

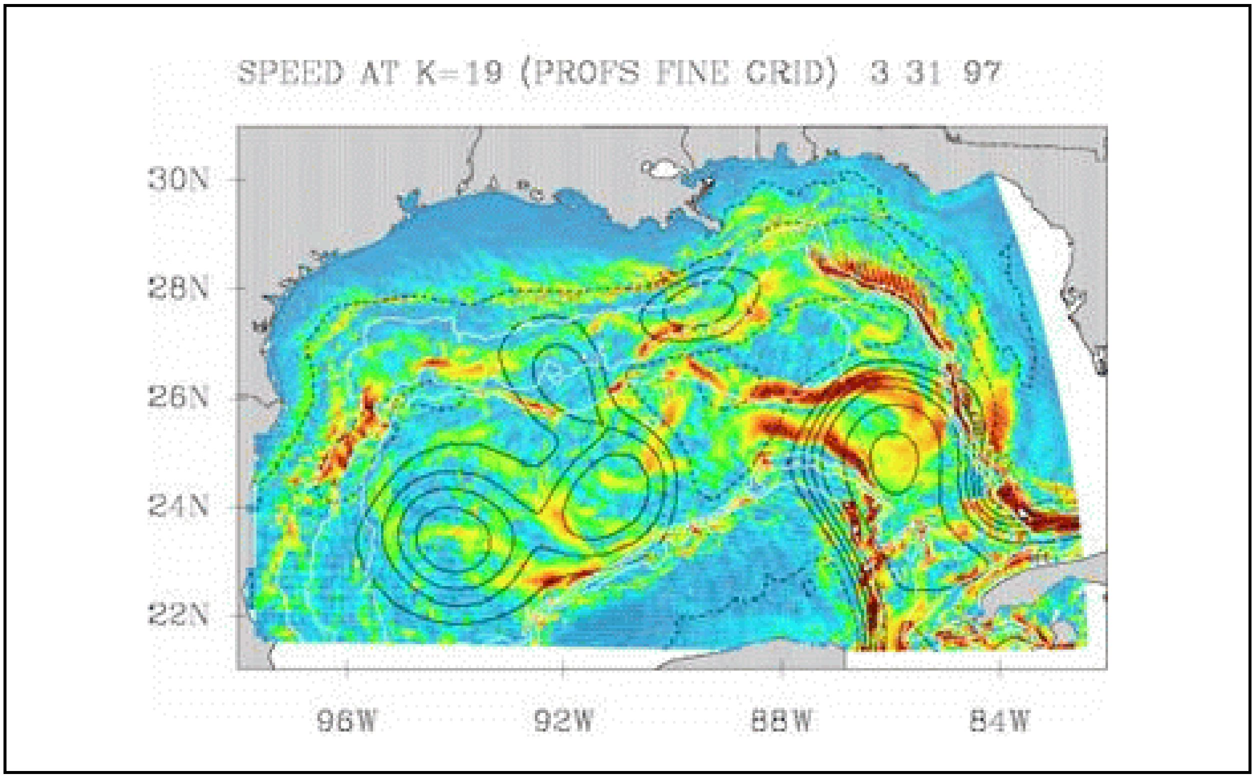

Figure 1G.14b. Generation and propagation of deep TRWs (b) lower panel – LC extension.

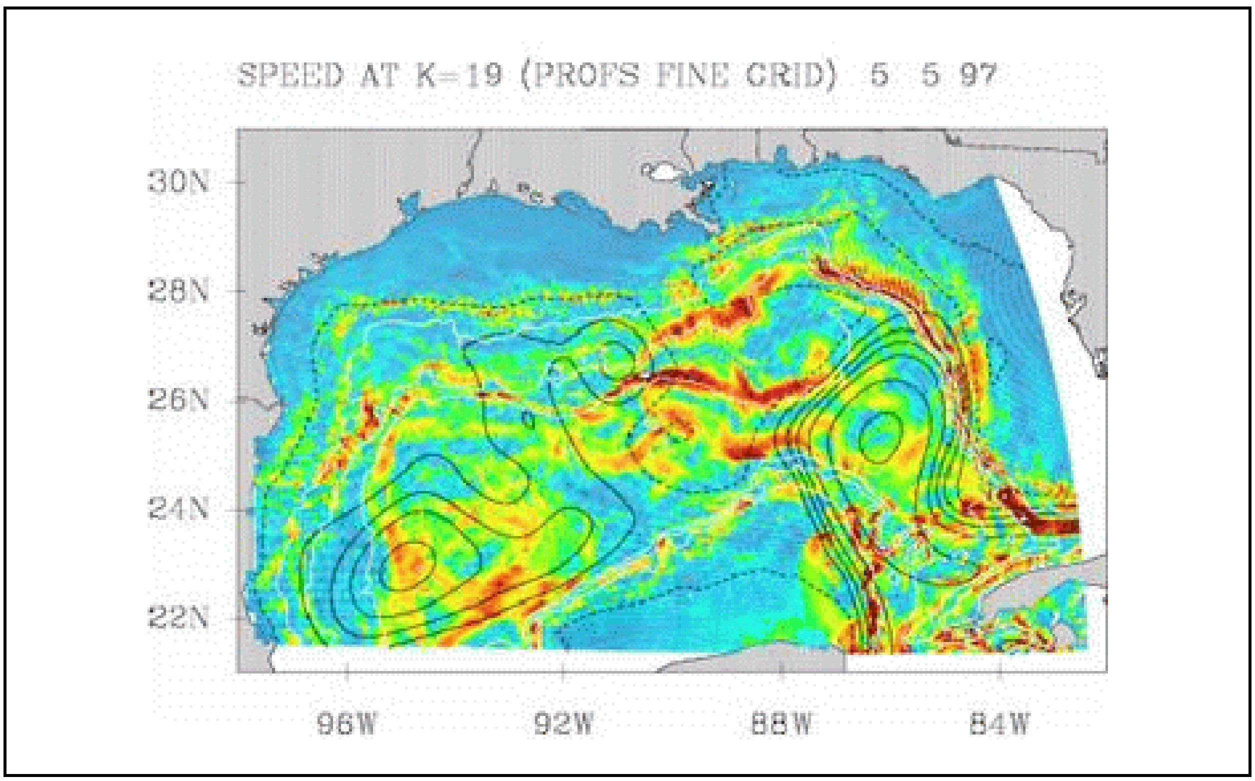

Figure 1G.14c. (c) upper panel – westward propagation of deep currents.

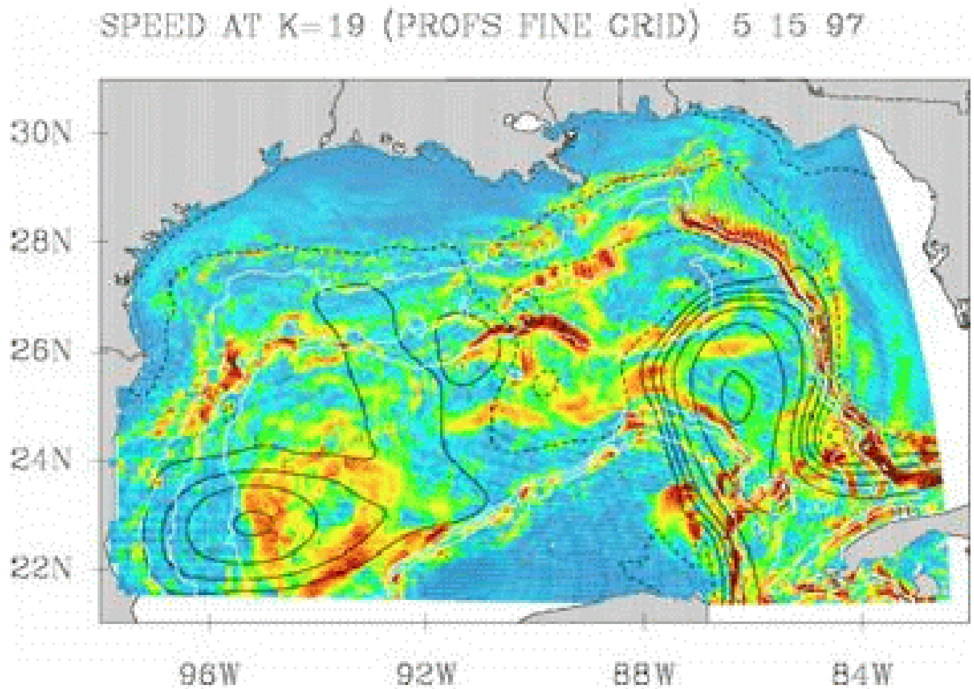

Figure 1G.14d. (d) lower panel – arrival of disturbance at 91°W, 26°N.

In summary, we have tested the model's sensitivity to grid resolution and data assimilation. The 'coarse' resolution (which is the resolution commonly used by existing published models of the Gulf), D»10km, shows much less eddy activity especially in the northern third of the Gulf than higher-resolution (D»5km) calculation. With assimilation using the coarse grid, the energy level improves, though at eddy scales of about 100km the energy is again underestimated.

The high-resolution experiments suggest that small-scale cyclones play an important role in driving the deep mean circulation, and in forcing high-frequency deep motions especially the TRWs. The cyclones are predominantly produced by the intense shears that develop along the western edge of the LC as the latter intrudes into Gulf, by cyclonic meanders around the LC, and also underneath the LC through as yet not well-understood dynamic processes.

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MODELING OF LOOP CURRENT EDDY INTERACTIONS WITH THE CONTINENTAL SHELF, SLOPE AND CANYONS OF THE GULF OF MEXICO

Dr. Lewis M. Rothstein
Accurate Environmental Forecasting, Inc.

Accurate Environmental Forecasting (AEF) is an environmental hazard modeling company that is beginning the third year of a four-year research and development program for the Minerals Management Service. Founded by two professors from the University of Rhode Island's Graduate School of Oceanography, the company's primary mission is to provide innovative, accurate assessments of natural and man-made catastrophes and other environmental impacts using sophisticated ocean and atmospheric models. This mission is directed at improving the business evaluation of financial risk exposure for investment decisions both long-term and in real-time as natural and man-made events evolve. We have helped to develop the only *official* coupled hurricane/ocean forecast system, used *operationally* by the U.S. National Weather Service and the National Hurricane Center; AEF presently offers added-value products based upon this forecast system to the insurance and reinsurance industry.

The objective of our project for the MMS is to better understand the fundamental physical mechanisms that govern the behavior of Loop Current Eddies (LCEs) as they interact with the continental shelf, slope, and canyons of the Gulf of Mexico (GOM). For this we employ two different types of physical models: (1) a process-oriented numerical model, based upon the "intermediate equations" of motion, that is specifically formulated for accurately representing vortex/topography interactions; and (2) a "primitive equations" GOM general circulation model designed for even more realistic simulations. The latter can be also configured with a unique two-way interactive nested grid structure for ultra high-resolution experiments (e.g. resolving the circulation within submarine canyons). The combination of these two models has enabled important physical insights into three fundamentally distinct physical processes that govern the trajectories of an LCE in the GOM:

- Surface-intensified cyclonic eddies. These are generated by an LCE's interaction with the shelf via the *process of high potential vorticity advection off the shelf* that tends to move the LCE slowly southward along the coast.

- Bottom-intensified eddies. These are generated by elliptically shaped LCEs via the *process of vorticity pumping over a flat bottom* which also tends to move the LCE southward along the coast, albeit more rapidly than the above process.

- Midwater-column currents. These are generated by LCEs via the *process of vortex tube compression* and is one of the few processes that tends to move the LCE northward along the coast, specifically towards the "eddy graveyard" in the northwest region of the GOM.

This knowledge will enable a GOM LCE forecast system to more accurately predict the location of an LCE into the future, a product that is presently under development. The remainder of this synopsis briefly illustrates these three processes.

SURFACE-INTENSIFIED CYCLONIC EDDIES

Figure 1G.15 illustrates the fundamentals of this generation mechanism. The left frame is the idealized geometry that we set in this experiment, and the right panel is a snapshot of the time when the LCE is vigorously interacting with the slope/shelf bathymetry. The shelf acts dynamically as an important source of high potential vorticity (PV) to the system and, as an LCE approaches the shelf, there is a vigorous advection of high PV off the shelf that generates a cyclonic vortex to the north of the LCE. The interaction of this cyclonic vortex with the LCE initially moves the LCE offshore and later drives it slowly southward. This idealized simulation was set within the framework of the intermediate equations of motion.

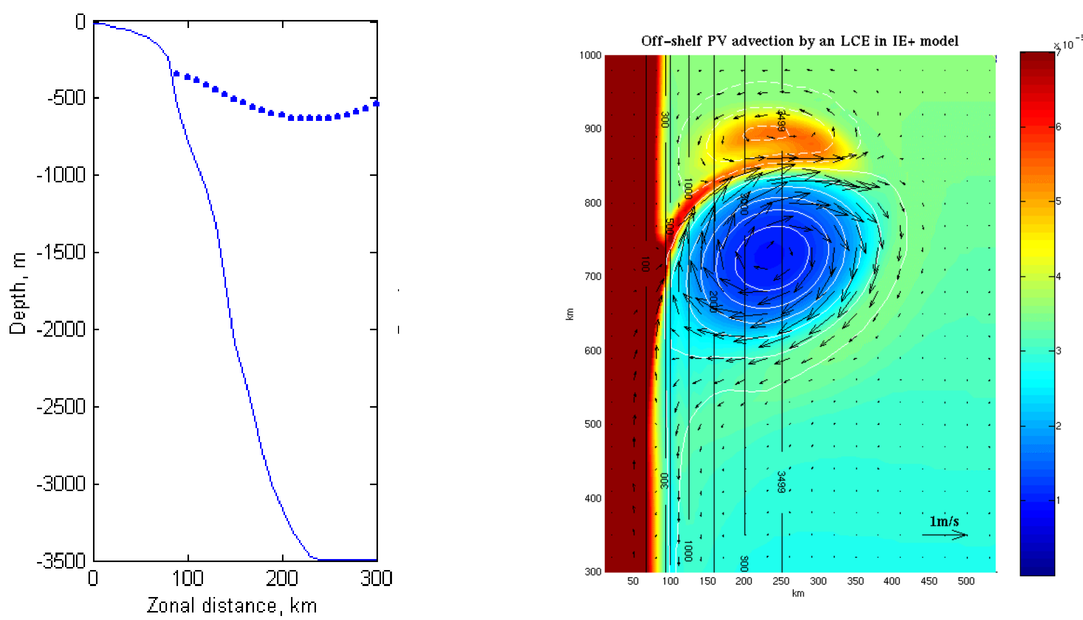

Figure 1G.15. The left frame is the idealized geometry set in this experiment, and the right panel is a snapshot of the time when the LCE is vigorously interacting with the slope/shelf bathymetry.

BOTTOM-INTENSIFIED EDDIES

The intermediate equations model is here employed in an experiment over a flat bottom (i.e. no topography). In Figure 1G.16, the arrows and the black contours indicate velocity and pressure in the lowest layer of an eight-layer model, respectively. The slight ellipticity of the LCE (as would be generated, for example, by the process of off-shelf advection of high PV water as illustrated above) enables the establishment of a quartet of eddies in the deepest layer. The process of PV pumping as the elliptic LCE rotates anti-cyclonically over the flat bottom is responsible for generating these deep eddies. If a narrow-enough slope is implanted in this system, then those deep eddies that can feel the slope would be suppressed, i.e. via the generation of topographic Rossby waves, and the resulting deep current field would be modified. In any case, the resulting circulation is such as to advect the LCE *rapidly* southward.

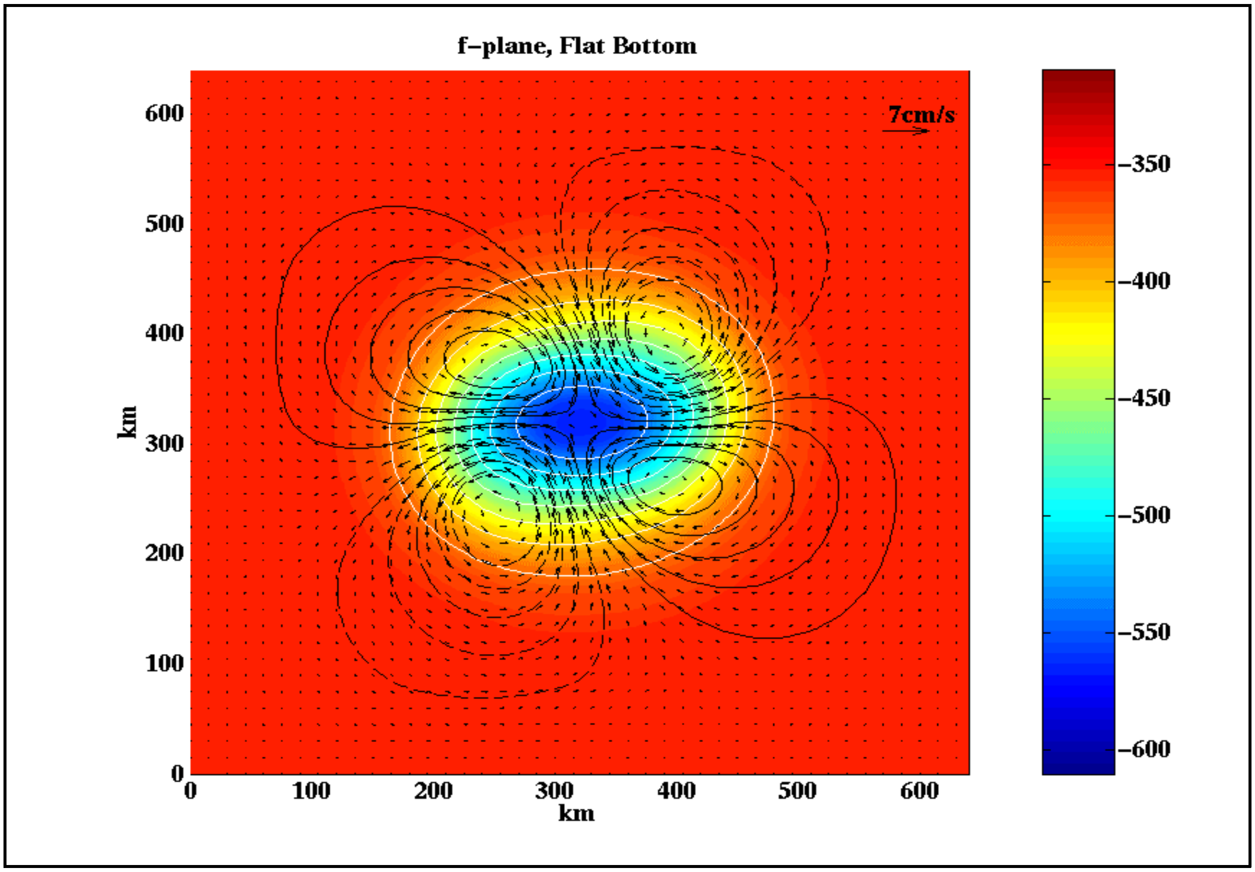

Figure 1G.16. The arrows and the black contours indicate velocity and pressure in the lowest layer of an 8-layer model, respectively.

MIDWATER-COLUMN CURRENTS

The final fundamental process is illustrated within the context of the full primitive equations model. We now add stratification below the thermocline, essential for this process. The left panel in Figure 1G.17 is the geometry of the experiment, and the right panel shows the PV in the upper layer. As the LCE moves onshore it “squashes” water columns in the intermediate layer, generating relative vorticity in the process. This vorticty generation essentially establishes an along-the-coast current that advects the LCE northward. Besides the so-called “image effect,” this is the only process that we find which can efficiently advect the LCE northwards towards the “eddy graveyard” in the northwest corner of the GOM.

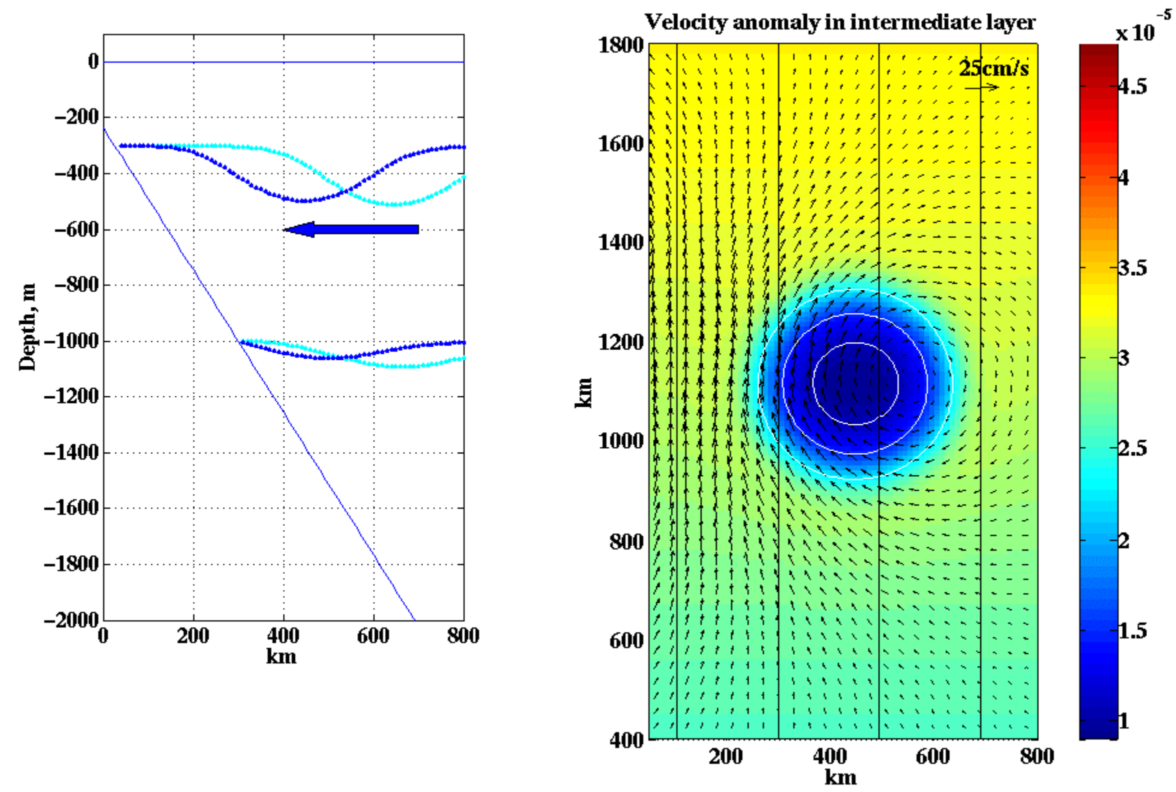

Figure 1G.17. The left panel is the geometry of the experiment, and the right panel shows the PV in the upper layer.

These three fundamental processes compete to define the LCE trajectory. Indeed, in realistic experiments (Figure 1G.18; with real coastlines and shelf/slope geometry), one can identify all three of these mechanisms for controlling the LCE trajectory (the black curve). Notice the initial northward LCE motion (due to the generation of midwater-column jets) that then gives way to southward motion governed by combinations of the first two processes. Similar physical processes can also be identified along the northern shelf/slope regions of the GOM.

CONCLUSION

We believe we now have a much clearer understanding of the fundamental physical processes responsible for defining the time evolution of an LCE in the GOM. This understanding will be used in LCE forecast systems that are presently under development by AEF. Future research for the MMS will continue to focus on ever more realistic simulations (e.g. with a more representative suite of initial LCE structures) as well as research near and within the DeSoto Canyon and in the northwest corner of the GOM. Our ultra-high resolution nested-grid models will be extensively used for understanding the role of smaller-scale eddies as well as for resolving details of the Canyon circulation.

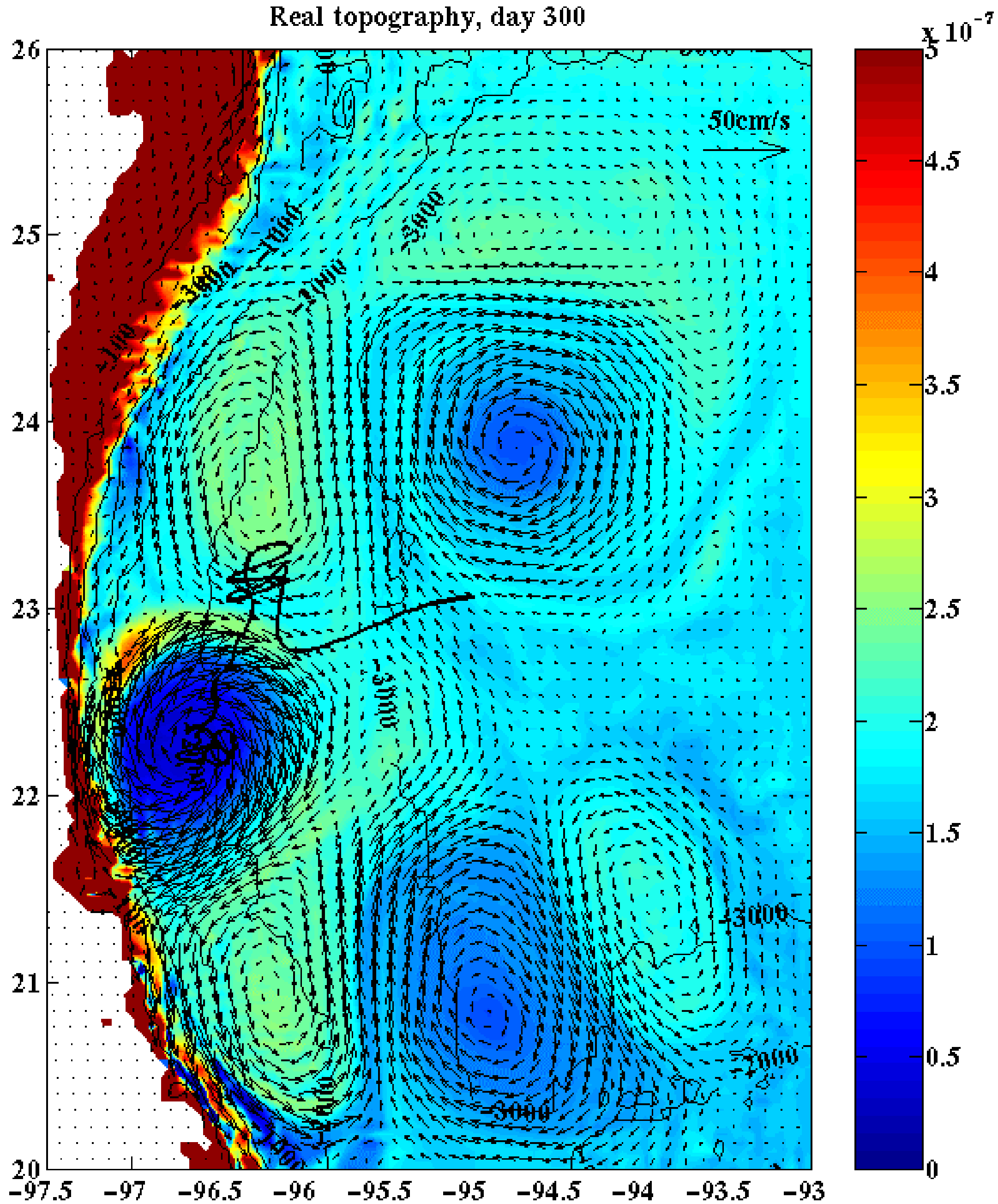

Figure 1G.18 In realistic experiments with real coastlines and shelf/slope geometry, all three mechanisms for controlling the LCE trajectory (the black curve) can be identified.

Dr. Lewis Rothstein received his Ph.D. from the University of Hawaii in 1983 and is presently a professor of oceanography at the University of Rhode Island as well as president and co-CEO of Accurate Environmental Forecasting, Inc. He is internationally recognized for his work in ocean numerical modeling and coupled air/sea interactions on time and space scales that encompass such diverse dynamical regimes as mesoscale ocean processes and global climate dynamics. He has authored or co-authored over 45 articles and book chapters on these and other relevant topics, and has also recently co-edited a major collection entitled *The TOGA Decade: Reviewing the Progress of El Nino Research and Prediction* that summarizes our present understanding of El Niño.

Dr. Rothstein was recently the editor of the *Journal of Geophysical Research*, one of the premiere journals in physical oceanography. He is presently a two-term member of the U.S. Science Steering Committee for the World Ocean Circulation Experiment, has served on numerous other national and international scientific committees, and has served on review panels for the National Academy of Sciences, the National Science Foundation, and the National Oceanic and Atmospheric Administration. He has delivered over 50 seminars worldwide, both at international meetings and oceanographic and atmospheric institutions, and he has chaired the committees of seven doctoral students. His research has been supported by the National Science Foundation, the National Oceanic and Atmospheric Administration, the U.S. Office of Naval Research, the Minerals Management Service, and the private sector.

DEEP WATER OCEANOGRAPHY: GETTING IT RIGHT

Dr. William Jobst
Naval Research Laboratory

INTRODUCTION

Within the last decade, ocean modeling has evolved from a regional science capable of describing ocean circulation in enclosed seas, to a global science providing routine operational forecasts. The purposes of this paper are to review developments in both technology and policy that have made this evolution possible, examine the standards for evaluating and comparing the performance of the wide range of models that are available today, and look at the manner in which both technology and policy might evolve in the coming decade.

LOCATION AND ORGANIZATION

Although we are a member of the research side of the Navy, our co-location with operational forecasters at the Naval Oceanographic Office (NAVOCEANO) in Stennis Space Center, Mississippi, and at the Fleet Numerical Meteorological and Oceanographic Center (FNMOC) in Monterey, California, puts us in contact with those who must solve the day-to-day problems of a large forecast center with real-time data sources and an ever-changing high performance computing complex. Together with many other international researchers, we help provide the research foundation on which the Navy's ocean forecasting skill rests.

Figure 1G.19 illustrates the multi-agency and multinational infrastructure, involving thousands of people, necessary to provide routine forecast products. Wind fields, for example, are generated at FNMOC in Monterey, California, but are the result of cooperative agreements with the United Nation's World Meteorological Organization, and nationally, with NOAA, NASA, Air Force, operational navy forces, and others. The estimates of sea surface temperature are likewise the result of multinational efforts to archive all available buoy data as well as XBTs from surface ships, aircraft, and submarines. Ocean climatology, derived from decades of multinational data, is merged with near real-time XBT and buoy observations and with sea surface temperature derived from multiple satellites.

The complexity of this infrastructure cannot be overstated. In the ocean forecasting business, we benefit from broadband access to global data sources, and we also benefit from data processing resources provided through the DoD High Performance Computing Initiative. Ocean models, exclusive of data ingest and quality control, require on the order of 1.5 million lines of code that must be configuration managed and updated as new computing architectures are introduced.

REMOTE SENSING; SATELLITE ALTIMETRY

Satellite altimetry has led to perhaps the most significant advancement in our ability to observe the world's oceans in the last decade. While the Geosat Mission was originally intended to map the

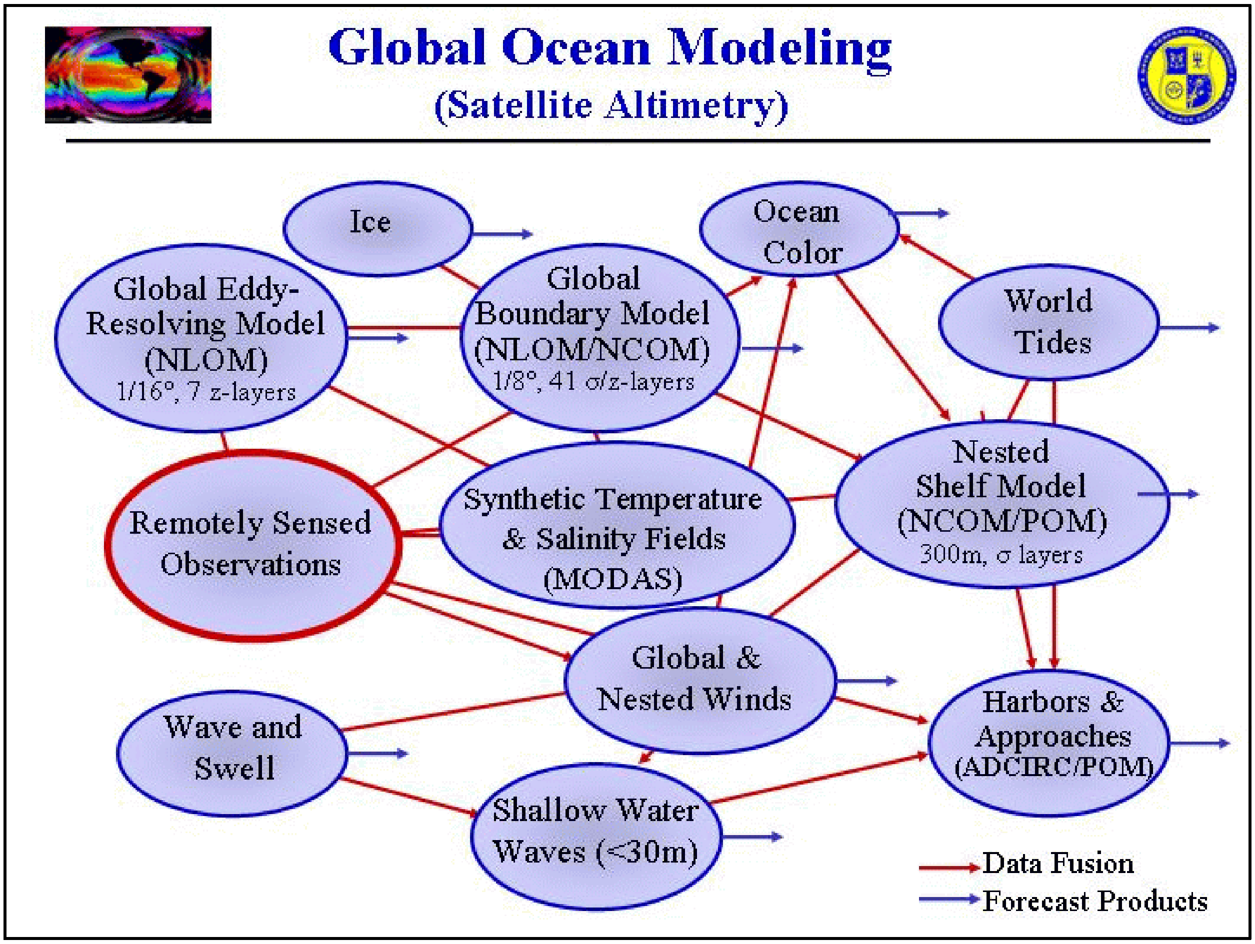

Figure 1G.19. The multi-agency and multinational infrastructure necessary to provide routine forecast products.

geoid for military navigation purposes, it soon became apparent that repeated tracks provided direct measurement of global ocean mesoscale dynamics; observations beyond imagination with previous oceanographic instrumentation. As the number of satellites increased and the quality of observations improved, it became possible not only to sense but also routinely to map the world mesoscale ocean variability. The Data Fusion Center at NAVOCEANO currently processes 3 altimetry satellites (soon to become 5). Daily altimetry products are available on our NRL website.

FORECASTING OCEAN MESOSCALE VARIABILITY

The coupling between ocean and atmosphere was clearly demonstrated by the El Niño event of 1982-83. While a number of laboratories contributed to the understanding of this event, the decadal impact was discovered at NRL and the ¼ degree resolution Navy Layered Ocean Model (NLOM) was the first to demonstrate that the long-term physical effects of the El Nino event could be duplicated numerically. Our new ability to observe and model the fundamental physical behavior of our planet was recognized by *The New York Times*, *Nature*, and *Discover* Magazine. The Computerworld Smithsonian Award program also recently recognized the significance of the

NLOM model, and you will find the NLOM simulation permanently archived in the Smithsonian National Museum of American History in Washington, D.C.

The NLOM model pedigree is important because it demonstrates the lengthy scientific evolution needed to move a model from a useful research tool into the world of routine operational navy forecasting. The quality control process involved many steps, and a few of them are worth showing here.

Many investigators have measured mean transport through the world's straits. It is a direct measure of the kinetic energy flowing into and out of ocean basins, and if the mean current transports are not correctly modeled, then oceanographic forecasts cannot be expected to capture mesoscale variability. Figure 1G.20 shows measured and modeled mean transport through Intra-Americas straits for 1/16 degree NLOM, the highest resolution model that can be run routinely on the processors available to the operational Navy today. While the flow rates are generally correct, the rates through the Yucatan Channel and Windward Passage are too low, while inflow through the Providence Channel is higher than reported experimentally. The result is a reasonable representation of Gulf Stream flow in the Florida Strait, but slightly too little energy in the Gulf of Mexico (GOM).

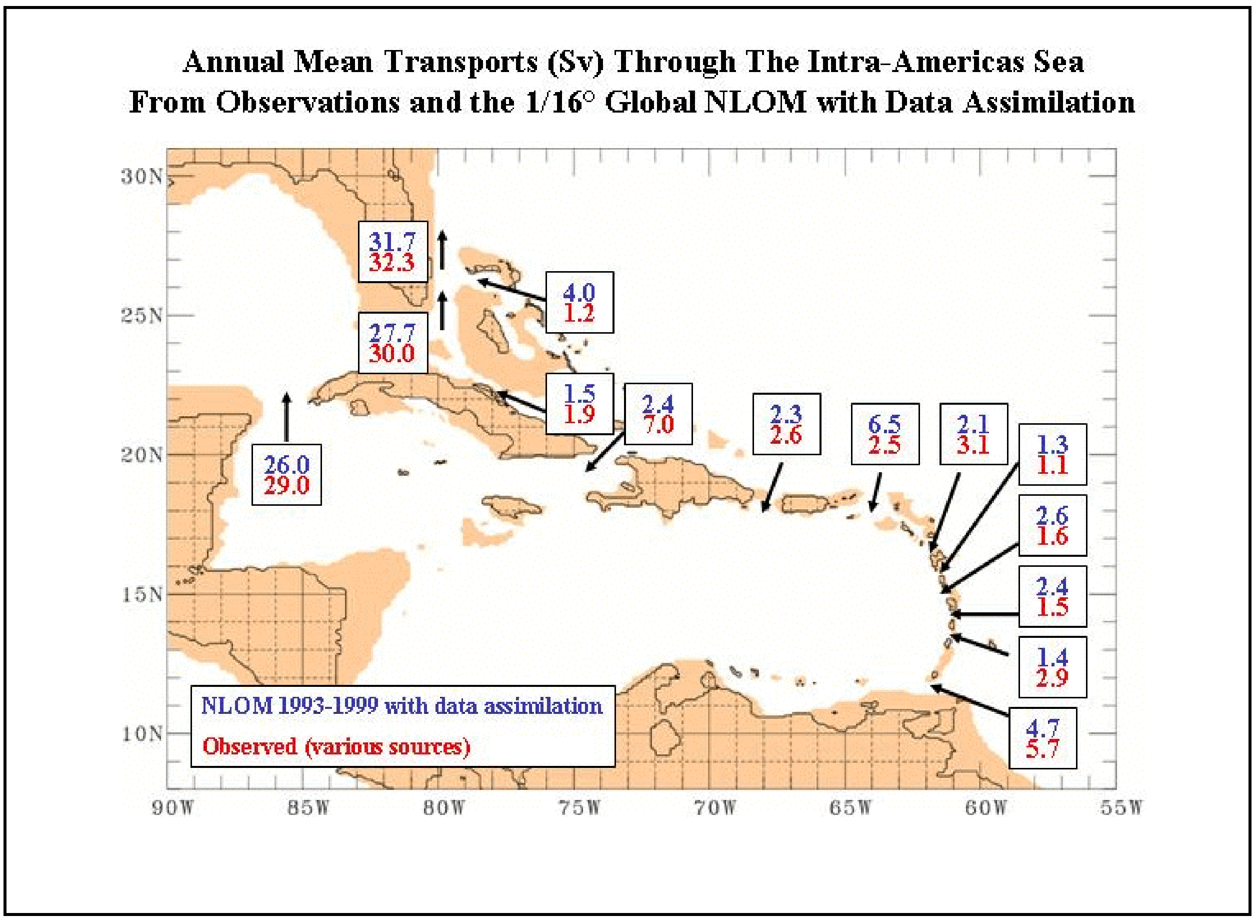

Figure 1G.20. Measured and modeled mean transport through Intra-Americas straits for 1/16 degree NLOM.

Figure 1G.21 shows the same transport, but modeled at 1/32 degree resolution. The agreement with observations is significantly better. It has been our experience at NRL, that models having less than 1/16 degree resolution, as might be expected, have difficulty representing the flow through straits.

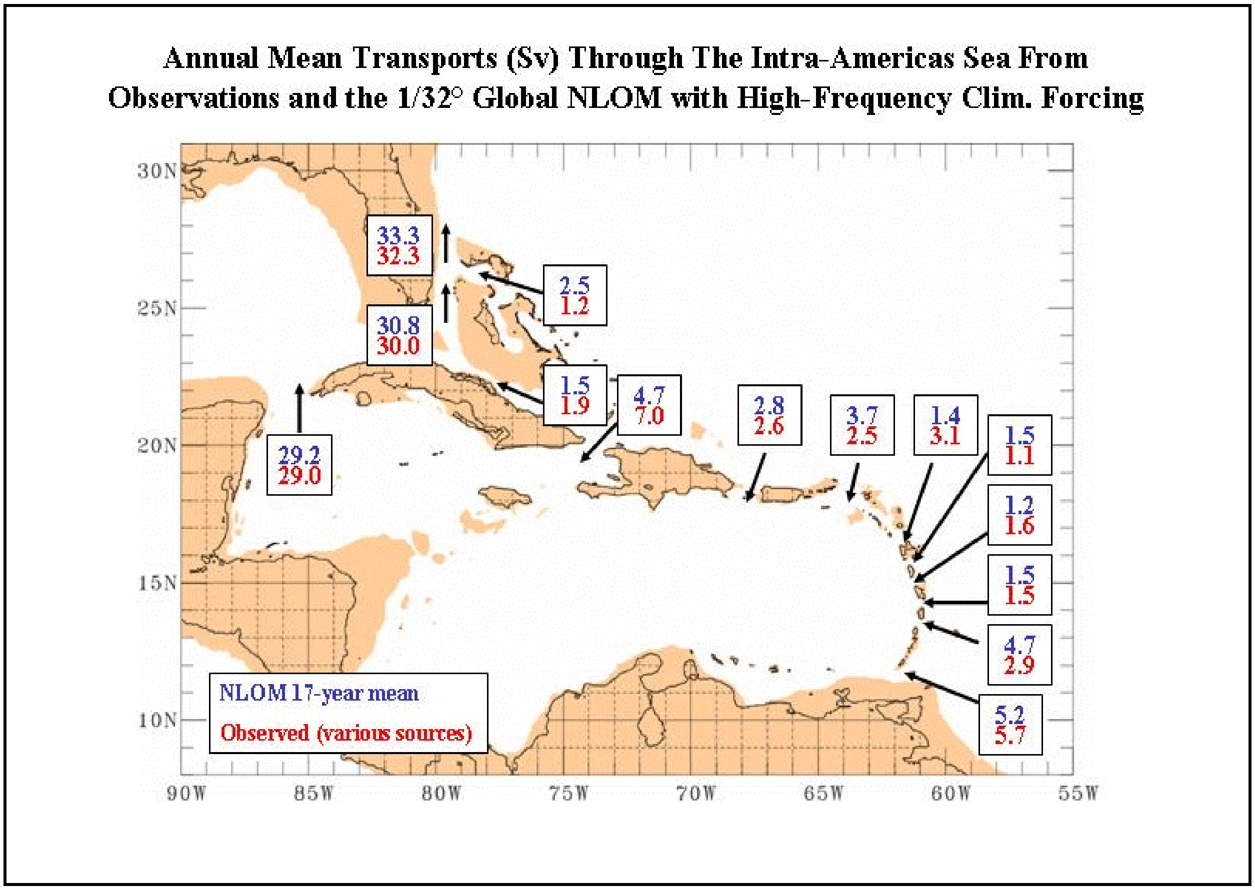

Figure 1G.21. The same transport as in Figure 1G.20, but modeled at 1/32 degree resolution.

To determine how much spatial resolution is necessary, a series of numerical experiments were performed at 1/8, 1/16, 1/32, and 1/64 degree resolution. As shown in Figure 1G.22, the 1/32 degree model captures most of the variability and is probably sufficient for forecasting frontal positions, although the 1/64 model extends the Gulf Stream kinetic energy into the North Atlantic and offers a slight improvement.

Once the flow through straits and mesoscale kinetic energy are well represented in the numerical model, there are several statistical measures of forecast skill. These measures compare forecast sea surface height and sea surface temperature with observations. Figure 1G.23 clearly demonstrates that the NLOM model, run without assimilated data, exhibits forecast skill well beyond 15 days. A rather remarkable achievement in our ability to understand the mesoscale behavior of the world's oceans!

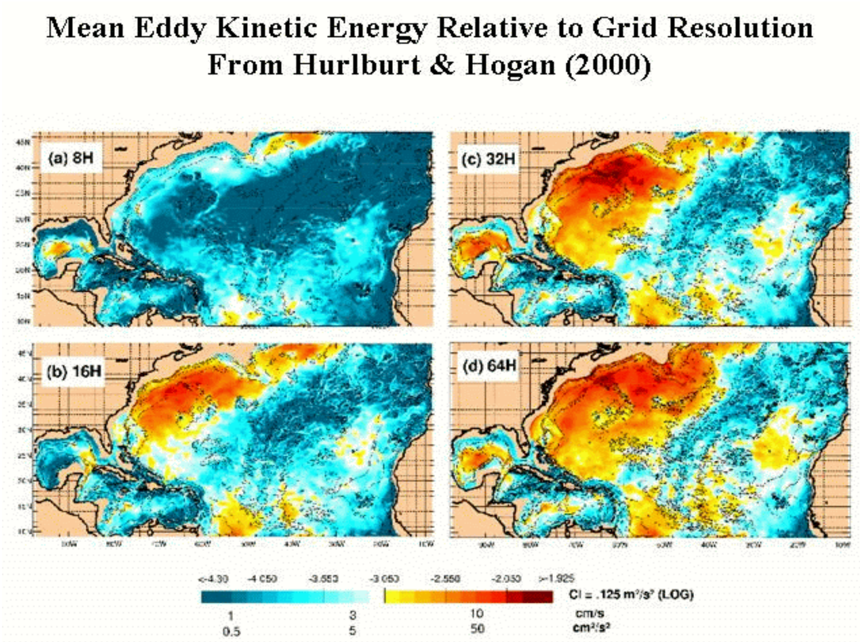

Figure 1G.22. The 1/32 degree model captures most of the variability and is probably sufficient for forecasting frontal positions.

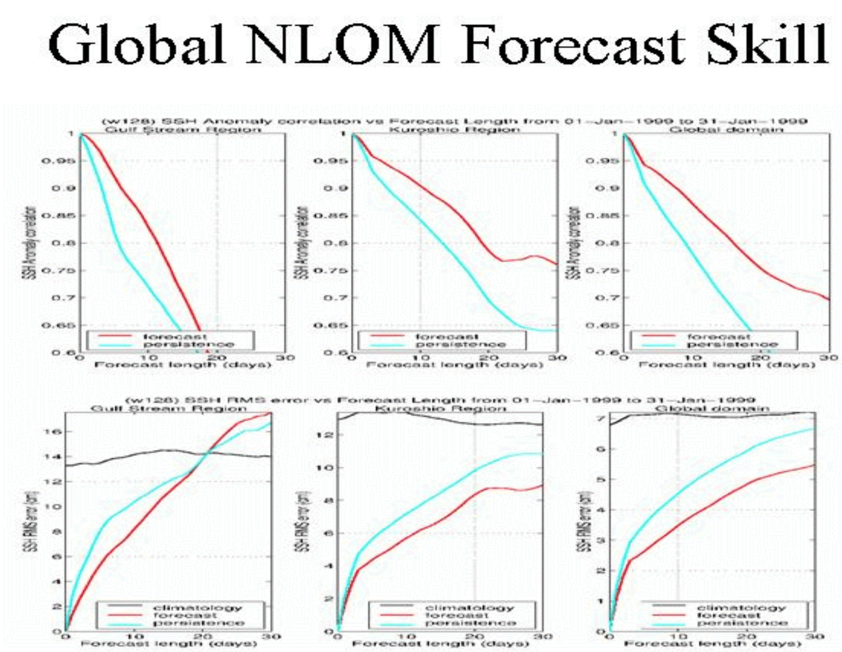

Figure 1G.23. The NLOM model, run without assimilated data, exhibits forecast skill well beyond 15 days.

FORECASTING ON THE CONTINENTAL SHELF

The Navy Coastal Oceanographic Model (NCOM) is our most advanced global forecasting system that propagates energy from ocean basins onto the continental shelf, to 5m minimum depth, and provides the vertical resolution necessary for ASW forecasts (41 levels in the vertical). Based on the Princeton Ocean Model, but with a hybrid coordinate system in the vertical, NCOM assimilates dynamic height from NLOM, converted to ocean temperature and density fields through MODAS. Since the model assimilates the density fields from NLOM, flow through straits and kinetic energy are similar. Recently, the Navy used NCOM to forecast currents in the central Barents Sea following the Kursk submarine crisis. Divers found the currents to be quite low, as predicted by the model and contrary to Russian expectations, Figure 1G.24.

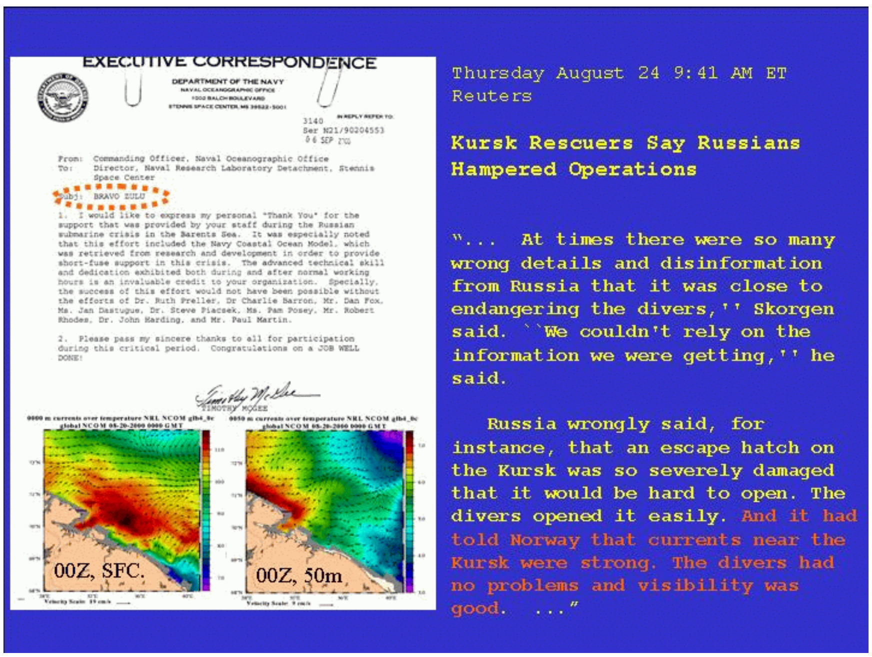

Figure 1G.24. The Navy used NCOM to forecast currents in the central Barents Sea following the Kursk submarine crisis.

FORECASTING FOR HARBOR APPROACHES

Although the global capability of NCOM has proven its value, forecasting for near-shore operations, especially for diver support, autonomous vehicle operations, or hazardous material spills clearly requires higher resolution modeling. The NCOM architecture was designed to merge with either existing POM code or with successively nested NCOM models, each at a higher resolution. The panels in Figure 1G.25 show a NCOM nest of the Chesapeake and Delaware Bays. The innermost nest is approximately 200m resolution. The salinity plume associated with the Chesapeake Bay is affected by local wind that drives the plume offshore after 200 hours into the model run.

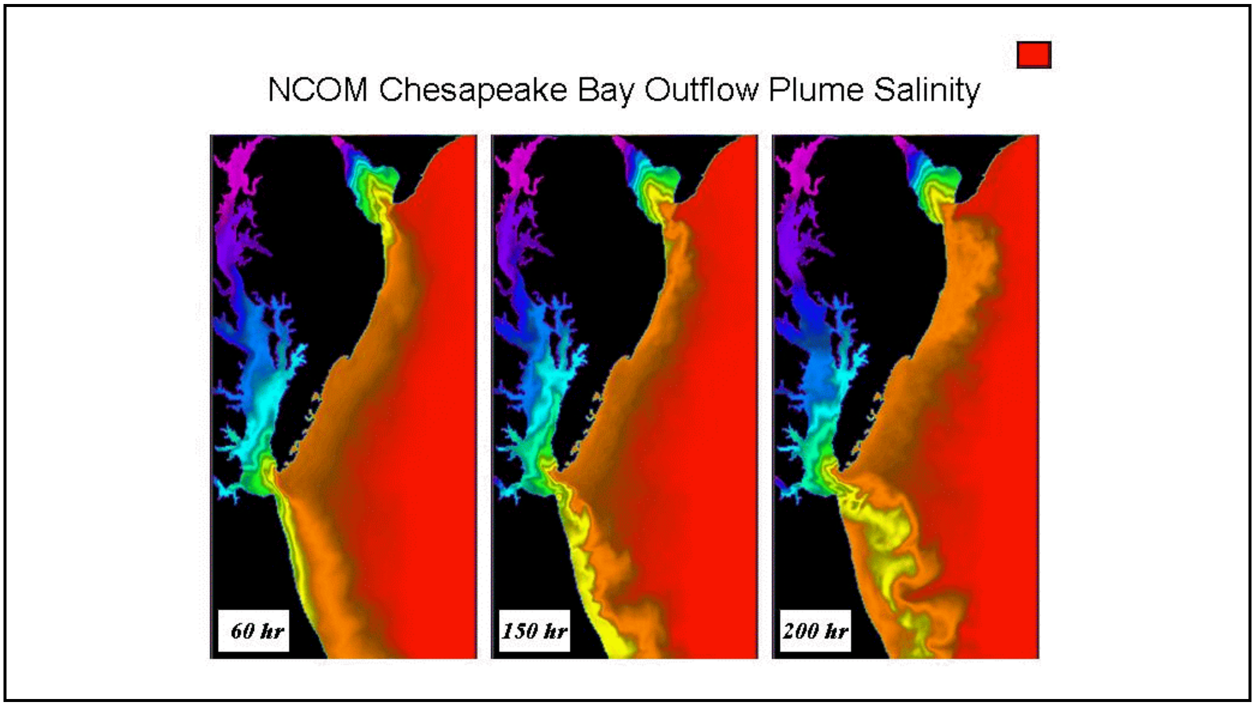

Figure 1G.25. The panels show a NCOM nest of the Chesapeake and Delaware Bays.

PLANS

Despite the successes of the last decade, global ocean modeling at the desirable 1/32 degree spatial resolution and approximately 40 layers depth resolution remains a Grand Challenge computational problem. In Figure 1G.26 the increase in processor speed following Moore's Law (processor speed doubles every 18 months) is the uppermost curve. The step functions beneath indicate upgrades to the DoD High Performance Computing (HPC) capability every two years. The bar graphs indicate the processor hours available operationally from DOD HPC sources. It is therefore possible to implement routine 1/32 degree forecasts with a layered model such as NLOM (7 layers) beginning in 2003. Future global modeling with improved physics and depth resolution, using models such as the Hybrid Coordinate Ocean Model (HYCOM) which is under joint development by NRL, Los Alamos National Laboratory, University of Miami, and others, is not expected to be practical at 1/32 degree resolution until near the end of the decade.

Even if the Grand Challenge of global modeling at 1/32 degree can be met at the end of the decade, model nesting will still be necessary for military and civilian littoral objectives. Measurements in coastal areas are particularly challenging due to heavy shipping and fishing. Figure 1G.27 shows a trawl-resistant mooring package, built by NATO's SACLANT Undersea Research Centre that will be tested this summer. Its pop-up communications package allows updating of coastal and shelf models in near-real time. Only through instrumentation of this type do we believe we will get the quality and density of data to develop accurate nested models of the near shore environment.

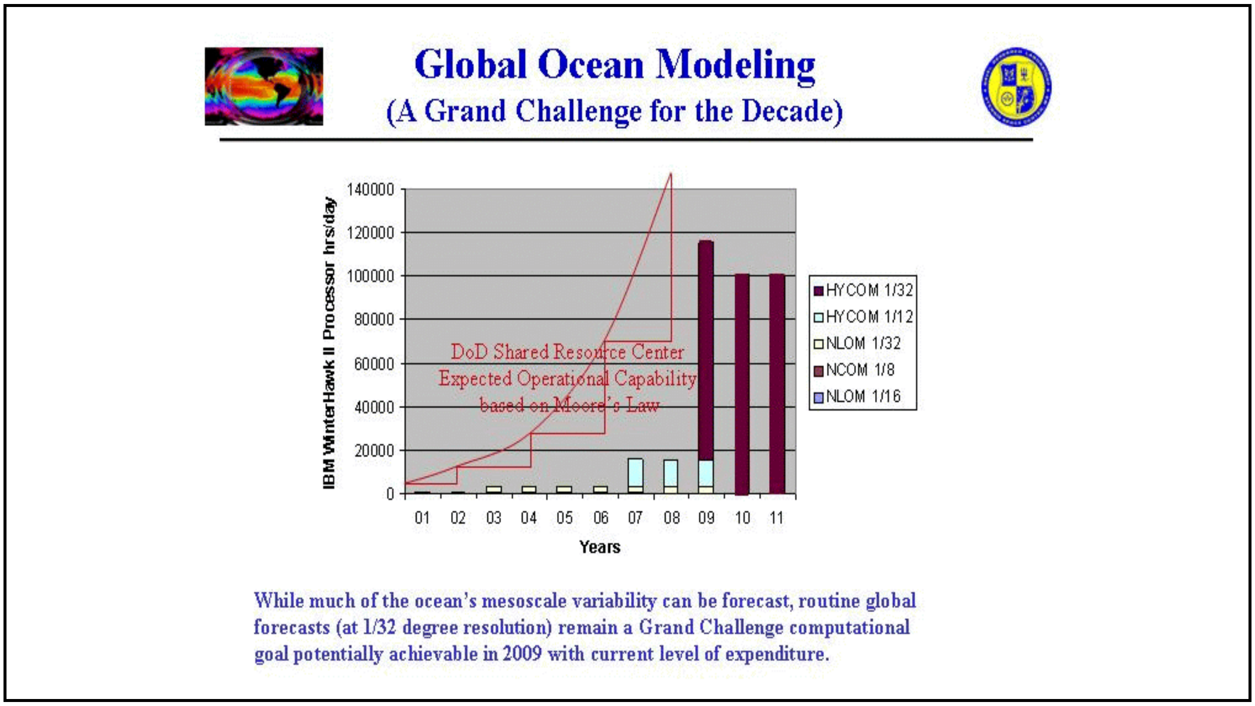

Figure 1G.26. The increase in processor speed following Moore's Law (processor speed doubles every 18 months) is the uppermost curve.

Figure 1G.27. A trawl-resistant mooring package, built by NATO's SACLANT Undersea Research Centre.

Ecosystem models are of importance to the Navy, both for predicting the performance of optical systems and for responsible custodianship of the marine environment. This broad view of ecosystem modeling was prevalent at NATO's SACLANT Undersea Research Centre, where the environmental problems of today were considered to be the political problems of tomorrow and the potential military problems of the next generation. Ecosystem research and public outreach programs were therefore important components of NATO's ASW research program. At NRL, we expect to see continued ocean color research related to an optical/biological component of the NCOM or, in the future, HYCOM model. Figure 1G.28 is one of many examples showing a close correspondence between upwelling, as observed from SEAWIFS, and NCOM forecasts of surface currents.

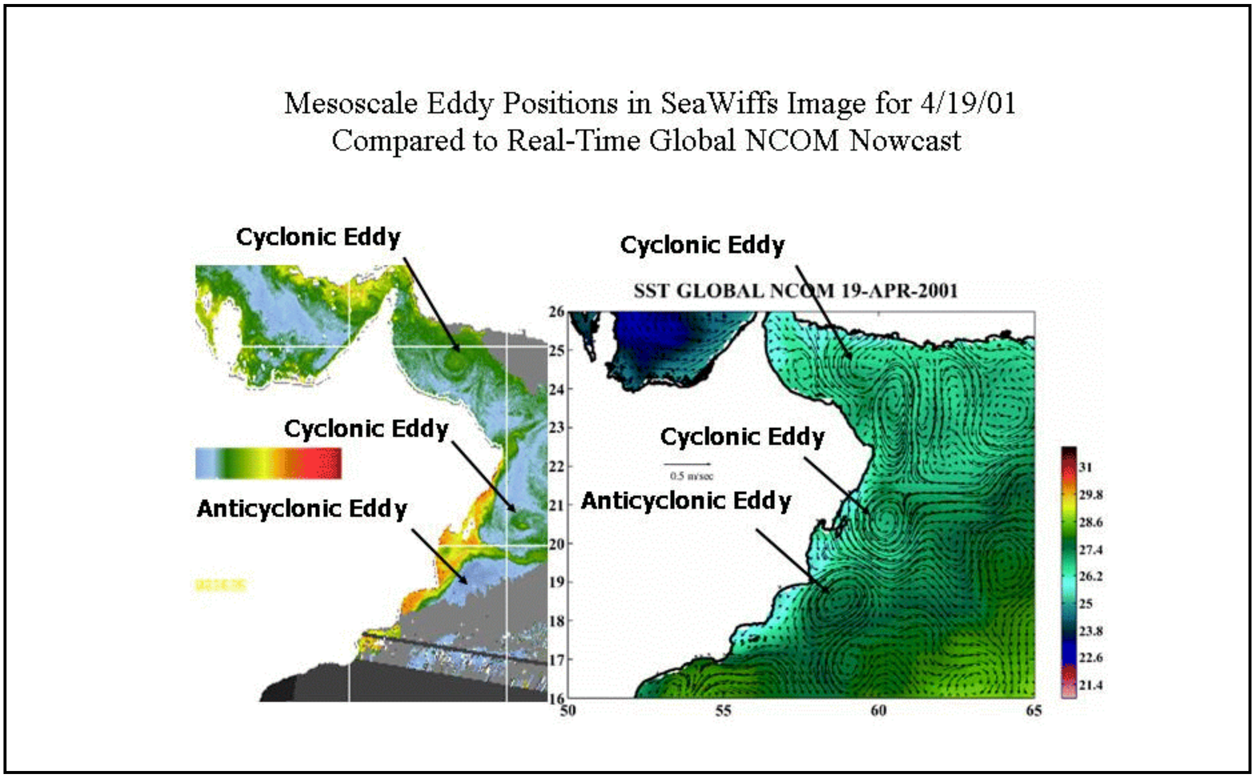

Figure 1G.28. An example showing a close correspondence between upwelling, as observed from SEAWIFS, and NCOM forecasts of surface currents.

We recognize that our view of the deep ocean is limited to what can be learned primarily from space and from a very limited number of deep ocean experiments that have spanned the past several decades. There is a strong need for continued basin scale experiments, such as that planned by MMS in the GOM. We hope to add to the MMS database of observations by installing ADCPs on the continental shelf and shelf break Figure 1G.29. Our goal will be to relate the deep basin mesoscale energy observed from the MMS arrays, to the energy observed at and on the continental shelf. We look forward to working with MMS in this regard.

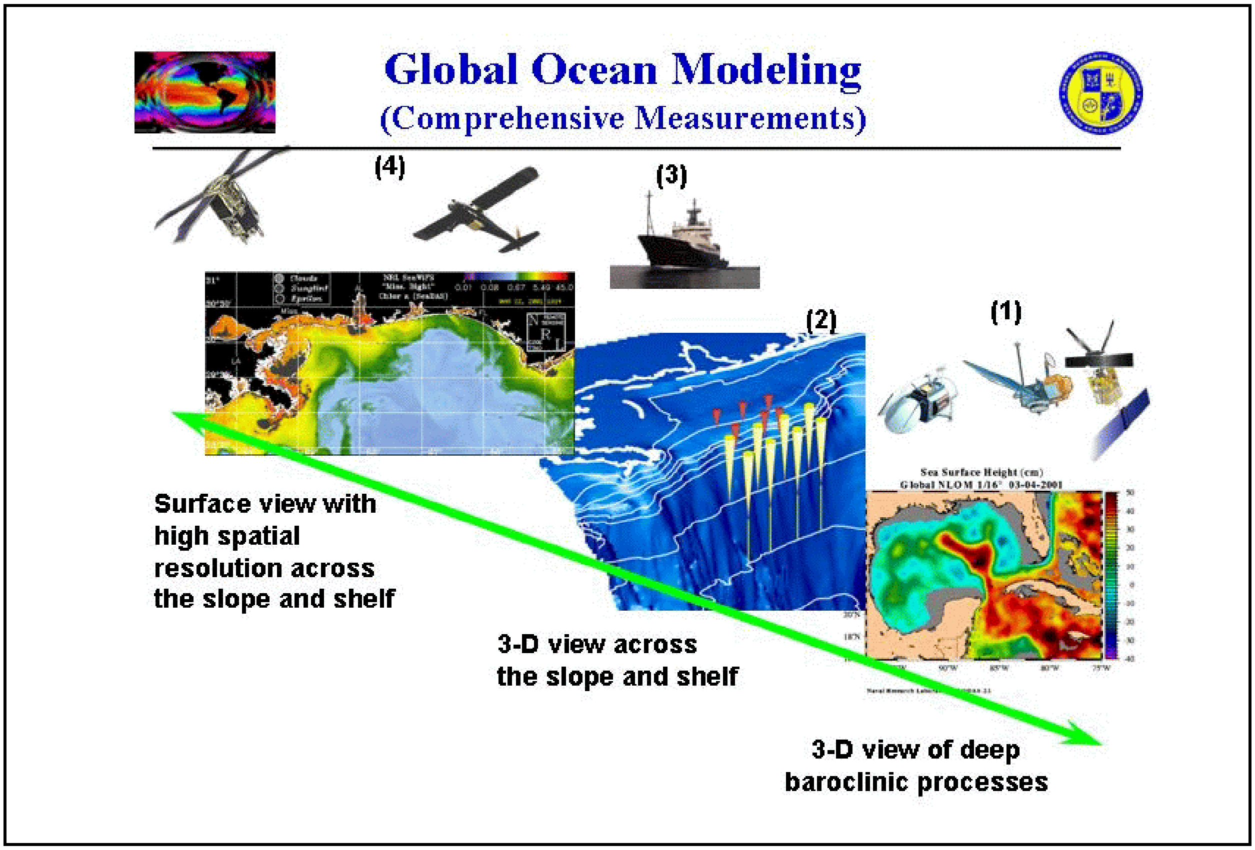

Figure 1G.29. We hope to add to the MMS database of observations by installing ADCPs on the continental shelf and shelf break.

PUBLIC POLICY

Finally, public policy is an important element in the advancement of ocean forecasting. It will be our goal to make products available on our website, as we are currently doing with altimetry, ocean currents and sea surface temperature. We are cooperating with several national and international laboratories and universities to further improve ocean models, and we believe that sharing of code through users groups is a proven roadmap to creating the best possible scientific products.

SUMMARY

Together with the operational Navy, we have helped to establish a routine forecasting infrastructure involving multiple national and international organizations. This infrastructure is based on a world-class computing capability supported through the DoD High Performance Computing Modernization Program. The ocean modeling components of this infrastructure have proven skill within the Intra-Americas Seas, and worldwide, as verified by mean flow through straits, kinetic energy and statistical forecast metrics. A policy of sharing results through our website and of sharing code through users groups will be, we believe, a roadmap to continued growth and improvement.

SESSION 1H

EXPLOSIVE REMOVAL OF OFFSHORE STRUCTURES (EROS) I

Chair: Mr. Jeff Childs, Minerals Management Service
Co-Chair: Ms. Judy Wilson, Minerals Management Service

Date: January 10, 2002

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INDUSTRY METHODS FOR DECOMMISSIONING OFFSHORE STRUCTURES

Dr. Robert C. Byrd
Twachtman Snyder & Byrd, Inc.

Click here to see Dr. Byrd’s slide show.

Dr. Robert C. Byrd is a principle in the firm of Twachtman Snyder & Byrd, Inc., of Houston, Texas. He has over 25 years of experience in the design, fabrication, and installation of offshore facilities. Dr. Byrd also has considerable experience with planning and executing offshore platform decommissioning projects. He has held positions with an international marine facilities contractor, consulting engineering firms, as a research engineer at the Norwegian Hydrodynamics Laboratory at Trondheim, and he is a former U.S. Coast Guard officer. He is a graduate of the U.S. Coast Guard Academy at New London, Connecticut, in marine engineering. Dr. Byrd received his Ph.D. in Engineering from the University of California, Berkeley, where he was a Hans Albert Einstein Fellow in hydraulic and ocean engineering . He is a licensed professional engineer and a certified project management professional.

FORECASTING EXPLOSIVE REMOVALS OF OFFSHORE STRUCTURES

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ABSTRACT

A statistical description of the explosive removal of offshore structures in the federally regulated Outer Continental Shelf of the Gulf of Mexico is presented based on data collected by the U.S. Minerals Management Service. The influence of factors such as water depth, planning area, configuration type, and structure age upon the application of explosive removal methods are explored. The number of structures expected to be removed from the Gulf of Mexico using explosive methods is forecast over a 5-, 10-, 15-, and 20-year time horizon according to structure configuration type, water depth, and planning area categorization.

SYNOPSIS

There are currently around 4,000 structures in the federally regulated Outer Continental Shelf (OCS) of the Gulf of Mexico (GOM) associated with oil and gas production. The structures vary according to function and configuration type and since 1947, 5,981 structures have been installed in the GOM and 2,004 structures have been removed (see Table 1H.1).

Table 1H.1. Total number of structures* installed and removed by water depth and planning area in the GOM (1947-2001).

Water Depth Range (m)	Installed			Removed		
	WGOM	CGOM	GOM	WGOM	CGOM	GOM
0-60	631	4,739	5,370	242	1,674	1,916
61-200	123	447	570	22	63	85
201-800	14	19	33	2	1	3
800+	2	6	8	0	0	0
Total	770	5,211	5,981	266	1,738	2,004

* Structures are defined as all caissons, well protector jackets, fixed, and floating configurations located within the federal offshore waters of the GOM

The majority of the structures removed (96%) have been in shallow water (0-60m) with caissons the most frequently removed configuration type (46%), followed by fixed platforms (42%) and well protector jackets (12%). Caissons and well protector jackets are installed to protect wells from damage, while fixed platforms refer to the familiar conventionally piled platforms with or without wells. Fixed platforms with wells hold the drilling and processing equipment necessary for hydrocarbon production, while platforms without wells are used to house personnel and to support gas compressor stations, production equipment, oil storage tanks, etc. Floating production systems are also employed in the GOM but their numbers are small relative to the traditional fixed structures, and only two floating structures have thus far been removed from gulf waters.

Data on the manner in which structures are removed has only been collected since 1986. From 1986-2001, 1,626 structures in the GOM have been decommissioned. This figure represents slightly more than 80% of the total number of structure removals. Most of the structures removed have been throughout the Central GOM (CGOM) planning area (84%) with the remaining structures distributed throughout the Western GOM (WGOM). Only a very small number of structures have been installed in the Eastern GOM (EGOM), and so far, no structures in this planning area have been removed. Explosive techniques of removal were employed in 954 of the 1,626 structures decommissioned to date—representing in aggregate a 59% explosive removal rate. Caissons were equally likely to be removed with either explosive or nonexplosive methods, while well protector jackets employed explosives 62% of the time and fixed structures were removed with explosives 66% of the time. The application of explosive methods appears to increase with the complexity of the configuration type; a dependence is also observed with the water depth and age of the structure upon removal.

The purpose of this research is to provide a comprehensive statistical description of structures in the GOM with a particular emphasis on the manner of their removal and the influence of factors such as water depth, planning area, configuration type, and structure age in the context of structure removal practices. All information on offshore structures in federal waters was obtained from the U.S. Minerals Management Service (MMS) from multiple databases. A forecast of structure removals in the GOM has been developed from historic trends and a life expectancy model developed for a medium-term forecast (see Tables 1H.2 and 1H.3). A short-term five- year forecast is compared using two models and historic averages in Table 1H.4.

Table 1H.2. Intermediate-term forecast of the number of structures removed by explosive technique (Model I: k = 1,3).

Water Depth Range (m)	Forecast Horizon	Caissons		Well Protector		Fixed		Total	
		W	C	W	C	W	C	W	C
0-60	2002-2006	14	97	4	64	52	155	70	316
	2007-2011	18	133	4	57	35	255	57	445
	2012-2016	8	104	5	41	62	222	75	367
	2017-2021	0	98	7	30	5	215	22	343
	2022-2026	0	115	9	29	0	203	9	347
Subtotal		40	547	29	221	165	1,052	234	1,818
61-200	2002-2006	0	0	5	0	19	62	24	62
	2007-2011	1	0	2	0	32	65	35	65
	2012-2016	1	1	0	0	15	83	16	84
	2017-2021	0	1	0	0	3	53	3	54
	2022-2026	0	2	0	17	0	17	0	36
Subtotal		2	4	7	17	69	278	78	301

Table 1H.3. Intermediate-term forecast of the number of structures removed by explosive technique (Model II: k = 0,1,2,3).

Water Depth Range (m)	Forecast Horizon	Caissons		Well Protector		Fixed		Total	
		W	C	W	C	W	C	W	C
0-60	2002-2006	30	168	10	91	89	250	129	509
	2007-2011	10	221	11	83	62	317	83	621
	2012-2016	0	132	8	47	14	280	22	459
	2017-2021	0	26	0	0	0	205	0	231
Subtotal		40	547	29	221	165	1,052	234	1,820
61-200	2002-2006	1	0	4	0	48	104	53	104
	2007-2011	1	0	3	9	26	97	30	106
	2012-2016	0	2	0	8	0	77	0	87
	2017-2021	0	2	0	0	0	0	0	2
Subtotal		2	4	7	17	74	278	83	299

Table 1H.4. Short-term infrastructure forecast (2002-2006) of the number of structures removed by explosives in the GOM.

Model	Water Depth Range (m)	Caissons		Well Protector		Fixed		Total	
		W	C	W	C	W	C	W	C
Historic	0-60	28	146	30	63	50	134	108	343
Average	61-200	0	0	4	5	7	18	11	23
I	0-60	14	97	4	64	52	155	70	316
	61-200	0	0	5	0	19	62	24	62
II	0-60	30	168	10	91	89	250	129	509
	61-200	1	0	4	0	48	104	53	104

Mark Kaiser is an associate professor-research at the Center for Energy Studies, Louisiana State University. His primary research interests are related to policy issues, modeling, and econometric studies in the energy industry. Mark conducts research and policy analysis on energy consumption and conservation issues, environmental effects of energy production, tariff analysis, and broad policy issues in electricity, natural gas, and oil markets. Since joining the Center, Mark's research has focused primarily on establishing the economic and environmental impact of a proposed Public Benefit Fund for the state of Louisiana and studies related to the infrastructure requirements in the GOM.

Dr. Kaiser is widely published with work appearing across a broad spectrum of energy, engineering, mathematics and scientific journals. His research has been published in journals such as *Applied Mathematics Letters*, *Applied Mathematical Modeling*, *Computers and Operations Research*, *Electric Power Systems Research*, *Energy*, *Energy Economics*, *Journal of Optimization Theory and Applications*, *Mathematical and Computer Modeling*, and *Simulation*. Mark has consulted and served as technical advisor to corporations and government agencies, and is a member of the United States Association for Energy Economics (USAEE), International Association for Energy Economics (IAEE), and The Institute of Management Science and Operations Research (INFORMS).

Dr. Kaiser received his Ph.D. in Industrial Engineering and Operations Research from Purdue University, and prior to joining the LSU faculty in 2001, Mark held appointments at Auburn University, The American University of Armenia, and Wichita State University.

TECHNICAL METHODS OF REMOVING STRUCTURES WITH EXPLOSIVES

Mr. Gary DeMarsh
TEI Construction Services
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This paper gives an overview of the technical aspects of explosives relative to platform removals. Input relative to these specific questions was obtained from all the explosive service companies operating in the Gulf of Mexico (GOM); they include DEMEX, Explosive Services International, and Jet Research Corporation.

BRIEF HISTORY

The first offshore platforms were installed in the GOM in 1947. Explosive usage for severing wells and piles began in the 1950s. It was not until the 1970s that platform removals became a business.

In 1986, there was a self-imposed moratorium on using explosives for platform removals. This moratorium was the result of large stranding of turtles and dolphins on the beach in Texas that corresponded with explosive platform removals. Although the strandings could not be directly attributed to the explosives, oil companies were from that time required to obtain a permit prior to using explosives for platform removals.

Explosive removal of offshore structures (EROS) is governed by several Federal statutes, which include:

- 1972 Marine Mammals Protection Act (MMPA) protects all marine mammal species
- 1973 Endangered Species Act (ESA) prohibits “taking” of endangered species

In order for EROS to continue after the 1986 moratorium, it became necessary to obtain an ESA Section 7 Consultation. The Section 7 Consultation examined the explosive removal process and determined that operations would have a minimal impact on affected species. Section 7 Consultation initiated specific criteria for operators and provided for monitoring of the removal site and the explosive removal process by National Marine Fisheries Service (NMFS) observers. These criteria apply to all EROS which utilize fifty (50) pounds or less of explosive material per charge, i.e. “generic” removals. All “generic” removals are required to follow the Section 7 criteria:

- 48 hour pre-blast survey by NMFS observers
- Aerial and/or vessel surveys: pre- and post-blast
- Daylight blasting
- 50 pound limit
- High velocity explosives
- Staggering of detonations

Additionally, there are basic regulatory requirements, which must be met, including:

- Minerals Management Service (MMS) or state permit
- U.S. Coast Guard permit for transportation of explosive materials
- Report summarizing explosive usage

Historically, explosive removals of offshore structures outnumber non-explosive removals. Non - explosive removals include abrasive cutting, mechanical cutting, or diver burning. According to MMS records from 1986 through 1999, non-explosive removals outnumbered explosive removals only in 1996.

OFFSHORE TARGETS & LIMITATIONS

Offshore targets are divided into two broad categories: (1) single layer targets and (2) multi-layer targets. Single layer targets include piles, which go to the surface or can be sub-sea, single string conductors and caissons. Multi-layer targets include conductors with multiple strings whose annuli can be filled with grout, drilling fluid, water, air or any combination of these materials. Multi-layer targets also include piles with inserts.

Explosive contractors are limited by both governmental and operational restrictions. Governmental restrictions include explosive weight, explosive type, severance depth (15 feet below mud line), and permitting. Non-generic permits can take as much as six months to be approved and may require additional mitigation measures. Resident turtles can also cause restrictions to be approved.

Operational considerations are pipelines, sub-sea equipment and vessels, divers, internal obstructions, out of round targets, lack of planning, and the possible re-use of the structure.

FINANCIAL ANALYSIS

In general, explosives are the least expensive method for platform removals. The cost of severing single and multi-layer targets is small in comparison to the overall cost of removals. As the water depth increases, so does the size of the equipment required for the removal. This is where the cost start to escalate rapidly as this marine equipment can cost ten to hundreds of thousands of dollars per day. Depending on the method and water depth, alternative methods can be from 19% - 81% higher than explosive cost. A good rule of thumb for a small removal project is that explosive cost account for about 5% of the total cost. For large removal projects, explosive costs will be less than 1% of the total costs.

Question #1

Describe the different kinds of explosives technologies available or under development to remove offshore structures.

Bulk charge: One single mass of explosive material detonated at one point. The energy release from the detonation of this type of charge is not directed. The technician is relying on the breaking strength; velocity and pressure release to overpower or rip and tear the target. Bulk charges are cylindrical in design. These charges vary in length and diameter to accommodate varying internal diameters of tubulars. These charge diameters range in size from 4" to 12". Smaller bulk charges can be arranged to create a larger diameter. This technique allows the technician to manipulate the cast explosive materials. The smaller charges can be placed in a ring to maximize the efficiency of the explosive material.

Double detonation (DD) Bulk Charges: The use of DD bulk charges is more effective and allows for slightly more finesse. Double detonation of the bulk charge is achieved by utilizing two detonation points to initiate the charge. This allows both ends of the charge to detonate simultaneously. The propagation of detonation begins at both ends, and converging shock waves collide at the center of the charge. This creates a radial energy spike, resulting in a portion of the energy concentrating radially.

Bulk Configured Charge: Once detonated, explosive materials are more effective for breaking tubulars when placed near the target. The octagon configuration allows the materials to be in close proximity to the target upon detonation. Point of detonation is important to the direction of propagation of the detonating material. The detonation points are strategically placed on the inner periphery of the explosive. Upon detonation of the explosive material, more energy is directed toward the target because the material is detonating from the inside out.

Shock Wave Enhancement Device (SWEDe): The SWEDe combines the positive features of all bulk charge designs: the explosive is closer to the target, there is extreme confinement of explosive, and there is multi-point detonation. The SWEDe is a focusing charge, not a shaped charge. Over the years various design changes have been made to the charge design to increase the efficiency of the device. The SWEDe design increases the range of a 50-pound charge up to 54" diameter pile.

The SWEDe is a rugged design enabling it to withstand the rigors of the offshore working environment. A plastic bonded explosive (PBX) is placed on the outer periphery of an angled steel ring. The apex of the angle points inward to the center of the device. The center of the rings is solid steel. The steel ring is housed between two steel plates. The PBX material is detonated at multi-points along the apex of the ring angle. This is the inner-most peripheral point. This process allows the explosive material to detonate outward on a radial plane.

Shaped Charges: Shaped charges for severing single layer and multi-layer targets for platform removals are either internally or externally placed. Primarily shaped charges are usually designed to sever single layer targets. The mechanics and physics behind shaped charges is a very complex phenomenon. Commercial and military explosive manufacturers spend a great deal of time and expense to improve the quality of shaped charge devices. Shaped charges incorporate a metal linear that when acted upon by the explosive, extrudes and forms a jet. This jet, traveling at high velocity, actually cuts the metal target.

- Internal Shaped Charge: the use of these devices incorporates reduced explosive weight, manufacturing, and design criteria. The target specifications must be known in order to properly design the charge. There must be a great deal of attention paid to the design of the charge as not to be affected by internal obstructions. If water intrudes into the “standoff” of the shaped charge, the device will become useless.

- External Shaped Charge: the most effective shaped charge has been one designed to sever a target from the outside. Unfortunately, a special permit is required to detonate this type of device. Operationally, outside jetting is required and they are remotely or diver set.

New Technology: The future of the explosive industry for severing single and multi-layer targets will come in the form of improved charges or new explosives. Examples of this new technology include improved shaped charges, flexible linear shaped charges, shock wave focusing charges and new explosives.

There is an ongoing MMS contract for an engineered charge that was awarded to Explosive Services International, SNC Technologies, and the Canadian Defense Department. All three companies will be working together to develop a charge for severing single wall tubulars. The work should be complete by late 2002. It is possible that additional work could involve pressure measurements with transducers during the field-testing portion of the project.

Question #2

Describe the steps typically used in planning, executing, and completing an explosive removal of an offshore structure.

Planning & Permitting: The planning process begins with consideration of safety issues regarding the proposed removal. Over the years it has been determined that explosives are the safest method for removing platforms. Other safety considerations include verification of pipelines in the area or sub-sea equipment that could be impacted by the detonation.

After the decision is made to utilize explosives, we review an “Offshore Removal Checklist” with the customer. We try to obtain as much information as possible regarding the environmental details, jacket details, main pile and/or skirt pile details, conductor details and operational details. The review process includes all relevant permits. Generally, most permits are “generic” and as such follow specific requirements for using explosives. Any scope of work that falls outside the “generic” range requires special permitting by the MMS which generates an independent Section 7 Consultation.

Explosive Removal Sequence: Prior to the deck removal, accessibility of the conductors to the pre-determined depth is verified and the conductors are “sniffed” to assure that no residual hydrocarbons or natural gas is present. The deck is lifted off of the jacket, placed on a materials barge, and welded into place to prevent toppling. The piles and wells are gauged for clearance to severance depth. Typically, there is mud inside the piling, which must be removed by jetting. After removal of the deck and the jetting of the pilings, the explosive technician will then insert the explosive charges into the conductors and/or piles and lower them to the pre-determined depth.

NMFS observers conduct their pre-blast helicopter survey while the charges are being loaded. The explosive technician brings the shot line from the vessel to the platform. At this time all divers must be out of the water within a two thousand (2,000) yard radius. Radio silence is established and all personnel, with the exception of the explosive technician, evacuate the platform. The explosive technician performs the tie-in of the Blasting Cap/Delay circuitry to the proper detonating cord to sever each piling with a 900-millisecond (0.900 second) delay between each successive detonation. The explosive technician returns to the vessel, proper warning signals are executed and a visual search for vessels (including unauthorized crafts) is performed. After receiving approval from the NMFS observer, the explosive technician executes the initiation, and detonation will begin. The explosive technician observes the effects of the blasts, shock waves, and bubble energy.

Question #3

Does industry need a flexible plan allowing for increased charge size (relative to the existing 50# generic removals)? If so, please support your position.

YES!

- Performance using explosives for removal of structures is very good. Overall, 91.3% average success ration on first shot for 1997 through 2002. 1,679 successful shots out of 1,839 were made. Problem targets which experience a drop in success ration are 30" or greater conductors with multiple strings, sub-sea wells, single layer targets that are 36" or greater in diameter. Additionally, during the planning stage, some plans include shooting the target at least twice.

- Regulatory limitations do not allow effective shooting of larger targets. There are also limits on the ability to shoot mid-water and open water shots. In addition, options are limited upon arrival on the job site. Frequently, actual targets in the field are different from the drawings that were reviewed during the planning process. There is a need for some flexibility with charge types or sizes if the actual target varies from permitted target.

Question #4

What are the demolition industry’s needs of MMS to efficiently and safely accomplish removals within the scope of existing laws. Of NMFS?

Understanding of the business of platform removals: SAFETY should be a major consideration. Once the charges are loaded, they should not be removed. The time interval between loading and detonating charges is also important. It is important to remember that “time is money.” All costs associated with compliance with environmental regulations are rolled into explosive removals. Severance failure occurs when cost escalates rapidly.

Existing regulations are restrictive and can be dangerous: In 1986-87 during the moratorium on explosive removals, regulations were quickly put in place without sound technical data. *Human* *deaths* (divers performing inside burn offs) have resulted from adherence to these regulations. Decisions are based solely upon meeting the requirements of the laws.

A positive effect of the regulations is they have raised awareness of the marine mammals and endangered species present in the GOM.

Regulation and permit flexibility: Ease the permit process to allow for operational changes in the field. If a non-explosive removal operation runs into trouble and the structure was not originally permitted for explosives, it is not possible to make the transition to explosives easily.

Charge sizes should be a function of the target not of the regulations. Mitigations, whether Section 7 mitigations or engineering mitigations, should be a function of true and realistic safe ranges. Furthermore, management of charge size, type and design in conjunction with corresponding mitigation should be identified through an all-encompassing matrix.

Operational flexibility: Exact adherence to Section 7 mitigation requirements can lead to costly delays. At times there are delays due to weather (helicopter unable to fly due to bad weather), helicopter delays can also be attributed to fuel problems and/or daylight problems. For example, on structures that are farther out, the helicopter may have to leave while there are still several hours of daylight remaining, in order to return to his shore base before dark. Even when good weather prevails available offshore, a helicopter can be fogged in on the beach.

With respect to NMFS, we would like to see relief on the 48-hour pre-blast surveys; the observers should have thorough training in identifying marine mammals and turtles as well as safety training. If possible, we'd also like to have the on-site observers have decision making ability with regard to weather delays, substitution of vessel surveys for helicopter surveys during weather delays, or when explosives are already loaded.

Question #5

What are the demolition industry's recommendations to minimize "taking" of protected species when removing structures?

Give the industry incentives for using explosive charges of lesser weights. Platform removals are economically driven. Instigate regulations that would decrease pre- and post-blast surveys or allow shooting at night when lower weight charges are used. Additionally, eliminate requirements for observers or helicopter surveys if it can be proven that lower weight charges or engineered mitigation of explosive charges can be shown significantly to reduce the impact area. Increased regulations stifle development of improved devices.

Limit exposure time that protected species are exposed to detonations. Limit the time on job site and expedite severance by decreasing down time and having a quick turnaround when re-shoots are required. Limit the number of detonations by allowing for more flexibility on non-generic targets.

With respect to the regulations, less is more. Presently, we work within the confines of the regulations. Performance and product development is limited by unrealistic parameters. We do not want to see unproven technology, such as acoustics and fish finders, put in place.

What the explosive industry needs is to keep working within the current parameters of Subpart M of the Marine Mammals Protection Act. Negate the negative connotations regarding explosives within the industry. It is necessary to establish the true safe range based on underground detonation of explosives charges and then develop explosive devices and mitigation devices relative to these parameters. Regulations need to be technically prudent as well as flexible to allow developing technology to be applied.

In conclusion, explosives are efficient and cost effective. Environmental considerations have increased awareness towards endangered species and marine mammals. Relief of regulations will only make explosives more cost effective and allow for future environmentally sensitive explosive devices to be developed. Limitations result from regulations, lack of planning, experience and imagination.

Gary DeMarsh has been involved in the explosive industry for over 23 years. He earned a bachelor's degree in business from the University of Louisiana at Lafayette and has worked towards his masters degree at Loyola University in New Orleans. His experience with explosives encompasses both offshore and industrial work. His involvement in EROS includes being an explosive technician for over 500 platform removals. Since 1995 he has been the Director and General Manager of the DEMEX. Division of TEI Construction Services. Included in his duties are directing DEMEX's R&D programs and client specific research programs. Mr. DeMarsh has also authored several papers on explosives and most recently presented a paper entitled "The Use of Explosives in Decommissioning and Salvage" at the Offshore Technology Conference. Mr. DeMarsh is the Chairman of Working Group D for Underwater Cutting with the American Welding Society, a member of the Society of Explosive Engineers, and holds blasters licenses in various states.

POTENTIAL IMPACTS OF EROS ON PROTECTED SPECIES

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INTRODUCTION

Underwater explosions, such as those occurring during Explosive Removal of Offshore Structures (EROS), may generate shock waves with large peak pressures and very fast rise times. Those shock waves and attendant pressure disturbances propagate outward from the source. Marine animals exposed to underwater explosions may be impacted in a number of different ways, ranging from mortality to a momentary behavioral response. This document outlines the relevant parameters necessary to quantify the sound levels received by animals for impulsive sounds and the potential effects of these sounds on marine mammals and sea turtles. A discussion of the recent *Winston S. Churchill* (DDG 81) Shock Trial environmental impact analysis is also included.

IMPULSIVE SOUND PARAMETERS

A *transient* sound has a well-defined starting and ending time. Sounds produced by percussive events (e.g., striking a drum), or only a few cycles of an harmonic sound are examples of transients. The term *impulsive sound* or *impulse* is normally used to describe a transient sound with a relatively short duration, large amplitude, and broad frequency bandwidth. In practice, the sound received by an animal may include not only the simple direct impulse but, under certain conditions, reflected or refracted versions of the impulse as well. Examples of impulsive sounds include those produced by explosions and gunfire.

Instantaneous and Peak Pressure

The *acoustic pressure* is defined as the incremental variation in the static (equilibrium) pressure within a medium as a sound wave travels through it. The unit of pressure is the Pa. In older literature, acoustic pressures were often presented in units of microbar (μbar); 1 μbar = 1 dyne/cm^2 = 0.1 Pa. Acoustic pressures are also sometimes specified in units of pounds per square inch (psi); 1 psi » 6890 Pa.

The *instantaneous pressure* $p(t)$ indicates the amount, at any instant of time, that the pressure exceeds the equilibrium value. The instantaneous pressure varies over time and the plot of that pressure over time is called the pressure-time waveform or simply waveform. The *peak pressure* indicates the maximum amount that the instantaneous pressure exceeds the equilibrium value. The *peak-to-peak pressure* (p-p) indicates the difference between the maximum and minimum values of the instantaneous pressure. Peak and p-p pressures are sometimes specified using subscripts attached to the variable name, such as P_{peak} or $P_{\text{p-p}}$, or subscripts on the units themselves: for example, Pa (p-p). For pure tones, $P_{\text{p-p}} = 2\,P_{\text{peak}}$; however, for impulsive sounds (with more complex instantaneous amplitudes), there may be no simple relationship between the peak pressure and the p-p pressure.

Describing the duration of an impulse may be difficult because often the amplitude of an impulse gradually decays to the point where it becomes indistinguishable from the background noise. For this reason, several different fixed criteria have been used to define the "effective duration" of an impulse, meaning a temporal index that is most highly correlated with observed tissue trauma (see Hamernik and Hsueh 1991). Two of the more common ways to define the effective duration are the so-called "A-duration" and "B-duration." The A-duration (Figure 1H.1(a))is defined as the time required for the initial (or principal) wave to reach the peak pressure and then return to equilibrium. The B-duration (Figure 1H.1(b)) is defined as the total time that the envelope of the pressure fluctuations (above and below equilibrium) is above 20 dB (10%) of the peak pressure level.

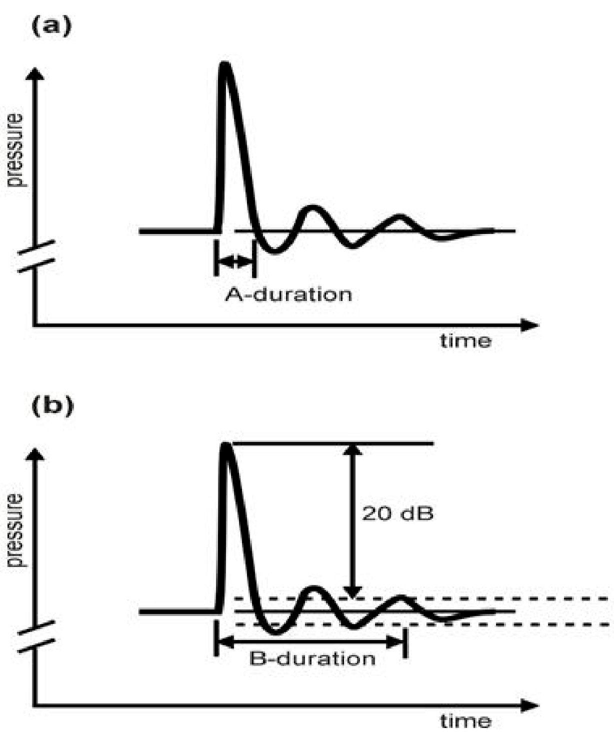

Figure 1H.1. The A-duration (a) is defined as the time required for the initial (or principal) wave to reach the peak pressure and then return to equilibrium. The B-duration (b) is defined as the total time that the envelope of the pressure fluctuations (above and below equilibrium) is above 20 dB (10%) of the peak pressure level.

Another widely used technique to determine the effective duration of an impulse is to calculate the cumulative integral of $p^2(t)$ as a function of time [this is proportional to the energy flux; see Equasions (3)–(5)]. The effective duration is then defined as the time interval between the 5% and

95% values. This technique may be more applicable to complex waveforms encountered at a distance from the source. Figure 1H.2 illustrates this procedure.

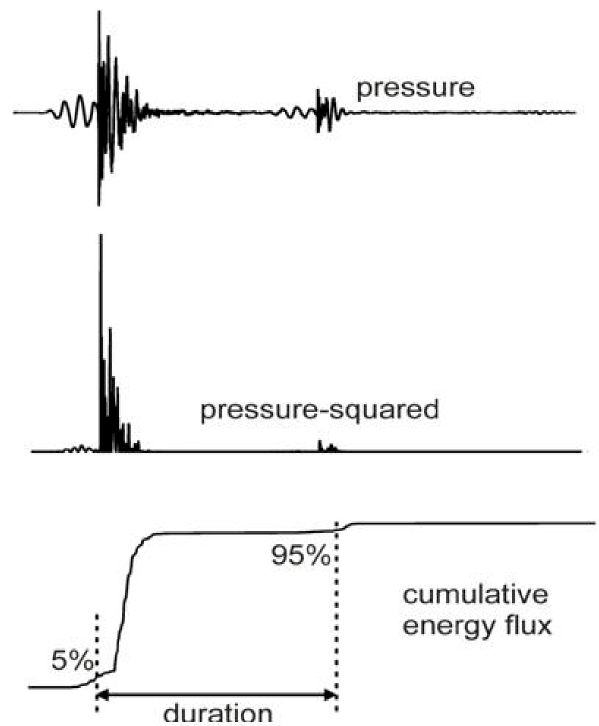

Figure 1H.2. To determine the effective duration of an impulse, calculate the cumulative integral of $p^2(t)$ as a function of time. The effective duration is then defined as the time interval between the 5% and 95% values.

RMS Pressure

A widely used measure of amplitude is the *mean-squared* pressure $\overline{P^2}$

$$\overline{P^2} = \frac{1}{T}\int_0^T p^2(t)\,dt \quad , \tag{1}$$

where T is the time over which $p(t)$ is integrated (averaged). For sinusoids it is common to integrate over an integer number of cycles; for other sounds it is common to integrate over long time periods, that is, to take the limit of Equation (1) as $T \rightarrow \infty$. The mean-squared pressure gives a measure of the amount of power contained in the sound. Because $\overline{P^2}$ does not have the same physical units as

$p(t)$, it is common to use the root-mean-squared (rms) pressure instead. The rms pressure $\overline{P}$ is defined as the square root of the mean-squared pressure:

$$\overline{P} = \sqrt{\frac{1}{T}\int_0^T p^2(t)\,dt} \qquad (2)$$

For pure tones (with T equal to an integer number of periods), Equation(2) simplifies to $\overline{P} = P_{\text{peak}} / \sqrt{2}$, where P_{peak} is the peak pressure. For more complex sounds, there is no fixed relationship between P_{peak} and $\overline{P}$. The rms level may not be a good indicator of the amplitude of an impulse; the peak pressure or p-p pressure is often used instead. The main reason for this is that the rms pressure is a measure of the “power” contained within the sound—because the duration of an impulse is short, it may be possible for an impulse to possess very little actual power, yet still have a very large amplitude, thus use of the rms amplitude may be misleading.

Energy Flux

The *acoustic energy flux* (also called the *energy flux density*) E_f, defined as the energy flow per unit area, is

$$E_f = \int_0^T I(t)\,dt, \qquad (3)$$

where $I(t)$ is the magnitude of the instantaneous acoustic intensity vector and T is the duration of the sound (for continuous sounds the limit should be taken as $T \to \infty$). In practice, Equation (3) is rarely used and plane waves are assumed. This is primarily because particle velocity measurements are more difficult than pressure measurements and the plane wave assumption is valid in many circumstances. For plane waves, $I(t) = p^2(t)/\rho c$, therefore Equation (3) becomes

$$E_f = \int_0^T \frac{p^2(t)}{\rho c}\,dt. \qquad (4)$$

The units of energy flux are J/m^2. The characteristic impedance ρc is often removed from the denominator of Equation (4), yielding

$$E_f = \int_0^T p^2(t)\,dt, \qquad (5)$$

which has units of Pa^2·s. The result of Equation (5) is sometimes referred to as the “sound exposure.” Both Eqs. (4) and (5) yield “energy flux-like” quantities. Equation (4) yields a quantity with actual units of energy flux; however, Equation (4) is only strictly valid for plane waves. The plane wave assumption may not be valid under some conditions, especially underwater at low frequencies close to a sound source or in an enclosed space. If Equation (4) is used, the actual value of *rc* should be stated, so that the value of Equation (5) may be derived as well.

Acoustic Impulse

The *acoustic impulse* I_a is defined as

$$I_a = \int_0^T p(t)\, dt \quad , \tag{6}$$

where *T* is the effective duration of the waveform. Often the A-duration (see Figure 1H.1) has been used. The form of Equation (6) is often used in structural mechanics where the effects of impulsive loads must be taken into account (Hamernik and Hsueh 1991).

Energy Flux Spectral Density

The *energy flux spectral density* (EFSD) is the energy per unit area and frequency. The EFSD is the most appropriate way to describe the frequency content of an impulsive sound. The EFSD at a frequency *f*, $E_f(f)$, is

$$E_f(f) = \frac{\left|F\{p(t)\}\right|^2}{\rho c} \quad , \tag{7}$$

where $F\{p(t)\}$ is the Fourier Transform of $p(t)$ (Fricke *et al.* 1985; Johnston *et al.* 1988). The units of $E_f(f)$ are $J \cdot m^{-2} \cdot Hz^{-1}$. If *r*c is removed from Equation (7), the result is

$$E_f(f) = \left|F\{p(t)\}\right|^2 \quad , \tag{8}$$

with units of $Pa^2 \cdot s/Hz$. The cumulative energy flux E'_f between frequencies f_1 and f_2 is obtained by integrating $E_f(f)$ between f_1 and f_2

$$E'_f = \int_{f_1}^{f_2} E_f(f)\, df \quad . \tag{9}$$

The total energy flux may be found by setting $f_1 = 0$ and $f_2 = \infty$ in Equation (9).

POTENTIAL EFFECTS OF IMPULSIVE SOUNDS

Impact Mechanisms

Marine animals exposed to underwater shock waves or impulsive waveforms with large peak pressures and very fast rise times may be impacted in a number of different ways, ranging from mortality to a momentary behavioral response. For discussion purposes, potential impacts of impulsive sound exposure are ordered on an approximate scale of decreasing severity that would roughly correspond to increasing distance from the source. For example, animals very near the source may suffer massive injuries and immediate mortality; those farther away may suffer temporary hearing loss (TTS) with no injury; those very far away may only experience a mild behavioral reaction, such as orientation or startle responses with no resulting loss of sensory function. It is important to point out that the direct tissue and behavioral impacts described in the following sections are not mutually exclusive (animals suffering injury would also be expected to suffer behavioral disruption) and there may be overlap between impact mechanisms.

Physical Injury (Non-Auditory)

Very close to an underwater impulsive source there may exist a region of lethal peak pressure and/or bulk cavitation. Although the effects of bulk cavitation on marine mammals and sea turtles are unknown, it is expected that within this region extensive physical trauma and mortality would occur immediately. Physical effects of exposure to shock waves with very high peak pressures may include external tissue damage, skeletal damage, or extensive trauma to the lungs and other tissues.

Beyond the bulk cavitation zone and range of immediately lethal peak pressure, animals exposed to an impulsive sound may suffer direct physical injuries due to the presence of gas-filled structures within the body. Gases (or gas-filled structures) are much more compressible than the surrounding water, thus at the gas-water interface there may be large pressure gradients and large particle displacements. Displacements may be large enough to cause tissues to tear or rupture. The primary sites of physical injury in marine mammals and sea turtles are expected to be the lungs, intestines, and auditory system.

Potential lung effects include pulmonary contusions (bruises), lesions (tears), and pneumo-haemothorax (hole in the lung wall). These conditions may contribute to increased difficulty in respiration, a reduced ability to absorb oxygen, and a retention of carbon dioxide. Depending upon the severity of the damage, suffocation is possible. Rapid compression of the lung can produce an overall increase in venous pressure capable of causing brain hemorrhage. Lesions to the lung may also introduce air bubbles to the circulation, which may lead to emboli in various regions of the body.

Potential injuries to the intestine include perforation and hemorrhaging of the intestinal lining. Such injuries can progress to bowel gangrene and peritonitis. Though death from intestinal trauma is not likely to be immediate, untreated damage may ultimately lead to death through progressive degeneration and infection.

Physical Injury (Auditory)

Because of the air contained in the middle ear cavity, as well as various membranous tissues of the auditory system (e.g., tympanic membrane, oval window and receptor cells), the ear may also be injured by exposure to underwater shock waves or impulsive waveforms. Physical injury to the auditory system may result in permanent total hearing loss, or a permanent threshold shift (PTS) involving less than full loss of hearing.

Eardrum rupture, disarticulation (dislocation) of the ossicles and sensorineural damage are all common results of exposure to high amplitude shock waves. Perforations of the eardrum may heal over time without a significant permanent reduction in hearing sensitivity; however, repetitive tears can lead to the deposition of calcium within the eardrum that weaken it, affect its ability to heal, and ultimately result in permanent hearing loss. A secondary concern of eardrum rupture is the potential for middle ear infection; a condition called otitis media. This condition, left untreated, can also cause a reduction in hearing sensitivity by affecting the ability of various middle ear structures to function properly.

Disarticulation of the ossicles refers to the dissociation of the connections between ossicles. If the connections between ossicles are damaged, the ability of the ossicular chain to respond to vibrations at the eardrum is greatly reduced. This, in turn, inhibits the vibratory stimulation of the oval window and the generation of pressure waves, within the cochlear fluid.

Sensorineural damage to the auditory system, including trauma to hair cells and other soft tissues of the cochlea, and damage to the bony structures of the cochlea may also result from impulsive sound exposure. Damage to hair cells and other soft tissues of the cochlea reduce the ability of the cochlea to register pressure waves in the cochlear fluid and generate nerve impulses. Damage to the bony structures can compromise the internal pressure of the cochlea, thus impacting the transmission of pressure waves, and may result in the loss of cochlear fluids.

Hearing Loss (PTS and TTS): Exposure to intense sound may produce an elevated hearing threshold, also known as a noise-induced threshold shift or simply threshold shift (TS). If the threshold returns to the pre-exposure level after a period of time, the TS is known as a temporary threshold shift (TTS); if the threshold does not return to the pre-exposure level, the TS is called a permanent threshold shift (PTS).

A PTS is a permanent reduction in the ability of the auditory system to detect a stimulus within a band of frequencies. The most common causes of PTS are aging and the long-term exposure to environmental noise. PTS may also occur as a result of exposure to high amplitude, rapid onset stimuli because the pressure from the event results in the “elastic limits” of the ear being exceeded. In such situations, e.g. shock wave exposure, damage to the ear membranes (e.g. eardrum, oval and round windows, basilar membrane), middle ear bones, and sensorineural components of the cochlea are possible. Exposure to high amplitude signals, even with extended onset, may also produce a PTS by overloading the cochlear partition and damaging sensorineural components.

A TTS is an increase in the auditory threshold that returns to a pre-exposure, baseline value over time. TTS thus represents a temporary loss of sensory tissue function. The best available evidence indicates that the affected tissues fully recover their function without loss of tissue and therefore, TTS should not be considered an “injury” in the same class as those previously described.

The magnitude and duration of a TS is affected by a number of different variables, including the amplitude, duration, frequency content, and temporal pattern of the sound to which an animal is exposed. A TS generally increases with an increase in the amplitude and/or duration of sound exposure. For continuous sounds, exposures of equal energy lead to approximately equal effects. For intermittent sounds, less TS is produced than from a continuous sound having the same total energy (some recovery occurs between exposures).

Behavioral disruption: As mentioned, behavioral disruption may accompany injuries and TTS. Additionally, at exposure levels below those expected to cause a TTS, animals exposed to underwater impulsive sounds may still experience other “behavioral disruptions.” In contrast to the direct physical effects on tissue, such as lung injury or TTS, these other behavioral disruptions represent indirect effects of the sound, because the response of the animal is mediated by the subject’s sensory and mental processes. Potential disrupting behaviors or responses include the following: conditioned (learned) avoidance (e.g., the animal moves away from a previously experienced, aversive source on the basis of some prior cue associated with that source, such as the sound of an approaching vessel it has learned to associate with seismic surveys), escape (moving away during exposure to reduce the aversiveness of the exposure), sensitization (post-exposure increase in reactivity to all environmental stimuli), orientating response to novel stimuli (typical of all mammals, this would be expected to be very brief), and startle, panic or post-exposure departure. There may also exist species-specific reactions to specific source characteristics.

Behavioral reactions such as these are difficult or impossible to predict, primarily because the sound exposure is only one of many factors influencing most responses. These influencing factors include the animal’s prior experience, motivational state, context, sound pattern and sound level. For single, time-isolated, brief impulsive events at levels below those inducing a TTS, NMFS has been unable to identify behavioral reactions that are “biologically significant” and have a reasonable probability of occurring (National Marine Fisheries Service 2001). It therefore seems appropriate that a discussion of potential impacts resulting from time-isolated EROS events be focused on the direct physical effects of the sound, such as mortality, injury (including PTS), or TTS.

Measured Effects of Impulsive Sounds

Blast injuries in sea turtles: There have been only three principle observations of blast injuries in sea turtles exposed to underwater detonations (summarized in Craig (2000)). Two immature green sea turtles accidentally exposed to a 20 lb detonation of C-4 suffered extensive lung damage and were killed (National Research Council 1996). It was estimated that the turtles were 100–150 ft from the source (estimated received peak pressure of 350–240 psi, respectively). In July 1981 three sea turtles were unintentionally exposed to underwater detonations of 1,200 lb of TNT at mid-depth on 120 ft of water. Turtles located at distances of 500–700 ft (258–178 psi) and 1,200 ft (99 psi) were killed and injured, respectively; a third turtle at 2,000 ft (57 psi) was not injured (O’Keefe and

Young 1984). In June 1986, eight turtles (4 loggerhead and 4 Kemp's ridley) were intentionally exposed to an EROS detonation of four 50 lb nitro-methane charges placed 16 ft below the mudline in 30 ft of water (Klima *et al.* 1988). Subjects were placed at mid-depth (in cages) at distances of 750, 1,200, 1,800, and 3,000 ft from the source (one of each species at each distance). After detonation, the four turtles within 1,200 ft, as well as the loggerhead at 3,000 ft, were unconscious. Turtles at all distances were affected to some degree. Many showed evidence of vasodilation , which lasted up to three weeks. Unfortunately, the actual pressure each subject was exposed to was not measured and the use of buried charges makes predictions difficult (Craig 2000). Overall, these three data sets show that both lethal and non-lethal injuries may occur in sea turtles exposed to underwater detonations; however, the data are somewhat anecdotal with little systematic control and do not allow confident predictions to be made regarding specific criteria and numerical values for turtles exposed to impulsive sounds.

Blast injuries in marine mammals: Although relatively few studies of blast injury in marine mammals have been conducted, there is evidence of mortality and injury in marine mammals exposed to underwater impulses. Richardson *et al.* (1991) cites lethal injuries observed in sea otters exposed to estimated peak pressures of 100–300 psi. Blast injuries have also been observed in humpback whales (*Megaptera novaeangliae*) exposed to the detonation of 5,000-kg charges (Ketten *et al.* 1993). Types of damage observed are consistent with the types of damage observed in human divers—fractures of the periotic bone, disarticulation of the ossicles, round window rupture, and pooling of blood within the middle ear were found.

TTS in marine mammals: Several studies have been conducted at SPAWAR Systems Center, San Diego (SSC-SD) to investigate the effects of intense underwater sounds, including impulsive sounds, on marine mammals. In these studies, a behavioral response paradigm is used to measure hearing thresholds in trained marine mammals before and after exposure to intense underwater sounds. Post-exposure thresholds are then compared to pre-exposure thresholds to determine if a TTS has occurred. Studies conducted in San Diego Bay used broadband "masking" noise to provide a listening background that keeps hearing thresholds consistent despite varying ambient noise (from biological sources and shipping). Data from these studies are referred to as MTTS (TTS in masked hearing thresholds) to indicate that the hearing thresholds were measured in the presence of masking noise. Recent TTS tests in a quiet pool with no masking noise suggest that the presence of the masking noise did not have a major effect on the measured amounts of TTS in these studies (Finneran *et al.* 2001). Details regarding the experimental design, data analysis, and interpretation of the studies may be found in Schlundt *et al.* (2000) and Finneran *et al.* (2000).

Three TTS studies were conducted at SSC-SD during 1996. In these tests, five bottlenose dolphins were exposed to 1-sec pure tones at frequencies of 3, 20, and 75 kHz. The data resulting from these tests were presented in a technical report (Ridgway *et al.* 1997). In 1997–1998 the study was expanded to include white whales and frequencies of 10 kHz and 400 Hz and five additional experiments were conducted. The results from these experiments using 1-s pure tones may be summarized as follows: The levels of fatiguing stimuli necessary to induce 6 dB or larger MTTSs were generally between 192 and 201 dB *re*:1 μPa (192–201 dB *re*: 1 $\mu Pa^2 \times s$ total energy flux). The exceptions occurred at 75 kHz, where one dolphin exhibited an MTTS after exposure at 182 dB *re*:1 μPa and the other dolphin did not show any shift after exposure to maximum levels of 193 dB *re*:1

μPa, and at 0.4 kHz, where no subjects exhibited shifts at levels up to 193 dB *re*: 1 μPa. The shifts occurred most often at frequencies above the fatiguing stimulus. The results of these experiments, as well as the re-evaluated data from Ridgway *et al.* (1997), may be found in Schlundt *et al.* (2000).

In 1998–1999 a study was conducted to measure MTTS in bottlenose dolphins and white whales exposed to single underwater impulses. This study used an "explosion simulator" (ES) developed by NSWC Carderock. The ES consisted of an array of piezoelectric sound projectors with accompanying hardware and software designed to generate impulsive sounds with pressure waveforms resembling those produced by distant underwater explosions. The pressure waveforms produced by the ES resembled those predicted by the Navy REFMS model; however, the frequency spectra showed a lack of energy at frequencies below 1 kHz. No substantial (i.e., 6 dB or larger) threshold shifts were observed in any of the subjects (two bottlenose dolphins and one white whale) at the highest received level produced by the ES: approximately 70 kPa (10 psi) peak pressure, 221 dB *re*: 1 μPa peak-to-peak pressure, and 179 dB *re*: 1 $\mu Pa^2 \times s$ total energy flux. The results of this study were published in Finneran *et al.* (2000).

In 2000–2001, impulsive testing was conducted using a seismic watergun as the sound source. The watergun was used because it was capable of producing impulses with higher peak pressures and total energy fluxes than the pressure waveforms produced using the ES. The watergun was selected over other seismic sources (e.g., airguns) because watergun impulses contain more energy at higher frequencies, where odontocete hearing thresholds are relatively low (i. e. sensitivity is relatively high). MTTSs of 7 and 6 dB were observed in a white whale at 0.4 and 30 kHz, respectively, 2 min after exposure to single impulses with peak pressure of 160 kPa (23 psi), peak-to-peak pressure of 226 dB *re*: 1 μPa, and total energy flux of 186 dB *re*: 1 $\mu Pa^2 \cdot s$. Thresholds returned to within ±2 dB of the pre-exposure value within 4 minutes of exposure. No MTTS was observed in a dolphin at the highest exposure conditions: 207 kPa peak pressure, 228 dB *re*: 1 μPa peak-to-peak pressure, 188 dB *re*: 1 $\mu Pa^2 \cdot s$ total energy flux (Finneran *et al*. 2002).

Figure 1H.3 compares the pure-tone TTS data from Schlundt *et al.* (2000), the ES study results from Finneran *et al.* (2000), and the results from the watergun exposures. Also shown are the TTS data from Nachtigall *et al.* (2001), who measured TTS in a bottlenose dolphin exposed to 50 min of octave-band noise centered at 7.5 kHz. Figure 1H.1 displays the peak pressure versus the exposure duration from each study. The red rectangles represent TTS-inducing stimulus levels from Schlundt *et al.* (2000) and Nachtigall *et al.* (2001). The green circles indicate exposure conditions from Finneran *et al.* (2000) (no MTTS was observed). The green triangles indicate exposure conditions from the watergun tests where no MTTS was observed; the red triangles indicate the exposure condition where MTTSs were observed. Peak pressures for Nachtigall *et al.* (2001) were approximated as the octave band (rms) level +3 dB. Figure 1H.3 also includes a line with a slope of 3-dB per doubling of time fit to the mean values of the TTS-inducing exposures. The 3-dB per doubling of time slope, or 3-dB exchange rate, is equivalent to an equal energy criterion for relating the SPL and permissible exposure duration (for continuous-type sounds). For the species and stimuli that have been studied, the 3-dB exchange rate provides a reasonable fit to the experimental data.

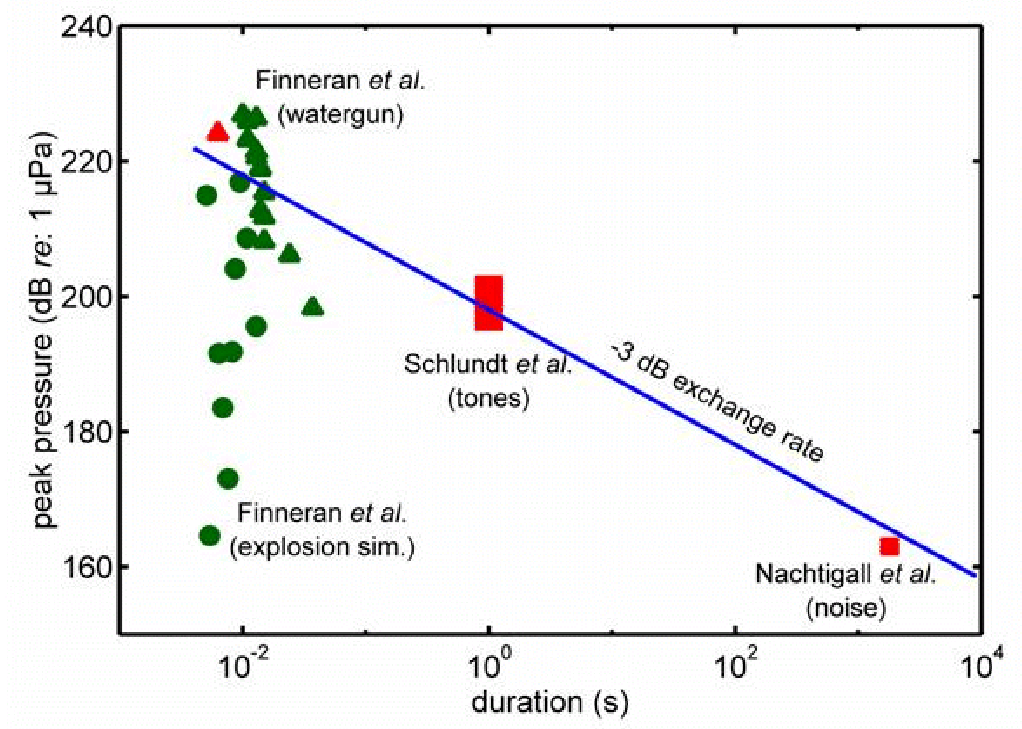

Figure 1H.3. Comparison of the pure-tone TTS data from Schlundt *et al.* (2000).

CHURCHILL IMPACT METHODOLOGY

The process used in the *Winston S. Churchill* (DDG 81) Shock Trial Environmental Impact Statement (EIS) (Department of the Navy, 2000) provides a logical precedent for EROS impact assessments on protected species. Although specifically designed for single, time-isolated impulsive scenarios, the approach used in the *Churchill* EIS is applicable to any general impact scenario. This methodology has five main components.

Categorize the Impacts

The first step is to group the types of expected impacts into categories which fit into the existing regulatory framework (e.g., the MMPA). For the *Churchill* EIS, the categories chosen were (1) mortality (both immediate and delayed), (2) injury (which included PTS), and (3) temporary sensory impairment. Both mortality and injury were considered Level A harassment under the MMPA; temporary sensory impairment was considered to be Level B harassment. The latter follows from the fact that temporary hearing impairment disturbs or disrupts all hearing- based behaviors that link the animal to its environment to the extent of the impairment.

Define Indicators, Criteria, and Values

The next step is to define *biological indicators*, *criteria*, and numerical *values* for each impact category. The term *biological indicator* refers to a particular effect of the exposure on tissue. For example, onset of minor lung injury and TTS are both biological indicators. The *Churchill* shock trial EIS included the following biological indicators (with the associated impact category in parentheses): onset of extensive lung hemorrhage (mortality), onset of slight lung injury and 50% probability of tympanic membrane rupture (injury), TTS (temporary sensory impairment).

The term *criteria* refers to parameters of the received sound used to describe the exposure. Examples of criteria include acoustic impulse and peak pressure. The *Churchill* shock trial EIS used acoustic impulse as the criterion for both onset of extensive lung hemorrhage and onset of slight lung injury. The criterion for 50% probability of tympanic membrane rupture was the total energy flux. The criterion for TTS was referred to as a *dual criterion*; the more conservative of either peak pressure or the energy flux in 1/3-octave bands were considered.

The *value* associated with each criterion is the numerical value considered to be the “threshold” for the impact to occur. For example, if the numerical value of TTS is exceeded, then the animal is considered to experience a TTS (and thus temporary sensory impairment and Level B harassment).

Table 1H.5 shows the impact categories, biological indicators, criteria, and numerical values used in the *Churchill* EIS. It should be noted that the results reported in Finneran *et al.* (2002) were not available at the time *Churchill* was written and the values used in *Churchill* for TTS were extrapolations from Ridgway (1997).

Table 1H.5. Impact categories, biological indicators, criteria, and numerical values used in the *Churchill* EIS.

	Impact Category	**Biological Indicator**	**Criterion**	**Numerical Value**	**References**
MMPA Level A	Mortality	Onset of extensive lung hemorrhage	Acoustic impulse	364 Pa×s	Richmond *et al.* (1973) Goertner (1982)
	Injury	Onset of slight lung hemorrhage	Acoustic impulse	175 Pa×s	Richmond *et al.* (1973) Goertner (1982)
		50% probability of tympanic membrane rupture	Total energy flux	205 dB re: 1 μPa^2×s	Yelverton *et al.* (1973) Richmond *et al.* (1973)
MMPA Level B	Temporary sensory impairment	TTS	Maximum energy flux in any 1/3-octave band	182 dB re: 1 μPa^2×s	Ridgway *et al.* (1997)
		TTS	Peak pressure	12 psi	Ketten (1995)

Identify Species Present

The specific sea turtle and marine mammal species in the operation area must be identified. For species that are expected to be present, the spatial densities of the animals must be estimated from existing databases.

Model the Sound Field and Calculate the Exposure

The next step is to model the sound field that will result from the detonations. For the *Churchill* EIS, the U.S. Navy's REFMS shock wave propagation model (Britt 1987; Britt *et al*. 1991) was used to calculate the received pressure waveforms at various depth/range combinations. Numerical values of the various impact criteria (e.g., peak pressure, acoustic impulse, and energy flux) are calculated from the pressure waveforms using equations such as Eqs. (1)–(9).

Establish Takes and Mitigation Ranges

The final step is to compare the calculated values at the various range/depth combinations to the established criterion values. "Zones of impact" around the source are defined using the maximum range at which a criterion is exceed. The impacted area and the species spatial densities are then used to calculate the estimated number of takes. Reference to the *Churchill* document should be made for illustrations of asymmetrical zones, their causes and interpretation.

CONCLUSIONS

Marine mammals and sea turtles exposed to underwater blasts may experience a wide range of effects, from small behavioral disruption (startle), temporary loss of sensory function (e.g., TTS), injury, or mortality. Although there are few direct data on the affects of underwater explosions on marine mammals and sea turtles, observations following unintentional exposures and extrapolation from terrestrial mammal data allow predictions to be made. Effects depend on the actual parameters of the sound exposure and are not likely to be a simple function of charge weight and distance from the source. Terrestrial mammal data suggest that physical injury to the lungs and intestines is correlated with the acoustic impulse. Data from terrestrials have shown that mild to moderate impairment from continuous sources is predicted by acoustic energy flux and that from impulsive sources requires consideration of both pressure and energy flux. Marine mammal TTS data confirm those relations for continuous sources and more work is required to confirm the relations for impulsive sources. Calculation of these parameters requires knowledge of the actual pressure waveform as a function of time, including any effects caused by multipath sound propagation, reflection, and refraction.

Although the specific impact categories, criteria, and values used in the *Churchill* EIS are most applicable to single, time-isolated impulsive sounds, the *Churchill* methodology provides a logical approach to estimate the potential impact of noise sources for any general scenario. This methodology would provide a good framework for EROS impact assessments.

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SESSION 1J

MODELING SOCIAL SCIENCE ISSUES

Chair: Ms. Stephanie Gambino, Minerals Management Service
Co-Chair: Ms. Vicki Zatarain, Minerals Management Service

Date: January 10, 2002

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Mr. Asa Janney, Applied Statistical Associates, Inc.

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Dr. David W. Hughes, West Virginia University Extension Service

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PRELIMINARY RESULTS OF THE LABOR NEEDS SURVEY BEING PERFORMED FOR MMS IN THE FEDERAL GOM

Ms. Zeta Rosenberg
ICF Consulting, Inc

Mr. Asa Janney
Applied Statistical Associates, Inc.

The presentation has been divided into four sections: the history of the project, a status report on the project, the lessons learned so far, and the preliminary results. The preliminary results have been divided into two parts: the employee survey results and the industry survey results.

HISTORY OF THE PROJECT

In the early 1990s technological changes such as the advent of three- and four- dimension seismic surveys and sub-surface completion systems brought an upsurge of activity on the federal offshore in the Gulf of Mexico (GOM). This activity translated into increased capital expenditures and labor requirements for the offshore, particularly the deep water. While there were estimates of the level of expenditures and the number of jobs directly or indirectly related to the offshore there was no publicly available standard statistical series that differentiated between the various geographic categories: onshore, state offshore, and federal offshore.

In their reviews of MMS programs the National Research Council (NRC) identified this lack as a serious data problem and criticized the MMS for failing to gather such data. The Labor Needs Survey was the result of this data lack.

The initial thrust of the project focused on the expenditures of the industry and the service industry and their labor needs. There was to be a detailed employee survey. However, the project began to be adapted to deal with emerging concerns. The four main concerns centered around

- The concern expressed by the industry advisors on how to represented the multinational connects of the industry
- The general concern felt by the contractors on the representation of the capital and labor leakages both in and out of the GOM
- The concern expressed by senior management at MMS over the representation of the value of the industry to the economy as a whole
- The specific modeling requirements of MMS

The survey that is finally being undertaken now consists of the following components:

- Seismic companies' capital expenditures in detail and labor costs
- Bidders' total expenditures for specific bids
- Operator companies' total capital expenditures in detail and labor costs

- Platform/rig companies' capital expenditures and labor costs
- Transportation (pipeline, marine, and air) companies' total capital expenditures in detail and labor costs

In addition, operator companies are being asked for a list of their contractors, and these contractors are being surveyed for their labor costs. Finally, there is also a sample survey being conducted of the employees of all the companies contracted.

The surveys are sorted by operator/field and then stratified by water depth and the life cycle activity of the field (i.e. is the field being developed? Is the field producing?, etc.). Data is being requested for the year 2000.

STATUS OF THE PROJECT

Once the survey instruments were developed, with input from both MMS and industry advisors, three sampling waves were planned for the survey. The three waves consist of a small pretest before OMB approval to gather data on burden and to identify problems, a larger second wave of roughly 10% of the universe, and the final larger third wave.

At the present time, the third wave survey instruments are ready for mailing. Returns are still being received from the second wave and there is considerable follow-up being undertaken. The data from the returns are being entered into an ACCESS database as the returns are received.

Once the third wave is completed what remains is the data analysis and the final report.

LESSONS LEARNED

The contractors are still accumulating information as the project goes forward. However, a number of general conclusions have been arrived at. Since MMS is considering making the survey a regular five-year event, these conclusions are important going forward.

- In general, the more interaction a sector has with MMS (i.e., permits are required for their activities) the more co-operative they are with the survey.
- The available databases of companies working in the GOM are very poor, and considerable time and effort has to be spent generating the sector universe once one moves away from operators.
- The current volatility in the industry means considerable time must be spent up front checking the companies, checking the addresses and identifying the correct person in the company to receive the survey.
- Some sectors, such as the platform/rig dealers, may have to be rethought, as the present definition has proven difficult to define, identify, and locate.
- It is critically important to have senior industry participation up front.

The lessons learned about the response time and willingness include the following:

- A motivated company takes approximately three months from date of receipt to respond.
- Employees respond well when privacy envelopes are included to assure that employers would not see the data.
- Those companies not responding have cited time, and implicitly cost, as their reasons for not responding.

Two final lessons are that (a) the contractor lists received from the operators have been much larger than anyone expected, and (b) it is very apparent that no matter how precise the wording, people will still misinterpret the survey questions. Follow-up telephone calls are critical.

PRELIMINARY RESULTS – EMPLOYEE DATA

The number of completed surveys received from the second wave is shown in Table 1J.1.

Table 1J.1. Completed surveys received from the second wave as of 12 November 2001.

Sector	Number Completed
Operators	59
Pipeline	13
Seismic	32
Transportation (Marine, Air)	22

Receipt, as expected, has slowed down over the holidays, but we do expect an increase in receipts now that everyone is back to work. In general, there do not appear to be any problems with the survey. One survey question to the employees that did raise some queries was the "income spending" question, which called for a breakdown of income by category (i.e., mortgage, food, etc.). The objections stated were that this was too private a question.

Employees in all sections were asked to break out their work in terms of location: offshore; onshore in support of offshore; onshore with some offshore support; and little offshore. The pie chart in Figure 1J.1 shows the breakout for the employees of operating companies.

For the operator employees, 48% of their time was spent offshore, 36% onshore in support of offshore activities, 7% onshore with some offshore assignments, and 9% onshore with little time spent devoted to offshore

The other sectors had similar distribution patterns with the exception of the seismic sector (Figure 1J.2), where the highest percentage was spent onshore in support of offshore activities. Figure 1J.3 shows that 90% of the employees worked offshore, while 10% worked onshore in support of off-shore activities. Figure 1J.4shows that the majority of workers commute from home, with 34% of transportation workers finding local housing.

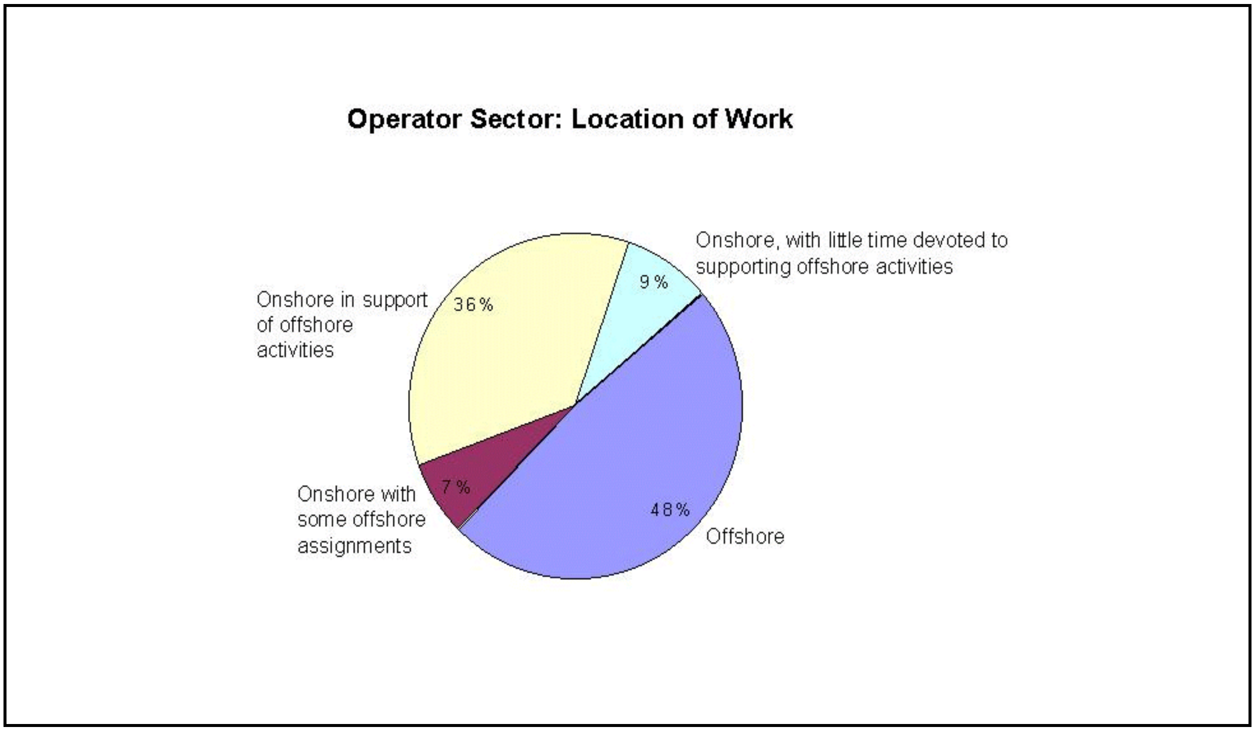

Figure 1J.1. Operator sector: location of work.

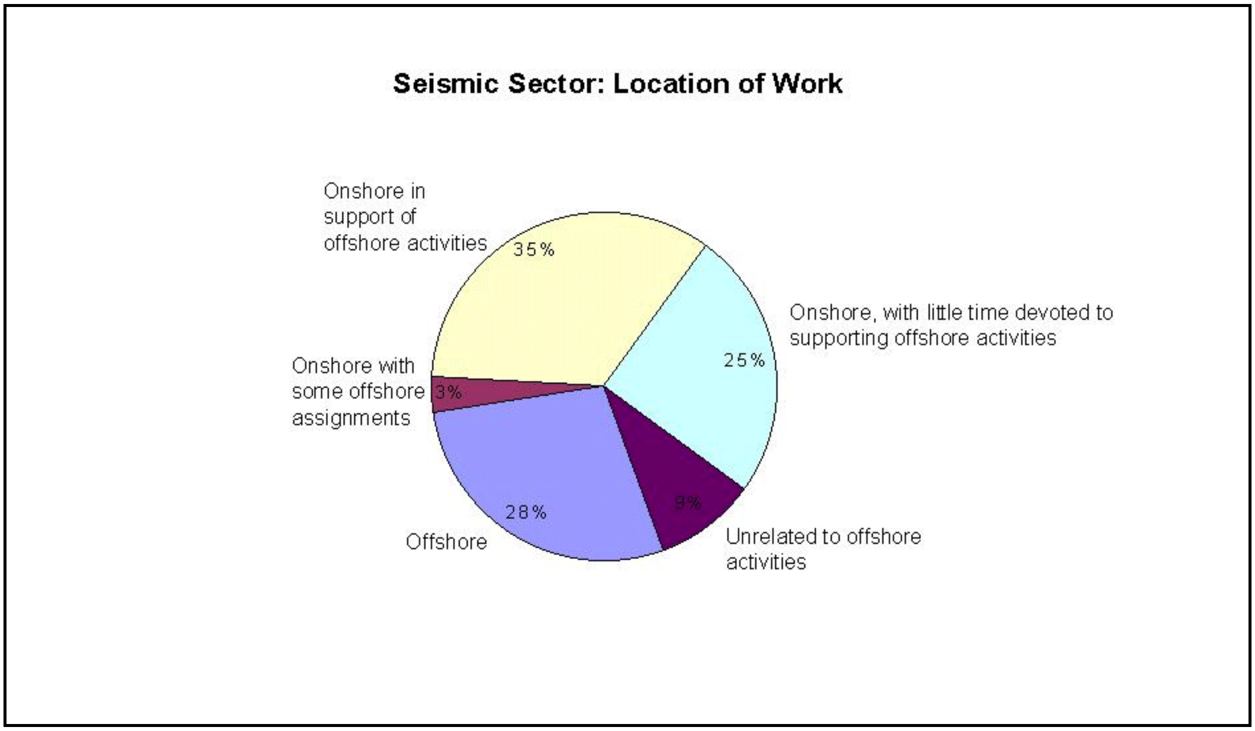

Figure 1J.2. Seismic sector: location of work.

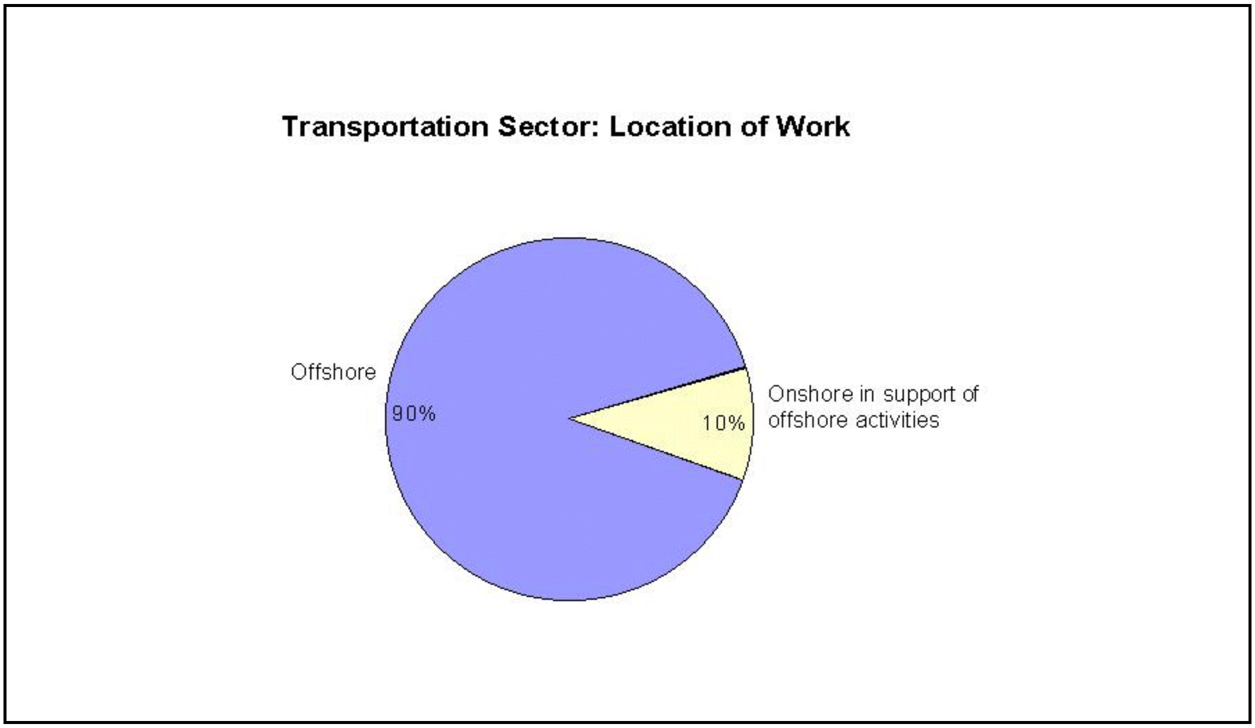

Figure 1J.3. Transportation sector: location of work.

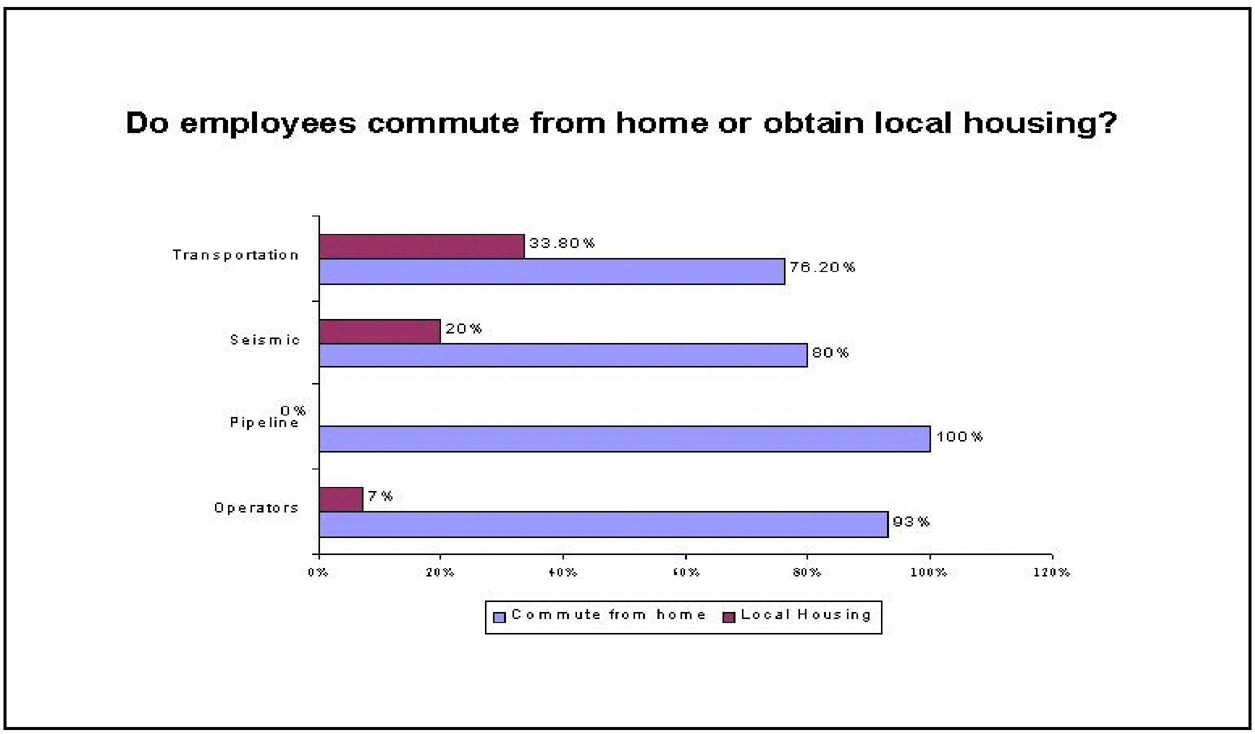

Figure 1J.4. Employees who commute from home versus those who obtain local housing.

Table 1J.2 shows that transportation workers have a slightly different pattern to their work schedule than the other sectors. As employees also supply the zip code for their home locations, we will be able to relate the distribution of commuting and local housing and work schedules to location both in and outside the Gulf.

Table 1J.2. Work schedule.

Sector	**N**	**5&2**	**7&7**	**14&7**	**14&14**	**9-80 and 28&28**
Operators	41	34%	44%	0%	2%	20%
Pipeline	11	36%	27%	0%	0%	36%
Seismic	14	14%	0%	0%	0%	86%
Transportation	20	0%	0%	10%	15%	75%

Table 1J.3 presents the current data on age. Immediately apparent is the younger age of the transportation employees (transportation here means marine workers and helicopter pilots). Cross checks with people in the industry confirmed that the jobs tend to attract younger personnel.

Table 1J.3. Distribution of employees by age category.

		Age Category					
Sector	**N**	**18-24**	**25-34**	**34-44**	**45-54**	**55-64**	**>65**
Operators	59	5%	5%	46%	41%	3%	0%
Pipeline	13	0%	8%	46%	31%	16%	0%
Seismic	29	3%	7%	41%	35%	14%	0%
Transportation	22	9%	32%	23%	18%	13%	5%

Figure 1J.5 shows the highest level of education completed for each section.

Table 1J.4 on marital status tends to cross check with the age distribution table. Transportation attracts younger workers who tend to be unmarried. Table 1J.5 shows the employment status of spouses for married employees.

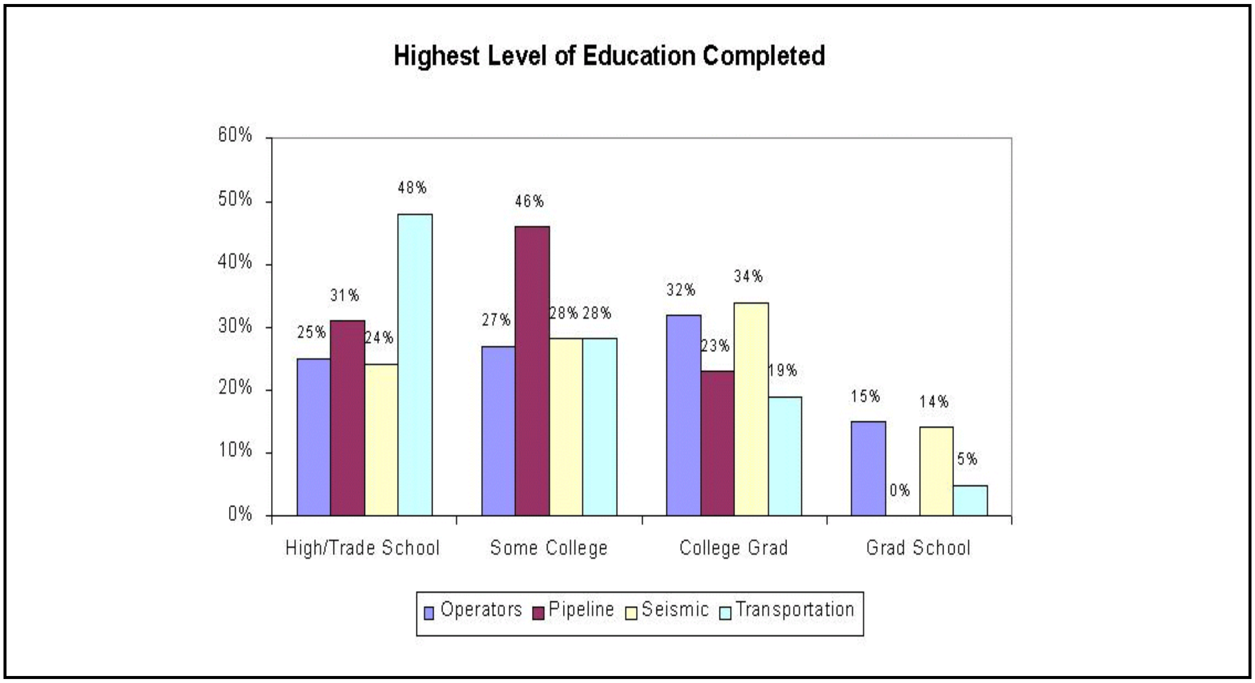

Figure 1J.5. Highest level of education completed for each section.

Table 1J.4. Martial status.

Sector	N	Single	Married	Divorced/ Separated/ Widowed	Age Category w/ highest frequency
Operators	59	8%	82%	10%	34-44
Pipeline	12	8%	75%	17%	34-44
Seismic	29	11%	83%	6%	34-44
Transportation	22	45%	32%	23%	25-34

Table 1J.5. Employment status of spouse.

Sector	N	Full-time	Part-time	Currently Unemployed	Homemaker
Operators	48	36%	31%	0%	33%
Pipeline	10	60%	0%	10%	30%
Seismic	23	39%	26%	0%	35%
Transportation	7	29%	0%	0%	71%

Figure 1J.6 graphs household income, while Figure 1J.7 breaks down sectors by sex.

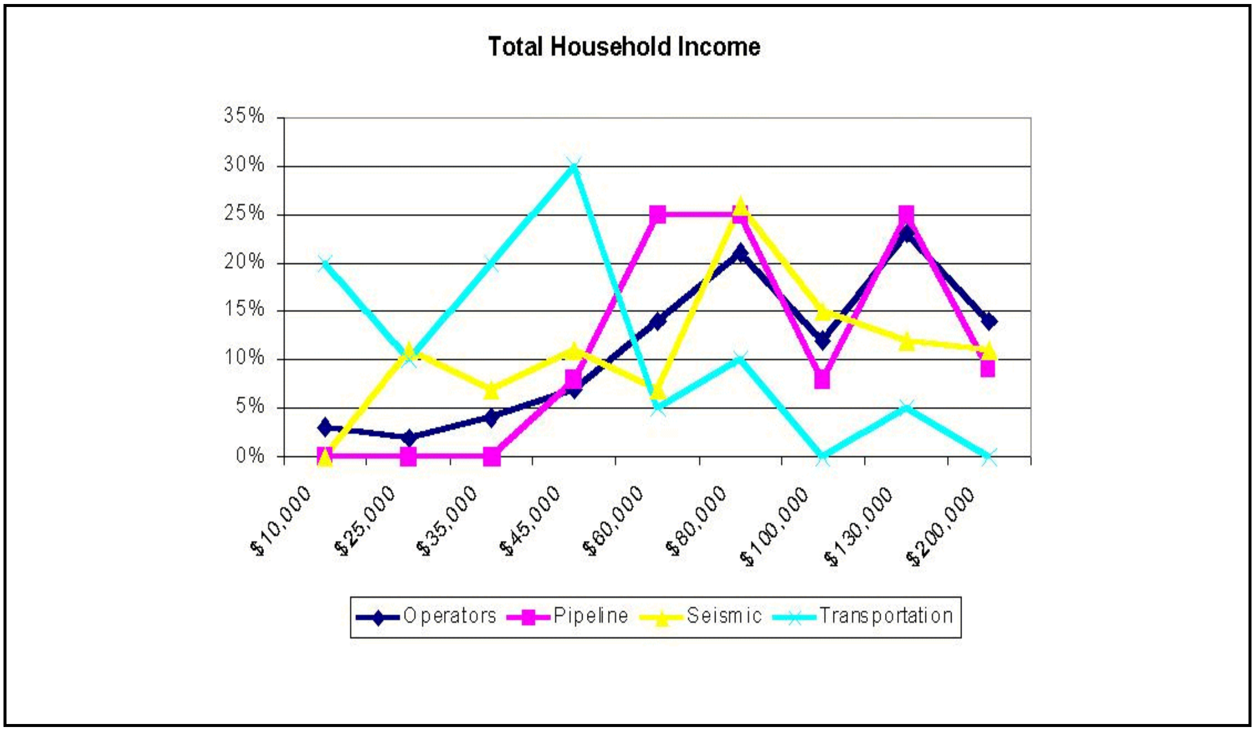

Figure 1J.6. Total household income by sector.

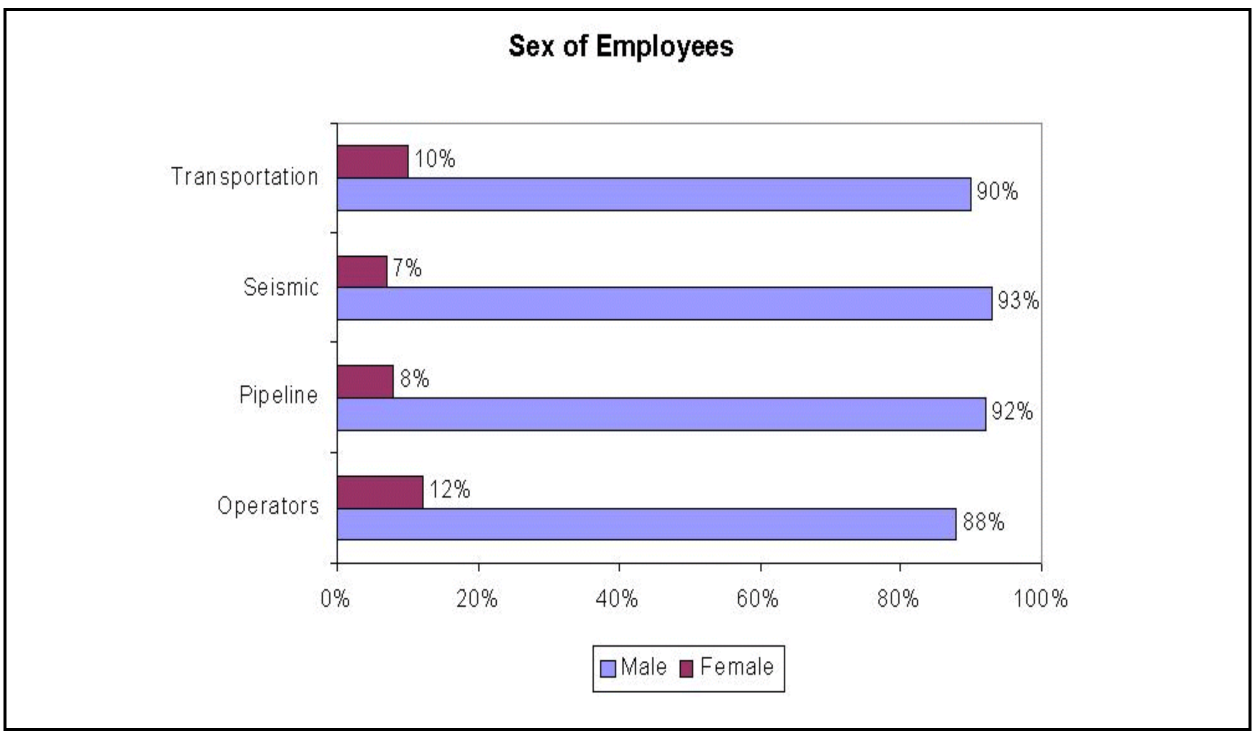

Figure 1J.7. The industry, in all sectors, is still overwhelmingly male.

Table 1J.6 shows the average position tenure, and Table 1J.7 breaks down distribution of expenditures by operator employees.

Table 1J.6. Average position tenure.

Sector	N	Average Tenure in a Position (Months)
Operators	58	54.7
Pipeline	13	60.2
Seismic	31	51.3
Transportation	22	60.0

Table 1J.7. Distribution of expenditures by operator employees.

Expense Category	Percent of Income
Car Insurance	5.26
Car Payment	10.90
Food/Clothing	19.69
Health Insurance	4.37
Insurance	9.36
Miscellaneous	12.33
Mortgage	19.53
Other	13.07
Recreation	12.05
Rent	22.50
Savings	12.08
Property Taxes	3.50

Table 1J.8 shows a summary of operators' expenditures and Table 1J.9 shows a summary of seismic companies' expenditures.

Table 1J.8. Operators' expenditure summary.

Expenditure Groups	Average Expenditures ($)	Total Expenditures ($)	Minimum Expenditures ($)	Maximum Expenditures ($)
Chemicals	14,508	87,049	1,465	70,000
Communications and Other Services	7,741	46,447	11,634	20,418
Maintenance and Repair	56,807	340,839	5,000	213,000
Rentals and Insurance	118,056	708,338	9,383	215,123
Seismic	184,886	1,109,313	75,000	595,000
Transportation	70,191	421,146	292	87,000
Other	207,287	1,243,721	409	1,168,700
All Expenditures	659,476	3,956,853	215,123	1,722,000

Table 1J. 9. Seismic companies' expenditure summary.

Expenditure Groups	Average Expenditures ($)	Minimum Expenditures ($)	Maximum Expenditures ($)
Marine Expenses	270,000	120,000	300,000
Payments to Contractors	6,133,000	266,000	9,500,000
All Expenditures	6,403,000	540,000	12,266,000

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ECONOMIC IMPACT ANALYSIS OF THE GROWTH IN THE DEEPWATER OIL INDUSTRY ON THE ECONOMY OF LAFOURCHE PARISH

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ABSTRACT

Port Fourchon's strategic location provides it with a competitive advantage as a supply base for oil-and-gas related activities in the Central Gulf of Mexico. These activities are diverse, ranging from supply boats used to service oil-and-gas rigs to the maintenance and repair of mobile drilling rigs. Further development of OCS activity and Port Fourchon is expected markedly to impact Lafourche Parish. A rapid increase in parish employment, which began in 1995, created 2,184 new jobs in 1998 and has been concentrated in the water transportation and shipbuilding sectors.

Community Impact Models (CIM) quantify the linkages among economic activity in local communities and the demand for and ability to support local government services. A CIM developed for Louisiana, tied to an input-output model used to represent the local economy, is used to evaluate the impact of the OCS mining industry on the economy and local government finances of Lafourche Parish.

The OCS petroleum is predicted to be directly and indirectly responsible for the addition of 6,349 jobs and $603 million in total output. The model results show an increase in population of 4.2% from 88,263 in 1997 to 91,977 in 2002.The results also indicate increases in various revenue and expenditure categories due to the OCS petroleum mining industry. Total, inflation-adjusted, revenues paid to local governments are expected to increase by $20 million (11.2%) in 2002 from the 1995 level. Model results also indicate marked increased in expenditures ($9.6 million) by 2002 thus implying that ongoing activity in the Gulf of Mexico should not strain the ability of local governments to deliver publicly provided services. However, if activity in the OCS petroleum mining industry should decrease rapidly in the future, given the boom and bust nature of the industry, local governments may eventually incur the costs of infrastructure development without obtaining the levels of revenue needed to meet such costs.

INTRODUCTION

The offshore oil industry has had a strong influence on local economies in Louisiana and other Gulf of Mexico states for many years. The industry has been boom and bust, with strong growth in the 1970s and early 1980s followed by a collapse in the mid-1980s. Recently, however, activity in the deepwater Gulf of Mexico (GOM) (depths in excess of 1,000 feet of water) has experienced a substantial resurgence, which may revitalize the economies of many GOM communities. But at the same time, attendant growth can be accompanied by pressures on publicly provided services.

Recent growth in the deepwater GOM mining industry activity has centered on Port Fourchon, located in Lafourche Parish Louisiana, as the major on-shore support base. Concerns have arisen as to the impact of resulting local economic growth on public services. Community impact models have been advanced as a way to evaluate such impacts. The research presented in this paper is based on a community impact model (LCIM) developed for Louisiana. The LCIM model is a combination of an input-output model of the local economy, a local labor market model, and a fiscal impacts model for local (parish area) government.

GULF OF MEXICO PETROLEUM ACTIVITIES

The GOM is an oval sea encompassing some 3.9 million square kilometers. It is the most intensely developed offshore oil and gas production region in the world, accounting for 90% of petroleum production in offshore waters of the United States (Anon. 1996). Between 1954 and 1993, this petroleum activity generated more than $90 billion to the U.S. Treasury in the form of lease bonuses and royalties (American Petroleum Institute 1998).

Exploration and drilling activities associated with these oil wells require substantial land-based activity to ensure continued operation. This land-based activity—including oil field equipment dealers, air transport, marine equipment and transportation services, and contract labor and engineering services—is primarily located in Louisiana and Texas and contributes significantly to the economies of local coastal communities. Until recently, the vast majority of oil-and-gas production from the GOM was shallow-water based (taken from depths of less than 1,000 feet). As recently as the late 1980s, most of the conventional fields were mature and declining in output (hence the reference to the “Dead Sea”). From 1985 to 1990, oil production declined from 351 million to 275 million barrels (a 20% decline) (MMS 1999).

Deepwater royalty relief and new exploration and extraction technologies have led to the exploration of deepwater discoveries in the GOM, however (Cranswick 1997). In addition, the passage of Public Law 104-58, Title III, the OCS Deepwater Royalty Relief Act (signed on 25 November 1995) is also believed to have stimulated deepwater bidding and leasing activities. From 1990 through 1997, production of oil from the GOM grew by 50%, with the last four years exhibiting particularly pronounced increases (MMS 1999).

The increasing oil production in the OCS since 1990 is primarily the result of expanding deepwater activities. Deepwater production of oil from the GOM equaled 12 million barrels in 1990, but deepwater production had increased to 108.5 million barrels by 1997. This increase in deepwater activity will require considerable land-based services, and the authors recognize that limitations of land-based service facilities could place restrictions on future deepwater activities. Much of the ongoing and anticipated future activities in the deepwater GOM are concentrated in the central planning area, which is most easily accessed from Port Fourchon. This study presents an analysis of the impact of ongoing deepwater oil-and-gas activities on Port Fourchon and Lafourche Parish and evaluates potential future impacts associated with expanding activities.

PORT FOURCHON

Port Fourchon, located in Southeast Louisiana near the mouth of Bayou Lafourche in southern Lafourche Parish, is the only major Louisiana port located directly on the GOM. The Port covers 3.6 thousand acres and extends approximately three miles along the east side of Bayou Lafourche from its junction with Belle Pass and Pass Fourchon to the Flotation Canal (U.S. Army Corps of Engineers 1994).

The Port provides logistical support for various types of economic activities (U.S. Army Corps of Engineers 1994) including the Louisiana Offshore Oil Port, other waterborne commerce, and commercial fishing. However, because of its strategic location, its primary function is serving as a land-based support terminal for the offshore oil and gas industry in the central GOM. Currently, more than 600 offshore platforms are located within a 40-mile radius of Port Fourchon and the Port is likely to play an increasingly important role as deepwater development progresses (Falgout 1999). There is a direct relationship between the economic viability of Port Fourchon and level of exploration and production activities of the offshore oil and gas industries operating in the Federal waters of the GOM (U.S. Army Corps of Engineers 1994; Melacon 1998). Furthermore, more than 100 businesses are currently operating at Port Fourchon (Falgout 1994) . The vast majority of these companies are either directly or indirectly involved in supporting deepwater petroleum mining.

The deepwater oil industry also has numerous links with a variety of other local and state industries that may or may not be located at the Port. These industries range in nature from restaurants that provide catering to offshore workers, shipbuilders that fabricate as well as repair drill ships and oil well service vessels, petroleum mining companies and other oilfield support firms, such as motor freight (truck) firms and providers of oil field waste disposal services.

ESTIMATING DIRECT IMPACTS OF THE DEEPWATER OIL INDUSTRY

To estimate the impact of the deepwater oil industry on the Lafourche Parish economy, changes in levels of economic activity in all sectors of the Lafourche Parish economy directly affected by the deepwater oil industry had to be estimated. Estimates through 1997 and in some cases 1998 were based on a combination of regression analysis using employment data, a survey of firms with facilities at Port Fourchon, and various other sources of published data. Estimates after 1997 were based on the assumptions that the estimated relationship between the deepwater oil industry and the sector in question would remain unchanged and of conservative future growth in future deepwater oil industry activity (slightly in excess of 4.0% per year). Future growth rates are based on recently published projects of GOM deepwater petroleum mining activity (Melancon 1998) and on the slowdown in deepwater mining activity due to sharp declines in crude oil prices at the time this research was conducted (Anon. 1998). Growth rates and resulting economic impacts are projected through the year 2002.

Major changes in employment and economic activity were estimated for construction, catering, water transportation, mining, shipbuilding, and air transportation. Relatively small changes in employment and economic activity were estimated for providers of oil field waste disposal, oil worker medical testing services, and equipment rental.[1]

THE LOUISIANA COMMUNITY IMPACT MODEL

Policy analysis tools called Community Impact Models (CIM) (Johnson 1996; Johnson 1997) have been recently developed to provide policy leaders a way to measure the potential impact of policy decisions on designated areas. Community impact models are a further development from earlier efforts where models of the local economy have been joined to demographic models of the community (Jones *et al.* 1998).

Community impact models quantify the linkages among the three major components of the community economics local government system (Figure 1J.8). When a change in demand for an industry basic to the local economy occurs, initial economic activity develops (Block 1, Figure 1J.8). The interdependency of local industries and spending behavior of local residents leads to multiplier effects in the local economy (Block 2, Figure 1J.8). An increase in external demand for the output of the local industry causes that industry to increase its purchases from other local firms and from local labor. These purchases are dollars injected into the local economy that in turn drive additional spending. Hence, the re-spending of money interjected by particular types of activity leads to growth in jobs and income in the entire economy. For this study, any Lafourche Parish industry directly tied to deepwater oil and gas activity belongs to the basic set of industries (Block 1, Figure 1J.8). A major research challenge, therefore, is ascertaining the change in economic activity for industries such as water transportation and shipbuilding directly due to growth in deepwater activity.

Multiplier effects from the local economy simultaneously result in increases in local government revenue and in demand for local public services (Block 3 and Block 4, Figure 1J.8). Changes in local government revenues are primarily due to changes in various forms of local taxes (usually property and sales) and user fees as the economy grows or declines. Intergovernmental transfers from state and federal government to local government entities are another source of local government revenue. Such transfer payments also tend to change in step with local economic activity.

Similarly, the demand placed on services provided by local government grows as the local economy grows (Block 4, Figure 1J.8). Changes in local government expenditures occur in a variety of categories, such as roads and schools. As the economy grows, for example, population would

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[1] Other parish industries, such as oil spill clean up firms, diving companies, oil field equipment manufacturers, and fabricated metal product manufacturers, were also evaluated for changes in employment due to growth in the offshore oil industry. No growth in employment or output was found for these industries in Lafourche Parish due to growth in the deepwater oil industry.

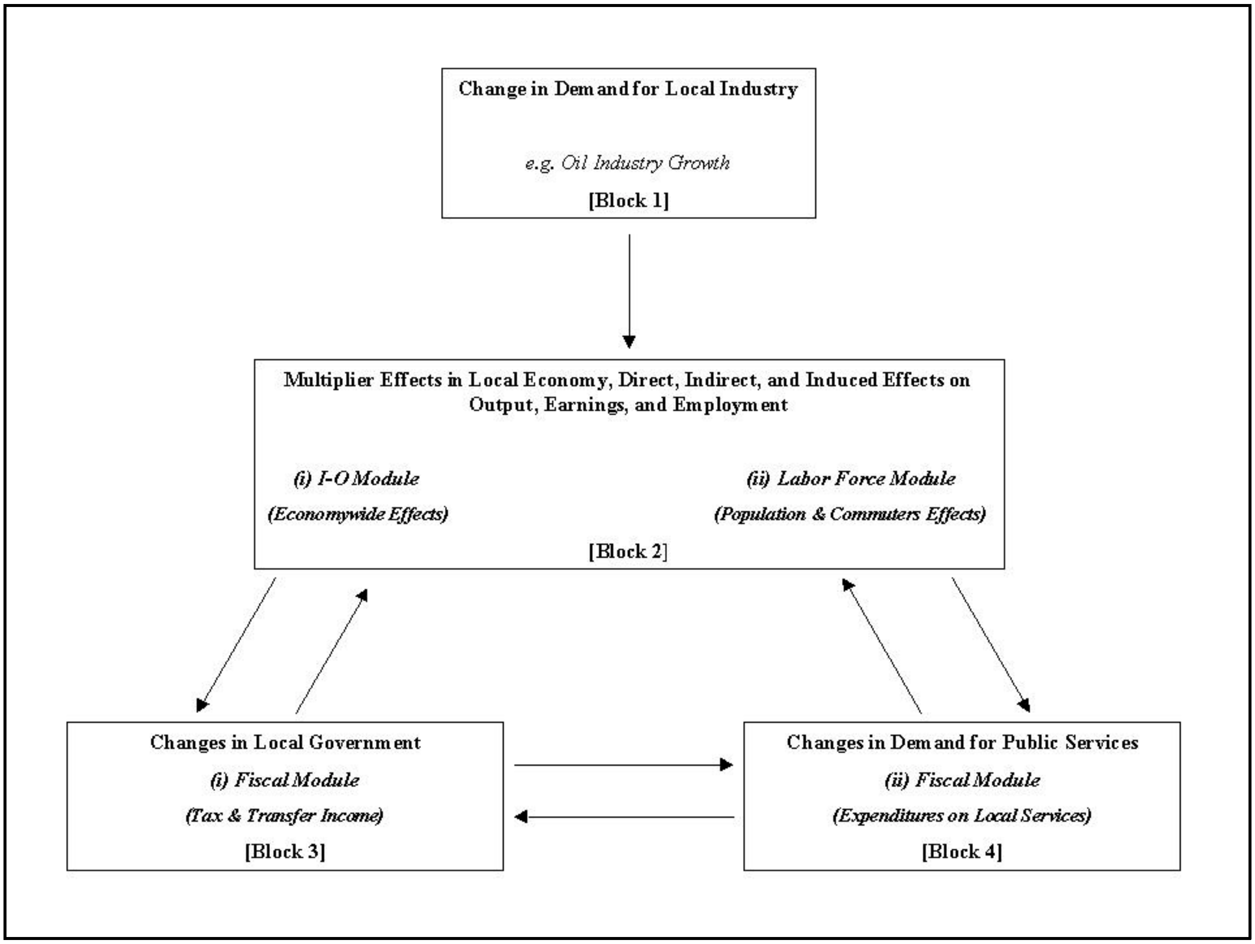

Figure 1J.8. Overview of the Louisiana Community Impact Model.

ultimately grow, meaning that schools and roads would become more congested. In the CIM, the backward linkages that occur as a result of government spending also lead to additional multiplier effects within the local economy. That is, spending by local government to alleviate pressure on publicly provided services, such as increased spending on education, will also interject dollars into the local economy. As local government revenues increase, local governments may have some additional discretionary spending, which can be used to provide new or improved public services.

In this study, a community economic model developed for Louisiana--Louisiana Community Impact Model (LCIM)-- is used to evaluate the impact of the deepwater industry on the economy and local government finances of Lafourche Parish. In LCIM, an input-output model and a labor market model together represent the local economy (Block 2, Figure 1J.8). A fiscal module represents both the generation of local government revenue (Block 3, Figure 1J.8) and the changes in demand for locally provided public services (Block 4, Figure 1J.8). The process originates with estimates of the impact of deepwater activity on Lafourche parish industry that directly support such activity (Block 1, Figure 1J.8).

Input-Output and Labor Market Models

Input-output (I-O) analysis is used to examine the flows of products between different industries of an economy in a formalized framework. Here, the IMPLAN (Impact Planning) modeling system [13] is used to compute the I-O model in this study. IMPLAN is a ready-made modeling system, which relies on secondary data, such as employment, and the assumption that the regional economy is similar in structure to the national economy [5]. The I-O model is conjoined with models that represent the regional labor market. For this study, a conjoined model is appropriate because jobs generated in the local economy often go to in-commuters or to the previously unemployed. Not accounting for these possibilities could lead to overestimation of both local population and resident income growth. Hence, a labor market module (set of equations) is also used to represent the local economy. This component of the LCIM model allocates demand for labor by firms in the local economy between in-commuters, unemployed local workers, and in-migrants. This component of the model also provides population estimates as the local economy grows or declines.

Fiscal Module of LCIM

The fiscal model receives input from the combined I-O and labor market module. That is, changes in population and earnings from the I-O and labor market model are “drivers” in the fiscal module. For example, tax yields from retail sales are a function of population and income growth. This growth is determined by results from the I-O and labor market module. Sixteen equations are included in the Louisiana fiscal module. Six of these equations are in the revenue generating part of the module. Two equations measure revenue capacity-assessed value and retail sales. Four direct revenue equations are included—severance tax revenue, state transfer revenue, federal transfer revenue (for both schools and other functions), and other tax revenue. Ten expenditure equations are estimated in the fiscal model. These equations attempt to explain changes in spending for school, road, general, administration and other, law enforcement, waste disposal, hospital, levee and drainage, fire, parks and recreation, and utility expenditures.

LCIM Model Results

To evaluate properly the impact of deepwater activity, one should account for economic growth that would have occurred in the parish without it. Based on discussions with local government and business leaders and examination of population and employment trends, it is assumed that the economy of Lafourche Parish would have grown at an annual rate of 1.0% from 1995-1998 and 0.5% from 1999-2002 without the development of the deepwater petroleum mining industry. These growth rates were based on employment data for major employers oriented toward outside markets and with no particular scrutiny of the deepwater oil industry. Employment data for other industries important to the Lafourche Parish economy, such as sugar mills and farm machinery manufacturing, indicated little or no growth. Overall population growth also indicated a slow-growing economy without the current growth in the deepwater oil industry.

Results from the Input-Output Module

The deepwater petroleum industry has and will continue to have a significant impact on the Lafourche Parish economy according to model results. The industry was responsible for direct and indirect employment impacts of 531 jobs in 1995, 864 jobs in 1996, and 1,270 jobs in 1997 before peaking at 1,424 jobs in 1998. Lower impacts in 1999 through 2002 are a result of conservative estimates concerning future growth in deepwater petroleum mining activity. Growth in output showed a similar pattern as output growth peaked at $146.986 million (1995 constant dollars) in 1998. It is important to note that impacts are assumed to be additions to growth in previous years. Hence, over the entire eight-year period, employment impacts are estimated at 6,349 jobs while total changes in output are estimated to be $603.038 million.

Direct employment impacts due to the deepwater petroleum industry in Lafourche Parish were 289 jobs in 1995 (out of 531 total jobs), 476 jobs in 1996 (out of 864 total jobs), 732 jobs in 1998 (out of 1,270 total jobs), and 330 jobs in 2001 (out of 570 total jobs). Accordingly, an “average” job in industries with direct links to deepwater petroleum production led to 1.837 total jobs (531 divided by 289) in the parish in 1995 (or 0.837 additional jobs for one direct job). Likewise, in 1998, 1.735 total jobs (1,270 divided by 732), and in 2001 1.727 total jobs (570 divided by 330) were generated by an average deepwater petroleum mining-related job. Among sectors with purely indirect and induced impacts, finance and real estate and trade experienced relatively large job impacts. Fairly large job impacts in services (323 jobs in 1998) were primarily due to the indirect and induced effects of the deepwater petroleum industry on Lafourche Parish.

Changes in Lafourche Parish Population

The LCIM model indicates growth in population due to the effects of the deepwater petroleum mining industry. Specifically, actual population estimates were 87,130 in 1994 and 88,060 individuals in 1997 (U.S. Forest Service 1996), an increase of only 1.06% over four years. Dramatic declines in the level of unemployment in the parish (starting in 1995) indicate that much of the job growth in the local economy has gone to the previously unemployed. Unemployment was at very low levels at the time this research was conducted (2.2% of the current labor force in late 1998). However, population levels should begin to show strong growth as the pool of available local workers is exhausted. For example, model results predict an increase in population of 3.2% (2,860) from 88,246 in 1997 to 91,106 in 2002.

Changes in Local Government Expenditures in Lafourche Parish

Local government expenditures were projected to increase by $5.325 million (1995 constant dollars) in 1998 from 1995 levels, a 3.6% increase, and by $9.551 million in 2002 from 1995 levels, a 6.4% increase. The school system was the largest government expenditure item responsible for 45% of all local government spending in 1995 and 2002. By 2002, expenditures on the public school system are predicted to increase to $71.152 million from $67.803 million in 1995, a 4.9% ($3.349 million) increase. Among the ten expenditure categories accounted for in the model expenditures, that on local public school had the largest absolute increases from 1995 to 2002. Other categories with large absolute increases in spending from 1995 to 2002 included healthcare ($1.722 million), law enforcement ($1.300 million), and general administration ($1.259 million). In relative terms, general administration (17.4%) had the largest increase from 1995 to 2002 among the ten expenditure categories accounted for in the model followed by law enforcement (12.6%) and waste disposal (12.0%).

Changes in Local Government Revenues in Lafourche Parish

Total revenues received by local government were projected to increase by $11.874 million (1995 constant dollars) in 1998 from 1995 levels (a 6.6% increase) and by $20.028 million in 2002 (a 11.2% increase) from 1995 levels.

Net Costs to Local Government of Deepwater Oil Industry Development

Model results indicate marked increases in both expenditures ($9.551 million by 2002) and revenues ($20.028 million by 2002) due to the effect of to the deepwater petroleum mining industry. As expected, changes in both variables are much larger than under the baseline scenario. Further, under the deepwater scenario, the effect of increased population causes revenues to increase more rapidly than expenditures. Hence, model results imply that ongoing activity in the GOM should not place additional strains on the ability of local government to deliver publicly provided services.

EVALUATION OF THE LCIM

The analysis in this study has been done with a model projection up to the year 2002. This is clearly a short-term horizon. This limited forecast horizon is because the I-O is not a forecasting tool per se; hence, it cannot fully capture long-range expectations of the activities of a highly cyclical industry such as the oil industry. However, a comparison of the actual values of the key “drivers” of the LCIM to the predicted values by the LCIM shows that the LCIM performs creditably well. For example, while the actual population of Lafourche has grown at an annual average of 0.54%, the model predicts a an average growth of 0.57. Similarly, in spite of the known difficulties in modeling commuting patterns across states, the LCIM predicts an average annual percentage change of 2.93 and 3.66% for labor force and employment respectively, compared to 2.28 and 3.11% corresponding actual values.

CONCLUSIONS

The deepwater petroleum mining industry is causing substantial levels of growth at Port Fourchon and in the Lafourche Parish economy in general. Model results are subject to certain assumptions about the level of activity for the deepwater petroleum mining industry. These assumptions may or may not be correct given changes in key factors, such as crude oil prices. However, this growth is predicted to continue to occur at least through the year 2002. As a result, increases in economic activity and population growth through the year 2002 are predicted to be substantial. Whether these benefits will outweigh the unintended social cost such as health care in the longrun are not certain.

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THE EFFECTS OF MERGERS AND ACQUISITIONS ON THE MARKET FOR OIL AND GAS LEASES IN THE GULF OF MEXICO OCS REGION, 1983-1999

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Changes in the structure of the global E&P industry began in the U.S. in the last two decades of the nineteenth century when the Standard Oil was conceived and grew to a near monopoly firm. Since then, the conduct and operational performance of the industry have changed repeatedly. Adapting to these structural changes continues to be a challenge, more so in the aftermath of the collapse in world crude oil prices in 1986 and 1998.

This study examines the impact of mergers and acquisitions (M&A) on the market for oil and gas leases in the Gulf of Mexico OCS Region. Specifically, the study evaluates, reviews, and analyzes the effects of M&A on the competitive structure of the bidding system, conduct of bidders, and the performance of the lease market in the U.S. Gulf of Mexico (GOM). The analyses are limited to the period beginning in 1983, which corresponds to the time that the U.S. Department of the Interior adopted area-wide leasing policy.

DATA AND METHODS

For the purpose of this study, leases have been classified into three categories on the basis of bidding participation or lease ownership:

- Group A: Leases with winning bids submitted (solely or jointly) by firms that were not involved in mergers and acquisitions from 1983-1999. This represents the control group in the analysis. No joint venture leases involving firms in groups B and C were included in this group.

- Group B: Leases won by joint- or solo-venture bids by firms that were candidates for mergers and acquisitions where M&A occurred prior to the time of lease sales during the period 1983-1999. Joint ventures leases, that involve firms from group A or C were included.

- Group C: Leases with winning bids submitted solely or jointly by firms that were candidates for M&A between 1983-1999, but where M&A had not occurred before lease sales. Joint ventures leases that involve firms from group A were included.

The study used two statistical analyses to answer research questions on the implications of mergers and acquisitions. The first approach is a descriptive analysis of the data and the testing of differences in the mean value of some lease attributes. The second approach is an econometric analysis of lease attributes, especially the mean values of high-bonus bids.

DESCRIPTIVE STATISTICS AND ANALYSIS

OCS Lease Market Structure

Table 1J.10 presents the trends in the number of bids per lease and number of bidders per lease. The table also shows the trends in these attributes by group for leases that have at least two bids per lease, henceforth referred to as competitive bids.

Table 1J.10. Trends in Aggregate intensity of competition for leases by structure.

Structure	Attributes	Period	Group A	Group B	Group C	Aggregate
All Bids	*Bids per Lease*	1983-89	1.44	1.47	1.42	1.44
		1990-99	1.49	1.38	1.32	1.48
	Bidders per Lease	1983-89	2.39	1.85	2.74	2.40
		1990-99	2.02	1.98	1.76	2.01
Competitive Bids						
(At Least Two)	*Bids per Lease*	1983-89	2.66	2.84	2.65	2.66
		1990-99	2.73	2.71	2.47	2.73
	Bidders per Lease	1983-89	4.82	3.54	5.41	4.85
		1990-99	3.88	3.95	3.56	3.89

The aggregate data in Table 1J.10 indicate that, on average, there were more bids per lease in the 1990s than in the 1980s. They also show a reduction in the number of participants in the bidding process per lease. This observation is consistent whether the bidding process is competitive or non-competitive. However, for group B leases, leases in which the winners include a firm or firms involved in a M&A plan, the data suggest fewer bids per lease and more bidding participants in the 1980s than in the 1990s.

To investigate whether M&A experience tends to decrease the intensity of competition in terms of bids per lease or bidding participants in the market for oil and gas leases in the OCS over time, a simple statistical testing of the equality of the mean was performed. The following hypotheses were confirmed at the 95% confidence level:

- The effect of M&A on bids per lease is statistically insignificant in the 1980s but highly significant in the 1990s.

- M&A involvement did limit, significantly, the number of bidding participants in the 1980s, but no such effect was evident in a statistical sense in the 1990s.

Bidding Methods for OCS Leases

Firms seeking the right to explore and develop petroleum resources on the Gulf OCS participate in lease sales either by bidding alone (solo ventures—SV) or by bidding as partners with other firms (joint ventures—JV). In offshore petroleum exploration and production (E&P) operations, joint venturing provides a means of facilitating the entry of relatively small operators into the OCS lease sale market, a venture that is by all standards very risky and capital intensive. Table 1J.11 presents share of joint ventures by group and period to contrast the effects of mergers and acquisition experience on bidding methods.

Table 1J.11. Frequency distribution of bidding by joint venturing.

Type	Method	Period	Group A	Group B	Group C	Aggregate
All Bids	*JV Total*	1983-89	39.7	13.6	48.3	39.9
		1990-99	26.8	33.7	21.1	27.6
	JV High	1983-89	36.4	11.7	43.8	36.6
		1990-99	25.5	36.5	20.0	26.9
Competitive Bids						
(At Least Two)	*JV Total*	1983-89	47.1	15.2	58.0	47.4
		1990-99	31.0	34.8	28.1	31.4
	JV High	1983-89	47.0	10.8	56.8	47.1
		1990-99	33.8	49.6	33.3	35.4

The share of joint-venture bidding reported in Table 1J.11 in an aggregate sense show that, on average, there was less joint bidding for leases in the 1990s than in the 1980s. However, bidders that were involved in mergers and acquisition plan in the 1990s were more favorably disposed to the use of joint bidding for leases. In fact, this distinction is more evident for competitive high bid leases. Nearly 50% of competitive high bids in the 1990s involved joint-venture bidders with some M&A experience.

OCS Lease Market Performance

Table 1J.12 provides point estimates of the mean values of high-bonus bids for the different categories of leases by lease structure and bidder structure. Lease structure as used in this section simply indicates whether the lease receives only one bid (non-competitive) or at least two bids (competitive).

Table 1J.12. Mean value of high bids by structure, conduct and lease category, $ million.

Structure	Conduct	Period	Group A	Group B	Group C	Aggregate
Competitive	*JV*	1983-89	4.500	1.550	10.600	3.331
		1990-99	1.650	1.750	0.686	1.183
	SV	1983-89	2.690	1.190	3.940	1.801
		1990-99	1.240	1.120	1.310	0.760
	All	1983-89	3.540	1.230	7.700	2.526
		1990-99	1.370	1.430	0.949	0.893
Non- Competitive						
	JV	1983-89	1.710	0.447	2.360	1.783
		1990-99	0.634	0.551	0.318	0.611
	SV	1983-89	0.974	0.396	1.440	1.000
		1990-99	0.393	0.293	0.584	0.385
	All	1983-89	1.210	0.402	1.800	1.257
		1990-99	0.446	0.377	0.526	0.438

The mean values of high bids reported in Table 1J.12 suggest consistently larger mean values of high bids for competitive leases than for non-competitive leases, irrespective of the bidding method. The estimates also show that joint-venture high bids, on average, tend to be higher than solo- venture bids for both competitive and non-competitive leases. To investigate the effects of mergers and acquisition on the expected value of leases, a simple statistical testing of the equality of the means is applied to the data reported in Table 1J.12.

The results of the sample means equality testing point to the following plausible effects of mergers and acquisitions on the mean values of high bids for OCS leases:

- The effects of M&A on the mean values of high bids for competitive—solo ventures and joint ventures—leases from 1983-1989 are statistically significant, but insignificant from 1990-1999.

- M&A effects on the mean values of non-competitive solo ventures are statistically significant in both sub-periods, whereas the effects of M&A on the mean values of high bids for leases that are joint-venture-single bids in the two sub-periods are insignificant at 95% confidence interval.

ECONOMETRIC ANALYSIS AND RESULTS

To analyze the bidding process further, a simple model to explain the patterns and relationships observable during the bidding process is developed. The model specifies that the value of the high-bonus bid (HB), which literarily means the winning bonus bid, is a multiplicative function of three sets of factors: economic condition, structure, and conduct. Symbolically, the general specification that has been commonly used for this type of empirical testing of the relative importance of the underlying determinants of the value of high-bonus bids has taken the form [1,2, 3]:

$$HB = f(V, S, C, Z) \tag{1}$$

Where:

- *HB* = the magnitude of the high-bonus bid for a lease. This is the dependent variable in our model. It is the highest bid received for the right to develop the lease.
- *V* represents the set of factors, which capture the expected gross value of the lease, herein referred to as "the economic factor."
- *S* defines factors that accentuate the degree of competition in the leasing program.
- *C* is another set of factors that serve as proxies for the conduct of bidders in terms of the bidding type—joint ventures or solo ventures, or planning area or whether the bid is a competitive or non-competitive.
- *Z* represents other necessary set of variables such as water depth (deep water or the shelf) the size and experience of the firm as well as time associated events.

A log-linear specification of Equation (1) yields parameter estimates that are interpretable as the relative change in the dependent variable with respect to an absolute change in the independent variable. Table 1J.13 presents the results of the SUR estimation of the linearized multiplicative function specified in Equation (1). In general, nearly all the independent variables are statistically significant and of the expected signs. The model explains about 50% of the expected variation in the relative value of high-bonus bids as indicated by the R^2 statistics.

To decipher the potential effects of mergers and acquisitions on the mean value of high-bonus bids through its determinants—intensity of competition, bidding structure, bidding conduct, location, economic conditions, and structural changes in the E&P industry, a Wald coefficient restriction test was applied to the regression results. The implications of the Wald test results are:

- M & A experience does not significantly alter the expectation that rising intensity of competition for OCS leases is associated with an increase in the mean value of high-bonus bids, *ceteris paribus*.

- The percent by which the mean value of high-bonus bids for leases that received at least two bids (competitive leases) exceeds the mean value of non-competitive leases is not significantly affected by M&A experience.

- The mean value of high-bonus bids for deep-water leases exceeds that for shelf leases by about 11%; this is not significantly affected by M&A bidders' participation in the high-bonus bid.

- On average, the value of high-bonus bids has dropped significantly since the collapsed of world crude oil prices in 1986, and the fall is significantly different, depending on whether any participating bidder was involved in any form of M&A group. The drop in the mean value of high-bonus bids seem to be less drastic when participating bidders have been involved in M&A experience.

- The parameters designated as fixed effects which characterize the uniqueness of each group of leases are significantly different in magnitude, thus suggesting that the relative change in the mean value of high-bonus bids for OCS leases, *ceteris paribus*, was on average smaller for leases in which participating bidders include a firm or firms that have been involved in M&A plan over the entire period 1983-1999.

Table 1J.13. Estimated model of the value of high-bonus bids on the Gulf OCS, 1983-99.

Determinants	**i=1 No M & A Leases**	**i=2 Post M & A Leases**	**i=3 Pre M & A Leases**	**Expected Sign**
Fixed Effects	13.6751*	13.1264*	12.1700*	
Intensity of Competition, *NBD*	0.3280*	0.3712*	0.3451*	+
Economic Environment, *CPP*	0.0001	0.0027	0.0189*	+
Bidding Arrangement, *DJ*	0.2603*	0.1826*	-0.0038	+
Bidding Structure, *DC*	0.3711*	0.4223*	0.3836*	+
Bidding Location, *DD*	0.1083*	0.0943***	0.1374**	+
Firm Size or Experience, *DZ*	0.0131	-0.2426*	0.3848*	-
Post Royalty Relief Act, *DY1*	0.0840*	0.0967***	-0.1912	+
Post 1986 Price Effect, *DY2*	-1.6101*	-1.3312*	-1.0549*	-

i=1, 2, 3 for null, post M & A and pre M & A Experience;
*, **, *** denote significance at the 0.01, 0.05, 0.10 levels, respectively.

SUMMARY AND CONCLUSIONS

This paper provides a framework for analyzing oil and gas leasing outcomes. Descriptive and econometric analyses were applied to data on lease sales in the U.S. GOM OCS region during the period 1983-1999. As competition increases the magnitude of high-bonus bids increases; this is not negatively affected if bidders with M&A experience participate in high-bonus bids. Bidding by joint ventures for leases is not anti-competitive even in the presence of M&A bidders, probably because of the ban on some categories of firms participating in joint bidding ventures.

On average, the mean value of high-bonus bids has declined since the collapse of crude oil prices in 1986; however, M&A experience seems to temper the extent of this decline significantly. The analyses also suggest that bidders tend to bid higher than expected for leases won in the GOM deepwater than they did for leases on the shelf. Competitive leases do have higher mean values for high-bonus bids, and the participating bidders with M&A experience also do not significantly affect these expectations.

In an aggregate sense, the econometric analysis shows consistent results with the descriptive analysis. These analyses suggest that the mean value of the high-bonus bids for OCS leases involving bidders with merger and acquisition experience was below the mean value of the high bids for other leases.

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THE IMPACT OF CRUDE OIL PRICE CHANGES AND OCS PETROLEUM RESOURCE DEVELOPMENT ON THE ECONOMIC PERFORMANCE OF U.S. COASTAL GULF STATES

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INTRODUCTION

The Gulf of Mexico (GOM) OCS region produces a substantial amount of oil consumed in the U.S. and about 97% of gas production in the country (MMS, GOMR 2000). Despite its importance, the few economic impact studies hitherto supported by the MMS have not been focusing on the effect of oil market variables on the economies of GOM communities. Perhaps the most important variable in the oil market is crude oil prices.

Over the past three decades, policy makers have been more concerned with the effects of oil price changes on the economic performance of nations or regions. The accelerated increases in oil prices in the 70s and the collapse of prices in the mid-1980s and the late 1990s heighten these concerns. Most studies of national economies have concluded that oil price changes affect macroeconomic aggregates and hence, growth of economies. An additional but less studied issue is oil market instability and its relationship to changes in some other important macroeconomic variables.

For effective policy and regulatory guidance within the context of overall national energy policy, agencies such as the MMS need reliable information, more at the regional levels, where most relevant oil and gas activities take place. This is because each state or region often posses unique environments that are at variance with national outlooks. Therefore, such a unique situation requires a different policy or regulatory framework. This study is proposed to fill these information gaps by extending previous national studies to sub-national economies, especially to areas where MMS has jurisdictional mandates.

This study constructs economic and econometric models to examine the impact of changes in crude oil prices on both the oil industries and the relevant regional economies in the GOM. The research uses recent econometric tools to provide quantitative estimates of the responsiveness and correlation between past and current activities of the oil industries and Gulf States' economic growth and oil price changes.

DATA AND METHODS

We rely entirely on secondary data for our analysis. Oil and gas production data were obtained from the MMS oil and gas database. The oil price series used is the crude oil producer price index deflated by the all commodities price index series, both available from the U.S. Bureau of Labor Statistics. Data on unemployment rates for the states were taken from the U.S. Bureau of Labor Statistics as well. The Bureau of Economic Analysis (BEA) provides an accurate source for the following series: the quarterly personal income and the annual revenue series for the states; U.S. real GDP, GDP implicit deflator and interest rates.

The vector auto-regression (VAR) approach is commonly used for forecasting systems of inter-related time series and for analyzing the dynamic impact of random disturbance on the system of variables. In this formulation, every endogenous variable is modeled, as being dependent on its own lag(s), other endogenous variables and their lags, and exogenous variables may also be included.

As an example, we present below the specific VAR model estimated for the interaction between Louisiana unemployment, oil and gas production in the shallow waters of the Gulf, and changes in crude oil price.

$$cppi = constant + \sum_{i=1}^{4} \beta_i^{cppi} goshall_{t-i}^{ocs} + \sum_{i=1}^{4} \gamma_i^{cppi} cppi_{t-i} + \sum_{i=1}^{4} \omega_i^{cppi} trb_{t-i}$$

$$+ \sum_{i=1}^{4} \varphi_i^{cppi} gdp_{t-i} + \delta_i^{cppi} dum1 + \mu_t^{PI}$$

$$goshall^{OCS} = constant + \sum_{i=1}^{4} \alpha_i^{OCS} laqur_{t-i}^{la} + \sum_{i=1}^{4} \beta_i^{OCS} goshall_{t-i}^{ocs} + \sum_{i=1}^{4} \gamma_i^{OCS} cppi_{t-i} +$$

$$\sum_{i=1}^{4} \omega_i^{OCS} trb_{t-i} + \sum_{i=1}^{4} \varphi_i^{OCS} gdp_{t-i} + \delta_i^{ocs} dum1 + \mu_t^{OCS}$$

$$laqur^{la} = constant + \sum_{i=1}^{4} \alpha_i^{ur} laqur_{t-i}^{la} + \sum_{i=1}^{4} \beta_i^{ur} goshall_{t-i}^{ocs} + \sum_{i=1}^{4} \gamma_i^{ur} cppi_{t-i}$$

$$+ \sum_{i=1}^{4} \varphi_i^{ur} gdp_{t-i} + \delta_i^{ur} dum1 + \mu_t^{ur}$$

where:

cppi =	log of crude oil price index;
goshall =	log of oil and gas production in the shallow waters of the Gulf;
trb =	the U.S. Feds three-month treasury bills rate in levels;
gdp =	log of U.S. real gross domestic product;
MSQUR =	Louisiana unemployment rate in levels; and
dum1 =	a deterministic dummy which equals 1 for the period 1979 to 1986 and 0 otherwise.

EMPIRICAL RESULTS AND ANALYSIS

Variance Decomposition

The variance decomposition procedures provide a way to decompose the effect of a shock to its component sources. This measures the percentage share of each particular shock (innovation to the one-step ahead forecast errors of a dependent variable). Hence, it provides an indication of the relative magnitude or importance of individual shocks in determining the observed variations in each variable. Some results of the estimated equations for Louisiana for the entire Gulf region are indicated in Tables 1J.14, 1J.15, and 1J.16.

The results in Table 1J.14 show that most of the variation in oil and gas production in the Gulf is explained by its own internal dynamics. The GOALL variable explains at least 78.6% of its own variation and at most 92.81% over time. The rest of the variation in Gulf oil production is accounted for largely by changes in oil price and to a minimal extent, by Louisiana's unemployment rates, LAQUR. These results also show that unemployment rate in Louisiana explains even more of its own variation than Gulf oil and gas production explains its own variation. LASQUR never explains less than 86% of its variation and up to an average of 97% in the short-term. Contrary to our expectation, this oil and gas production in the OCS has no significant influence on unemployment rate in Louisiana.

In Table 1J.15, as reported, oil price explains more of the variation in Louisiana personal income (about 14%) over time than Gulf oil production (about 3%). LAQPI is responsible for over 80% of its own variation. In the case of revenue effects, both oil price and Gulf oil production have more impact compared to the impact on unemployment and personal income (Table 1J.16). Price impact range from about 11% in the short-term to 16% in the long-term while oil and gas production effects range from about 10% to 12%.

Table 1J.14. Variance decomposition.[1]

Decomposition of Variance for Series GOALL				
Step	**Std. Error**	**QCPPI**	**GOALL**	**LAQUR**
1	0.034542807	7.195	92.805	0.000
2	0.038024900	5.945	91.447	2.608
3	30.040881889	9.959	87.447	2.594
4	0.041240251	11.299	86.126	2.575
5	0.046363821	15.842	81.906	2.252
6	0.047219267	15.636	82.067	2.297
7	0.048512870	16.760	81.056	2.184
8	0.048635661	16.796	81.009	2.195
9	0.050335293	17.955	79.976	2.069
10	0.050614781	17.810	80.035	2.155
11	0.051331593	18.408	79.472	2.120
12	0.051422816	18.431	79.448	2.121
Decomposition of Variance for Series LAQUR				
Step	**Std. Error**	**QCPPI**	**GOALL**	**LAQUR**
1	0.336225117	0.450	0.012	99.538
2	0.560933258	1.463	0.825	97.712
3	0.768496720	2.029	0.776	97.195
4	0.887893492	1.552	1.341	97.106
5	0.962117314	1.606	1.273	97.121
6	1.013757257	3.095	1.311	95.595
7	1.060583459	5.508	1.235	93.257
8	1.107306728	8.270	1.307	90.423
9	1.147719455	10.109	1.303	88.588
10	1.181401448	11.055	1.366	87.578
11	1.207645078	11.344	1.400	87.256
12	1.229174148	11.393	1.487	87.120

[1] Variables are defined as follows: LAQUR=Louisiana unemployment rate; LQPI=Louisiana personal income; GOALL=Gulf oil and gas production; QCPPI, CPPI=quarterly and annual composite oil price index.

Table 1J.15. Decomposition of variance for series LAQPI.

Step	Std. Error	QCPPI	GOALL	LAQPI
1	0.007695638	5.910	2.653	91.437
2	0.007791171	6.966	3.563	89.471
3	0.008540526	13.396	3.102	83.502
4	0.008642427	14.218	3.141	82.641
5	0.008754272	14.770	3.115	82.115
6	0.008782268	14.694	3.204	82.101
7	0.008793072	14.660	3.199	82.142
8	0.008802914	14.627	3.263	82.110
9	0.008808268	14.610	3.274	82.116
10	0.008811873	14.610	3.293	82.097
11	0.008812844	14.614	3.293	82.093
12	0.008814172	14.609	3.312	82.079

Table 1J.16. Decomposition of variance for series LAARV.

Step	Std. Error	CPPI	GOALL	LAARV
1	0.032377458	11.456	6.934	81.611
2	0.036888446	11.270	10.121	78.608
3	0.037521050	10.938	12.916	76.146
4	0.041030161	12.784	10.985	76.231
5	0.044263735	16.241	10.695	73.064
6	0.044833751	15.832	12.466	71.702
7	0.044914652	16.063	12.421	71.516
8	0.045551140	16.770	12.077	71.153
9	0.045946506	16.604	12.569	70.827
10	0.046219546	16.604	12.428	70.968
11	0.046320091	16.617	12.577	70.806
12	0.046386656	16.584	12.601	70.815

IMPULSE RESPONSE DYNAMICS

Impulse response function is another alternative way to characterize the dynamic effects of an unexpected shock in a given economic system as represented by a VAR. These functions allow us to examine the dynamic paths of the effects of an exogenous shock of one variable on other variables and to further characterize the stability and duration of these variables. The persistence of such a shock reveals how fast the system adjusts back to equilibrium. The faster a shock dampens, the faster the adjustment (Brown and Yucel 1999). Some Louisiana results for the entire Gulf region are indicated in Figures 1J.9, 1J.10, and 1J.11.

The unemployment rate falls and oil production increases in response to a one-time positive shock in price as shown in Figure 1J.9. Unemployment rate reaches its highest levels at about 0.6% (within10 quarters) above its initial equilibrium level while it reaches its minimum of 0.25% (in 3 quarters) below equilibrium. GOAL also rises to a maximum of 0.35% (in 5 quarters) and falls to a minimum of 0.25% (in 3 quarters) below its initial level. Price returns fairly quickly to its initial level after a shock (in 11 quarters), while unemployment rate gradually moves towards equilibrium after reaching its maximum. On the other hand, oil production fluctuates around its equilibrium level over the time horizon. It is also observed that variables did return to their original equilibrium, although the dynamic paths are different; oil production fluctuates much more than unemployment rate.

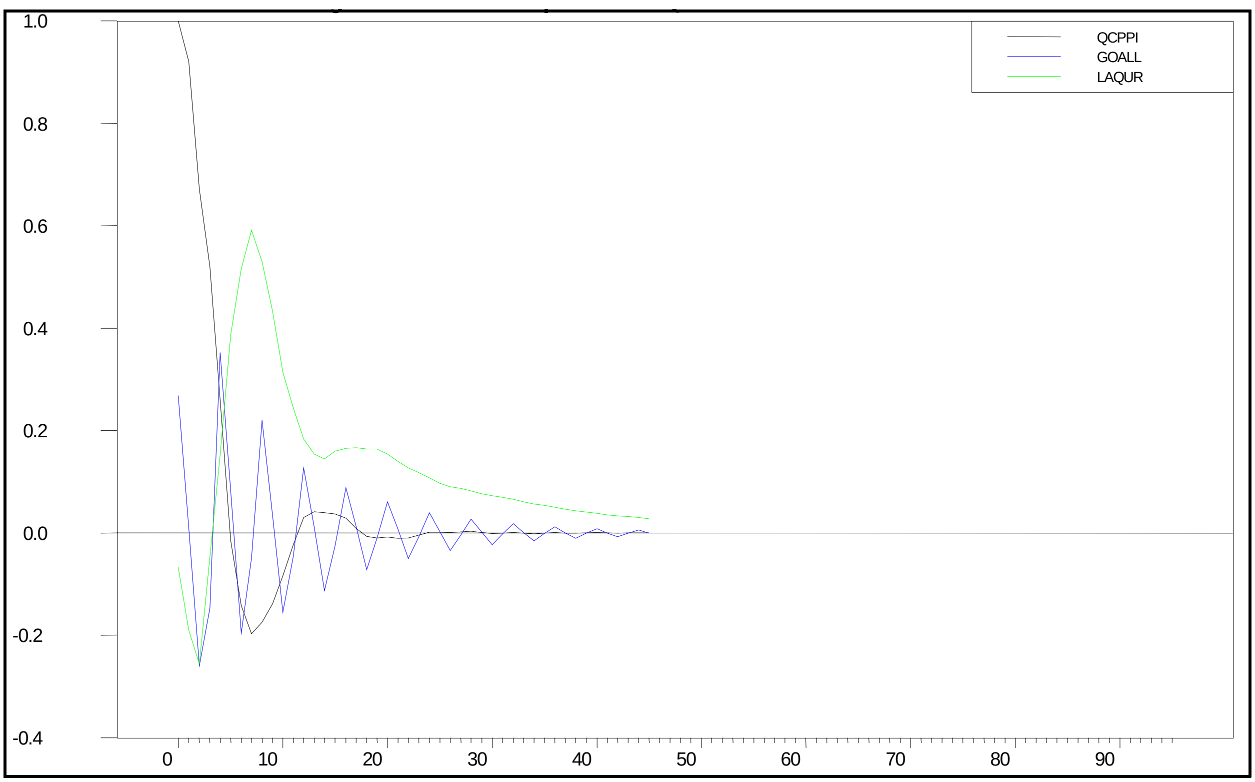

Figure 1J.9. First plot of responses to QCPPI.

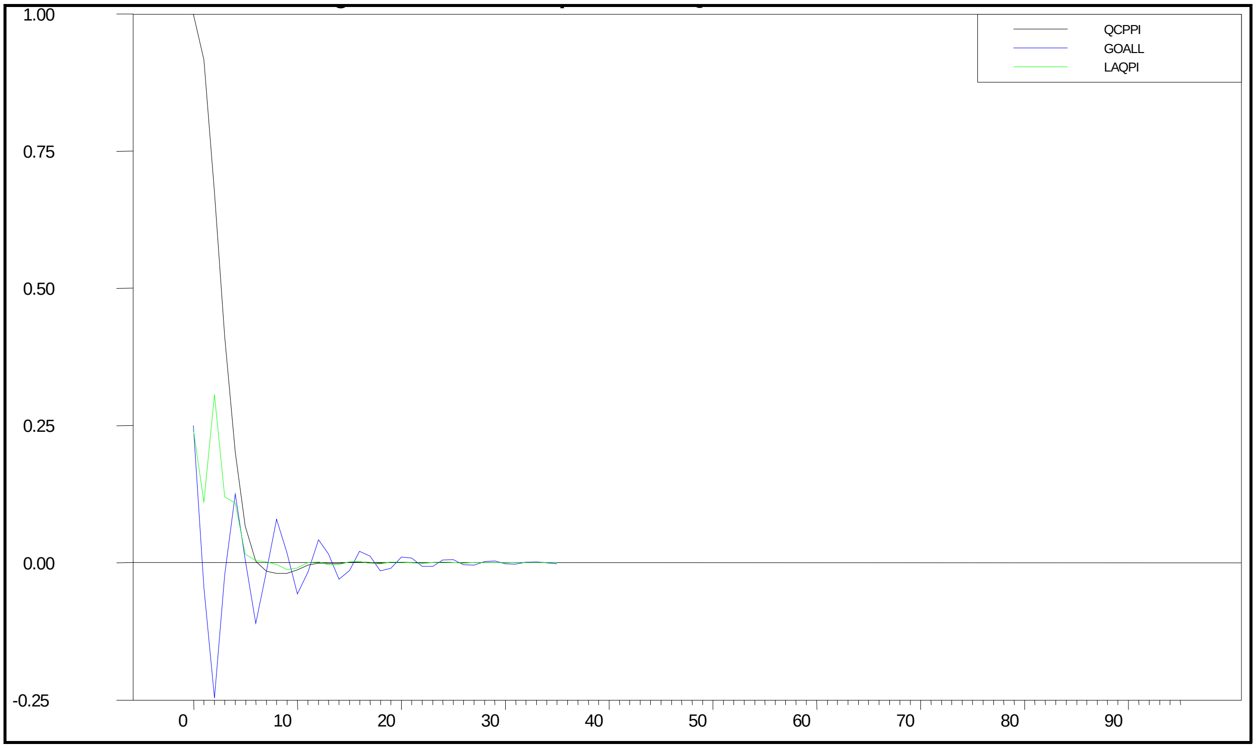

Figure 1J.10. Second plot of responses to QCPPI.

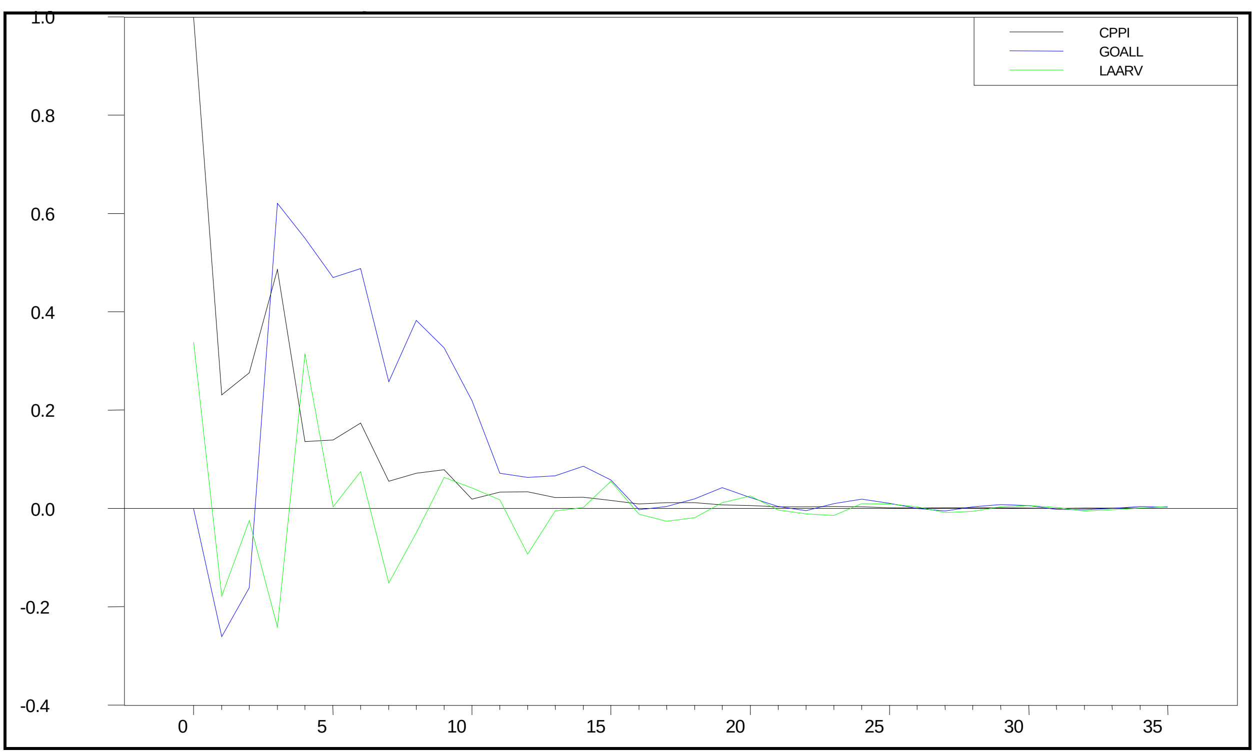

Figure 1J.11. Plot of responses to CPPI.

The dynamic response of Louisiana personal income (LAQPI) to price in the context of all Gulf oil production is depicted in Figure 1J.10. A positive shock to price initially leads to a positive response from both oil production and personal income. The affected variables return to initial levels relatively quickly. In Figure 1J.11 we show the dynamic paths of price, production, and revenue. Louisiana revenue increases following a price shock. Revenue rises to a maximum 0.32% of its initial levels before a shock. However, in this case all variables fluctuate widely, albeit towards equilibrium restoration; and movements in production and revenue are much more in tandem than price.

The impulse response functions and their corresponding graphs are used in estimating elasticities of response for both oil and gas production and state macroeconomic variables. The results are shown in Table 1J.17. These elasticities are estimated by normalizing production and macro-variables at their corresponding maximums by oil price increases. Hence, we implicitly assume a constant-elasticity basis (Brown and Yucel 1999). As the results in Table 1J.17 shows, oil and gas production is generally mildly elastic to price in the Gulf (1.17). Estimated at this average elasticity, we obtain oil and gas production equivalent of a 3.367 MMB quarterly as a result of a unit percentage change in price. If the elasticities are examined by water depth, these results show that Gulf oil production in the deep-waters is price inelastic in contrast to price elastic response in Gulf shallow waters. When examined by planning areas, central oil and gas production seems to be more price-elastic than the production in the western waters. In general, for a unit change in price it is expected that a greater production change will occur in the central waters of the Gulf than in the west.

Table 1J.17. Average oil and gas price elasticity of production in Gulf waters.

	GOALL	**GODEEP**	**GOSHALL**	**COALL**	**CODEEP**	**COSHALL**	**WOALL**	**WODEEP**	**WOSHALL**
Elasticity	1.170	0.812	1.250	1.162	0.807	1.291	1.025	1.271	0.995
Quantity Equiv. (MMB)	3.367	0.193	3.342	2.757	1.794	0.228	0.516	0.119	0.448

Note: COALL: production in central gulf; CODEEP: Production in central deep waters; WOALL, WODEEP, WOSHALL: indicates production in western waters, western deep waters, and western shallow waters, respectively.

SUMMARY AND CONCLUSIONS

In this study, we estimated a 3-VAR model to analyze the impact of oil price changes on oil and gas industry activities and Gulf State economies. The main hypothesis is that the impact of oil price on state economic aggregates would mostly be through industry activities.

However, the results show that changes in oil price have both direct and indirect effects on economic aggregates, but only direct effects on oil production, a proxy for industry activity.

From these results we conclude that

- Price is a significant variable for industry and state economies.
- Price effects on industry are more than on unemployment rate and personal income.
- On the other hand, state revenue is relatively more sensitive to both price and industry activities.
- Elasticity measures show that the sensitivity of industry activity and state economic indicators to price changes may differ by planning areas and water depths.

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SESSION 2G

SOCIAL SCIENCE II: HOW PEOPLE RESPOND TO THE CHANGING OIL INDUSTRY

Chair: Dr. Claudia Rogers, Minerals Management Service
Co-Chair: Dr. Harry Luton, Minerals Management Service

Date: January 10, 2002

The Current Dynamics of the Oil and Gas Industry 641
Ms. Barbara Wallace, TechLaw, Inc., Bethesda, Maryland

Labor Migration and the Deepwater Oil Industry 645
Dr. Katharine M. Donato, Department of Sociology, Rice University

The Coastal Division of Industrial Labor over Time and Space: Continuation and Expansion of a Community Study 653
Dr. John J. Beggs, Louisiana State University
Dr. Charles M. Tolbert, Baylor University

Migration and Commuting in Louisiana: the Case of Extractive Industries 677
Dr. Joachim Singelmann, Department of Sociology and Rural Sociology, Louisiana State University

THE CURRENT DYNAMICS OF THE OIL AND GAS INDUSTRY

Ms. Barbara Wallace
TechLaw, Inc., Bethesda, Maryland

BACKGROUND AND OBJECTIVES

The U.S. oil and gas industry has been transformed by sweeping changes in the last 20 or so years. Perhaps the most obvious evidence of change is the disappearance of the “seven sisters,” the multinational, multi-division corporations that were long dominant in national and international trade. Of the seven, Exxon, Chevron, Shell, British Petroleum, Mobil, Gulf, and Texaco, only the first-four named still exist as they did in 1980. Chevron acquired Gulf and Texaco, and Mobil merged with Exxon. Gulf succumbed because of poor performance and Texaco and Mobil were acquired or merged as giant corporations sought economies of consolidation and scale. John D. Rockefeller’s original Standard Oil of Ohio (SOHIO) and Amoco (Standard Oil of Indiana) were both acquired by British Petroleum, which had acquired Sinclair’s down stream assets, principally gasoline stations and refineries, when Arco bought Sinclair in 1968.

In the 1980s, the Gulf of Mexico (GOM) was considered a mature area for the offshore oil and gas industry, and activity was waning. Within a few years, this situation was reversed. Leasing activity increased. Exploration followed. Production from deepwater began to make a significant contribution to total U.S. oil and gas production. When activity increased in the GOM, changes in the industry were evident. Some of these changes were unanticipated; others were slow to emerge as trends.

To gain a better understanding of the industry changes and their implications, this study examined the oil and gas industry in the GOM from 1980 to 2000 and synthesized the implications of those changes on industry, socioeconomic, and onshore and offshore impacts in the GOM. The study focused on two issue areas, oil and gas price changes and corporate organization and strategy, and four crosscutting topics, economics and finance, technology, labor, and the regulatory environment. Changes that occurred in the issue areas and crosscutting topics reflect changes in industry in general, the oil and gas industry specifically, or individual companies or projects. The study was conducted through a review of industry, government, and academic publications and personal communication with industry representatives.

ISSUE AREA FINDINGS

Oil and gas price changes. Major elements in the transformation of the oil and gas industry are price volatility[1] and a general decline in the value of production, particularly of crude oil in the upstream sector. In 2000 dollars, the swings moved from a high of $54.46 per barrel in 1981 to a low of

[1] Price volatility describes the temporal rate of price fluctuation, and is measured by the day-to-day percentage difference in prices.

$11.26 in 1998. For natural gas the swing of wellhead price in 2000 dollars moved from a high of $4.02 in 1984 to a low of $1.69 in 1995.

Corporate organization and strategy. In the last 20 years, producers consolidated, restructured, implemented cost-saving technologies, and cost cutting programs. Companies sought economies through elimination of layers of management. They also re-examined properties, shedding some and acquiring others. Some companies reorganized to encourage effective adaptation to rapidly changing conditions and related opportunities. Sale of properties and company acquisitions created some large new independent producers. Large producers invested in foreign and offshore U.S. exploration and production. Foreign, nationally owned oil companies bought access to the U.S. market and took an interest in the GOM. Improvements in 3D seismography and the more rapid processing of data have progressively supported exploration in ever-deeper water. Exposure to risk was reduced through the use of joint ventures and alliances. The model of functional integration, from exploration to production, transportation, refining, and marketing, long the dominant model for large and medium sized oil companies, has undergone change. This model was displaced by asset management strategies, alliances, partnerships, and divestures.

CROSSCUTTING THEMES AND IMPLICATIONS

The issues and topics examined, prices, corporate organization and strategy, economics, technology, labor, and regulation, are so interwoven in the dynamics of the industry that consideration of one soon involves most or all of the others.

Drivers of Change

The following factors stand out as major forces that created change in the oil and gas industry between 1980 and 2000:

- Increasing volatility of prices. By 2000, price volatility, uncertainty, and risk had become facts of life for industry companies.

- Rising costs of oil and gas projects. In the last 20 years, OCS as a share of total domestic natural gas production increased modestly, while the share of total domestic oil production from OCS sources almost tripled. Deepwater production grew even more dramatically. Offshore projects, in general, and deepwater projects, in particular, are expensive, involving billion dollar investments.

- Globalization of the industry. The oil industry is international in scope. In the last 20 years, the GOM has had to compete with other areas of the world for investment by companies involved in projects around the world. Even independent companies that have traditionally restricted their activities to the Gulf began to operate internationally.

- Increased concern for shareholder value. In the last 20 years, the mission of oil companies shifted from extracting oil to providing shareholder value.

- Ascendance of technology. Like all industries, technology has enabled change. The flow of information and the speed of information have been drivers of change. Technology specific to the oil industry has enabled the industry to work in deeper water and more effectively exploit existing wells.

- Management of risk. Techniques used to manage risk represent changes in the industry and include use of improved technology to increase the potential for successful exploration, multi-company partnering for individual projects, use of futures, options, and other hedging instruments to protect against drop in prices, and the shift of research and development to contractors or research consortia.

Resurgence of the GOM

A convergence of factors led to the resurgence of oil and gas activity in the GOM. The shift to areawide leasing allowed companies to assemble a sufficiently large number of contiguous tracts to increase the potential for finding oil and gas and to justify deepwater exploration. The Deep Water Royalty Relief Act allowed MMS to suspend royalty payments to increase interest in deepwater exploration. Seismic imaging reduced the probability that exploration would be unsuccessful and increased the probability that additional oil and gas would be found in properties being reworked. Technology also made improvements in production. Prices were generally improving in the mid-1990s.

Industry, Socioeconomic, and Onshore and Offshore Impacts

Changes in the industry between 1980 and 2000 led to industry and socioeconomic impacts onshore and offshore. The industry is now a high-tech, new-economy industry. Risk management, corporate strategy, technology, and other factors have pushed the oil and gas industry in the direction of increasingly complex arrangements and operations. In the 20-year study period, the industry shifted from science-based to economic-based production. Technology generally allowed the industry to produce more oil and gas with less infrastructure and fewer personnel. The time required to do work has been reduced and the amount of information to do work has increased.

The industry responded to price volatility with a series of cost cutting programs that changed the way the industry uses personnel and how prospective workers respond to the industry. The cost cutting programs have left the industry with a shortage of personnel in all areas, reduced worker loyalty, dispelled the idea of job security, and made recruitment more difficult.

The basic steps to find, produce, and market petroleum remain unchanged and involve both onshore and offshore activities and result in onshore and offshore impacts. Changes in the industry are modifying these impacts. The rise of information technology is redefining where work is done. The ability to easily transmit electronically large amounts of information and monitor physical activities remotely means that workers, in many cases, can be physically distant from where actual oil and gas development or production work is done. Technological advances have meant more can be done with fewer people. Corporate decision-making has led to the ascendancy of Houston as a concentrated center of oil and gas companies and employment, shifting activities from New Orleans, Denver, Tulsa, and other formerly prominent oil and gas cities.

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LABOR MIGRATION AND THE DEEPWATER OIL INDUSTRY

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INTRODUCTION

This project draws on data collected from employers, community leaders, foreign-born workers, and other residents in four communities in southern Louisiana in the 1990s. Drawing on these data, the project examines the community impact of new immigrant populations in this area. Although Louisiana has not been a common destination area for U.S. immigrants in the past, field reports in the early 1990s suggested that many Latino migrants were working in shipbuilding and fabrication yards in the southern coastal areas of the state in the late 1990s. This paper presents findings from two of the four communities.

As a first step toward understanding differences in the community impact of immigrants in southern Louisiana, I describe the two communities used in this study: Houma and Morgan City (see Figure 2G.1). Both locales have been unusually tied to oil production and refining during the twentieth century. They house many fabrication and shipbuilding companies, and operate ports and canals to service offshore oil industry.

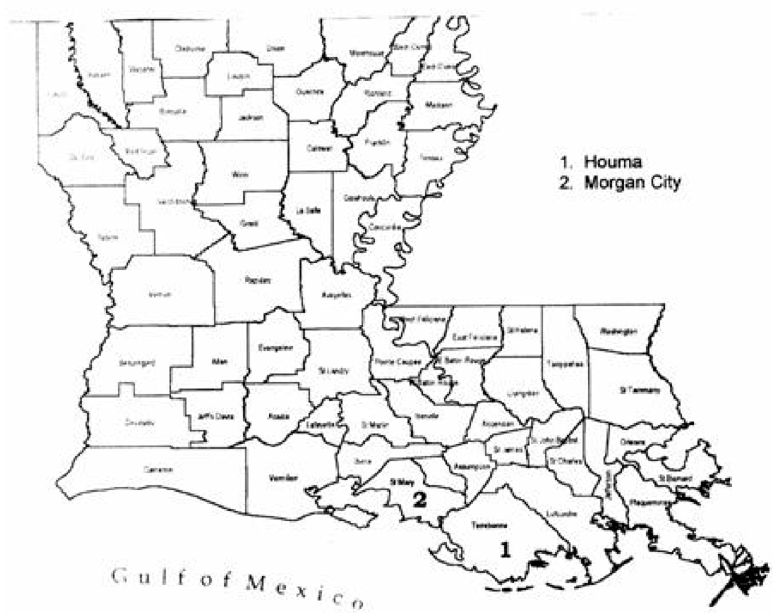

Figure 2G.1. The two communities used in the study: (1) Houma and (2) Morgan City.

The two communities share many characteristics. For example, both witnessed dramatic growth in the oil and gas industry during the first half of the twentieth century. Given that wetlands cover much of the geographic area, growth in the development of support construction services in these two communities was spurred on by the development of submersible drilling barges in shallow water in the 1930s (Gambling 1996). As a result, many migrated to the area, lured by economic opportunities and new federal investments in highways. They settled on land next to the natural levees found in the marshlands, also known as “string town” settlements (Kniffen 1968).

More able-bodied workers led to the development of new canal networks. Critical to Houma was the Houma Navigational Canal, completed in 1961 as a 30-mile connection between Terrebonne Bay and the Gulf of Mexico (GOM). In Morgan City, the port has operated since the mid 1950s to service a wide variety of vessels in the GOM.

In addition to the development of canal networks, new technology permitted drilling for oil offshore. In 1947, Morgan City became nationally known when its waters housed the first offshore oil well. This set in motion debates about land ownership, which once settled, led to the implementation of newly refined offshore technology that permitted drilling and processing in up to thousands of feet of water and in places located hundreds of miles offshore (Gramling 1996). The new technology includes seismic imaging, deepwater production and processing, and remotely operated vehicles. All together, these and other developments fueled growth in offshore oil production and onshore support services through much of the century, including the 1990s.

One consequence is that these two communities rely heavily on the oil industry for employment. For example, of the major private industry employers in each of these two areas in 1998, more than 80% were in oil and related services (*http://leap.ulm.edu*). Moreover, among all employees in the major private companies, more than 80% were employed in oil and related industries.

Despite these similarities, however, the demographic profiles of these two communities are quite different (see *http://leap.ulm.edu* or *www.census.gov*). Data from the 2000 decennial census show that the population of St. Mary’s Parish was about half the size of Terrebonne (58,000 vs. 97,000, respectively). Moreover, although these figures represent a population decline at a rate of 7.9% for St. Mary’s Parish, for Terrebonne they represent an increase at approximately the same rate.

Census data also suggest considerable shifts in the Hispanic composition of the two parishes in the 1990s. St. Mary’s Parish increased its overall Hispanic population by just 2.1%, whereas the Hispanic population in Terrebonne Parish increased at a rate of 18.5%. Differences in the growth of the Hispanic population during the decade are more dramatic when we make city comparisons. For example, Houma (in Terrebonne) experienced a 32.5% increase in its Hispanic population during the 1990s, but Morgan City (in St. Mary’s) experienced a 9.9% decline. These gains and losses compare to a 15.8% increase in Hispanic population for Louisiana as a whole.

Therefore, although the oil industry represented the key economic activity in both areas in the 1990s, their demographic profiles look remarkably different. One question that arises is whether and how the differences signal differences in the economic assimilation of Mexican immigrants, a point we discuss later. Before doing so, we briefly describe our data and summarize why Mexicans have begun to immigrate to coastal communities in southern Louisiana.

DATA AND METHODS

Our data collection effort was twofold. First, we gathered information from guided conversations with community stakeholders (leaders such as the mayor, school board president, medical expert, and director of social services), employers, and immigrants, to provide the basis for assessing the impacts of immigration (Lofland and Lofland 1995). This type of field research has been an effective means of data collection to capture the social processes underlying social science research (Orum, Feagin, and Sjoberg 1991; Tolbert and Tootle 1996). Second, we gathered interview data with information from a telephone survey of 200 randomly selected households in Morgan City and Houma. Using CATI technology, we implemented a survey that contained a wide variety of questions about immigrants and the oil industry.

Collection of new data was critical to the integrity of this project for two reasons. First, because the presence of immigrants was a very new phenomenon in these communities, 1990 data from the U.S. Census failed to capture the immigrants now settling in these areas. Second, although data from the 2000 Census will be useful in teasing out the effects of immigrant settlement, the detailed data will not become available until late 2002 (at the earliest). Even more critical than the five-year wait (between when the project began and when these data become available), we collected our own data to avoid missing capturing the earliest part of the immigrant experience in the United States.

The guided conservation methodology used in this project articulated in an interview guide (available upon request). Table 2G.1 summarizes the numbers and types of our guided conversations completed as part of this project. Of the total 94 guided conversations, we spoke with 21 community officials involved in civic organizations and local government, 43 employers, and 30 immigrant workers, of whom all were directly involved oil and gas development activities (Gramling 1996). With permission from respondents, we recorded these conversations on tape to avoid normal interruptions that occur from taking notes (either on a computer or by hand). Our interviewers conducted most worker interviews in Spanish, and then we had them translated them into English.

Table 2G.1. Number of guided conversations by type and community.

Community	Employer	Community Leader	Immigrant Worker	Total
Morgan City	14	14	19	50
Houma	26	7	11	44
Total	43	21	30	94

Louisiana Migration Project 2001

Once interviews were completed, they were then transcribed and coded into a series of data bases designed to summarize data from qualitative interviews. In using English versions of interviews conducted in Spanish, we retained files with the original Spanish to check for accuracy.

Using these data, we begin by presenting an overview of why Mexicans have migrated and continue to migrate to the United States, emphasizing explanations for Mexican migration to southern Louisiana. We then describe the process of economic integration of these migrants, how it differed by community of reception, and how contextual factors explain observed differences in the economic assimilation of Mexican immigrants in two southern Louisiana communities.

WHY MIGRATE TO LOUISIANA?

Although Louisiana has not been a common destination for the foreign-born during most of the twentieth century, it has become a destination for immigrants from Mexico since 1990. Propelled into movement by shifting supply conditions in Mexico, migrants primarily went to coastal communities in southern Louisiana searching for work. Here jobs in the oil industry were plentiful and offered reasonable wages because employers faced a serious shortage of skilled labor. Mexican workers were recruited to the area in formal and informal ways. Employers formally recruited workers by traveling to Mexico and arranging their transportation, housing, and legal documents while they lived and worked in the United States. After the first Mexican immigrants arrived, however, employers also offered these workers cash to recruit their friends and family members. New workers then arrived because they heard about well-paying, skilled and semi-skilled jobs in the fabrication centers and shipbuilding companies that supply and service off-shore drilling platforms. Therefore, consistent with studies by Krissman (1998) and others, employer demand for labor provided jobs that were subsequently filled by a supply of immigrants employers actively recruited.

Southern Louisiana employers were attracted to Mexican workers for a number of reasons. Motivated by a shortage of skilled workers in the local labor market, many employers saw Mexican workers as the answer: they had the skills for the jobs employers needed to fill, and they had a strong work ethic. Employers also sought out Mexican workers because they were profitable; they comprised an inexpensive workforce that was expendable. This is a necessary attribute for fabrication workers in southern Louisiana. During periods of high productivity, employers seek to hire as many workers as possible, but as the local economy loosens, employers must quickly scale back their workforce either by reducing hours or employees. Employers often targeted Mexican workers as their expendables to avoid affecting local workers and the community at large.[2] Finally, our interviews revealed that Mexican workers were paid less than their local counterparts. In some cases, this meant lower wages but in others, inequality took the form of contract workers hired without benefits. Therefore, because Mexican workers were seen as expendable, temporary, and

[2]One employer admitted to initiating a raid by the Immigration and Naturalization Service (INS) to reduce his workforce by approximately one third just before the holiday season, when business is typically very slow and many fabrication yards close down for several weeks. By having the INS raid his workplace, the employer got the INS to do what he did not: to layoff workers. INS intervention insured that the employer would not lose credibility with migrant workers, and as a result, when his company reopened that January, he had more than enough new applicants.

cheaper, employers in southern Louisiana increasingly hired them, sometimes placing them at the very top of the hiring queue.

DIFFERENT FORMS OF IMMIGRANT ECONOMIC INCORPORATION

Given similarities in the economic makeup of Morgan City and Houma—their heavy reliance on the oil industry and demand for blue collar labor—we expected to observe similarity in the economic incorporation of Mexican immigrants. Consistent with this idea was the expectation that immigrant workers in the two communities would not differ in their stock of human capital. In fact, from our immigrant interviews, we learned that most immigrant workers in Houma and Morgan City were born in Mexico. In addition, unlike recent studies suggesting that Mexican workers are settling in new U.S. destinations because they are searching for areas where their entire family may live, the substantial majority of our sample were men who migrated without their families. However, most men had families (wives, children, and parents) living in Mexico. They reported maintaining strong connections to their origins—emotionally, financially, and socially. Most sent money home to their families and returned frequently to visit. Many expressed a strong desire to return permanently to Mexico once they had improved their financial well-being. In short, workers in both communities maintained their social and economic attachments to Mexico through remittances, frequent return trips, and other forms of communication.

With respect to educational and work experience, most workers had only a few years of formal schooling. Some reported experience with welding and other jobs found in the oil industry before arriving in southern Louisiana. Although this job experience was acquired in Mexico or Texas in the past, on the whole most workers did not have papers certifying their welding or other work experience. The result was that they were hired as assistants to welders or as other semi-skilled laborers. Immigrants without any prior experience in welding or oil-related jobs typically began as helpers. Therefore, our interview data suggest no community differences in the human capital immigrant workers presented to their employers.

Despite the similar profiles, we found significant community differences in the economic experiences of Mexican migrants. Differences in communities' contexts of reception, we argue, ultimately led to different incorporation profiles for the two groups of immigrants. As many researchers have shown, the process of immigrant incorporation varies widely and largely depends on the characteristics of the arriving immigrant group and the context within which the immigrant group is received. In one part of their new book, Portes and Rumbaut (2001) describe how immigrant assimilation may be dramatically different for the same group of immigrants entering different social environments. In contrast to the idea that assimilation is a linear process where immigrant groups become more incorporated into the American mainstream as time progresses, the assimilation process of immigrants is segmented, not linear, and varies with the human capital brought by the group of newcomers' and with the context of the receiving community (Zhou 1997). Portes and Rumbaut (2001) describe three contextual factors that shape the process by which immigrants are incorporated into a particular community: government policies, societal reception of newcomers, and existing co-ethnic communities. Governmental policies in place at the time of migration shape the newcomers experience and affect the ability to use human capital and skills. According to Portes and Rumbaut, governmental policies may exclude, passively accept, or actively encourage immigration. If immigrant groups are not allowed to legally enter the United States, then they will not be offered any form of protection or assistance by the government and may be forced into an underground economy. In contrast, policies emphasizing passive acceptance may legally admit immigrants but do nothing to assist newcomers with incorporation. A final governmental policy, active encouragement, not only legally admits immigrants, but actively encourages migration of a particular group and provides a variety of adaptation resources. This occurs when the receiving country has a shortage of professional workers or when a particular group of immigrants are classified as refugees and participate in a government resettlement program. In both cases, the group is given special consideration and assistance that facilitates adaptation and possible upward mobility.

A second contextual factor affecting incorporation is the host community and its reception of newcomers. This refers to the extent to which newcomers are accepted by community members and employers. It affects the amount and quality of interaction between residents and newcomers and the willingness of the local community to provide valuable incorporation assistance (e.g., social services such as assistance with housing, transportation, language, employment, etc). Portes and Rumbaut (2001) state that newcomers who are most similar to the community members are most likely to be favorably received; those differing in appearance based on race/ethnicity, class, or some other attribute face greater barriers.

Finally, the extent to which a co-ethnic community has been previously established in the host community affects the newcomer's experience. Immigrants entering a community with well-established co-ethnic networks benefit by receiving invaluable assistance in finding jobs, housing, transportation, food and other immediate needs. Without a number of compatriots residing in the host community, migrants must often tackle their foreign community alone and often have more difficulty incorporating into the community.

All three modes of incorporation play a role in shaping the immigrant experiences in Houma and Morgan City. Utilizing the framework provided by Portes and Rumbaut (2001), we describe how these three factors led to differences in the economic and social assimilation despite striking similarities in the economic development and human capital of newly arrived immigrants in the two communities. Table 2G.2 places our southern Louisiana communities into Portes and Rumbaut's framework by describing the modes of incorporation of immigrant groups in each of the communities.

Table 2G.2. Modes of immigrant incorporation in two Southern Louisiana communities, 1999.

Community	**Mode of Incorporation**		
	Government	**Societal**	**Co-Ethnic**
Morgan City	Neutral	Prejudicial	Working class; concentrated
Houma	Favorable-neutral	Neutral-prejudicial	Working class; concentrated

Source: Portes and Rumbaut (2001)

In the final report, we use this table to help us describe the economic and social incorporation of the Hispanic newcomers in Houma and Morgan City. We rely on data from conversations with employers, community leaders, and Hispanic workers to explain how varying contextual factors shaped these outcomes. Employers, community reception, and co-ethnic networks all played key roles in the incorporation of the Hispanic newcomers to southern Louisiana, but in different ways.

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THE COASTAL DIVISION OF INDUSTRIAL LABOR OVER TIME AND SPACE: CONTINUATION AND EXPANSION OF A COMMUNITY STUDY

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INTRODUCTION

This research continues a project that began with a focus on Abbeville, a small community in southwestern Louisiana (Vermilion Parish). With funding from the U.S. Minerals Management Service (MMS), we are expanding the scope of the initial community study to test hypotheses derived from it. Abbeville appears to be particularly resistant to the income volatility that is generally associated with periods of increasing and decreasing oil and gas development activities. Previous research on census places in coastal Louisiana indicates that Abbeville experienced relatively less of the economic upheavals often associated with the downturn of the oil and gas industry in the early 1980s (Tolbert and Shihadeh 1995). Our current research suggests that its resiliency during the 1980s reflects a historical and cultural legacy that fosters rich social resources, facilitates economic development, and yields a local industrial structure that enables it to weather economic disruptions. Our findings suggest that, unlike most oil- and gas-dependent locations, Abbeville's industrial base is diverse. This industrial diversity is reflected in part by relatively large routine manufacturing, extractive (agriculture), and producer services sectors. The producer services sector is largely oil- and gas-related, as Abbeville is a center for operations and logistics.

In this study conducted at the Center for Economic Studies, we employ confidential longitudinal establishment data to analyze the distribution of coastal industrial labor over time and space. We are interested in the extent to which spatial and temporal divisions of labor, similar to those of Abbeville, exist within the oil and gas sectors elsewhere along the Gulf coast. We are also interested in the socioeconomic implications of these industrial patterns for coastal communities. Our goal is to develop measures of income volatility in coastal areas that are superior to those derived from summary information from decennial census long-form data. These measures and the analyses that they facilitate will contribute to a better understanding of the role of oil and gas activity vis-a-vis other industrial activity in local coastal communities.

FRAMEWORK

Socioeconomic conditions depend primarily upon patterns of industrial organization. Local economies are based on the allocation of employment across distinct industrial sectors. Each sector is associated with different working conditions, opportunities, and job outcomes (Lobao 1990). Industrial organization theory generally divides industries into extractive, manufacturing, and service categories. The manufacturing and service sectors can be further divided into four more discrete sectors, defined on the basis of the magnitude of the complexity of their operations and the earnings/benefits of workers: complex and routine manufacturing, and producer and consumer services (McGranahan 1988). In general, complex manufacturing and producer services are associated with higher wages and stable employment, while routine manufacturing and consumer services are associated with lower wages and unstable employment.

In rural areas (where much of the oil and gas activity is staged), sound economic performance often depends upon a diversified economy. This diversification tends to produce more consistent economic growth. Although specialized economies can expand rapidly, they are particularly vulnerable to local- and national-level economic swings. Because of a division of labor across space, most rural areas tend to specialize in low-wage routine production and consumer service sector jobs. Typically dominated by a single industrial sector, these communities are vulnerable to business cycles and foreign competition that encourage capital flight (Bluestone and Harrison 1982; McGranahan 1988).

Because diversified local economies do not depend upon any single sector source of employment and earnings, they are better prepared than more specialized economies to weather the economic downturns associated with specific industries (Killian and Hady 1988), such as the impending shutdown of large-scale production facilities throughout southwestern Louisiana (Acadiana). Unlike many of the communities in Acadiana, Abbeville does not depend solely upon such large-scale production facilities. Oil and gas activity is an integral part of its industrial structure and may help to counter the economic downturns associated with the flight of routine production facilities offshore by either absorbing some surplus labor or increasing local household earnings.

Because of the tendency for rural areas to specialize in routine manufacturing and consumer services, the industrial organizational and rural research literatures pay very little attention to producer services in rural areas. It is readily apparent that producer services in rural areas are linked closely to a dominant industrial base, such as mining (Glasmeier and Howland 1995). However, it is not at all clear how these linkages develop across time and space. The Abbeville area differs from other oil activity centers because it appears to be more central for oil field logistics and operations than oil field fabrication. We think that the concentration of oil-related producer services in Abbeville is a major factor in Abbeville's resiliency to the decline in oil and gas activity. For the most part, these oil-related producer services firms remained active, albeit at a diminished rate, throughout the 1980s. However, we currently do not have the necessary spatial and temporal data to examine and compare the distribution and differential impact of oil and gas activity across time and space.

Although instructive, this discussion begs a number of questions: How many specialized service firms are there in Abbeville? How long have they been there? Have these oil and gas service establishments agglomerated in identifiable clusters or is there considerable regionalization or spatial dispersion among them? Are these firms sufficiently embedded in the Abbeville economy to assist in cushioning the impact of a major plant closure or some other episode of economic volatility? Are the same industrial patterns exhibited in coastal communities elsewhere? Do those communities also have a history of less volatile responses to boom and bust episodes? Answering questions of this sort requires a combination of qualitative and quantitative data and methods. In the following section, we discuss these.

METHODOLOGY

Analysis of Enterprise Data over Time and Space

We believe our findings in the Abbeville case study are sufficiently robust to support a hypothesis for testing on other communities. The hypothesis is based on our observation of a thriving producer services sector in the Abbeville economy. Are similar service sectors evident in other coastal communities? Can such sectors be shown to be statistically related to the desirable outcomes we have observed in our Abbeville research?

To adequately assess the development of a producer services sector in Abbeville and other coastal communities, we plan to develop models of the coastal division of industrial labor, comparing socioeconomic outcomes for coastal areas with varying industrial and service sector compositions over time. We are especially interested in the extent to which industrial divisions of labor similar to that of Abbeville exist in other coastal communities. Assuming that we can identify areas with similar industrial profiles, we will analyze socioeconomic outcomes and compare those to the results we have in hand for Abbeville.

To accomplish this modeling task, we need data on the location and age of establishments, as well as very detailed industry classifications. These data requirements surpass such readily available data sources as *County Business Patterns* or published versions of data from the Economic Censuses. Although these data compendia are generally very useful, confidentiality concerns dictate that they frequently do not report data for small areas and small numbers of establishments. Although these establishment-level microdata are not in the public domain, they can be accessed through an agreement with the Center for Economic Studies (CES), U.S. Bureau of the Census.

CES has assembled establishment responses to various economic censuses. These data in conjunction with an age proxy available from the Census Bureau's SSEL (essentially a national business register), allow us to study the "embeddedness" of establishments. A major, related—and exploratory—interest of this project is studying the establishment formation/dissolution/survival and identifying how measures of churning in these establishment populations relate to measures of well-being. The economic census data also provide detailed industrial classification (four- and five-digit SIC codes) and establishment type (single-unit vs. multiple location) information. Access to these data represents a significant step forward for socioeconomic analysis. All previous socioeconomic work under the auspices of MMS has necessarily been based on public domain data that are often suppressed for reasons of confidentiality *and* that do not contain information on establishment age or type. By contrast, the economic census data contain no suppression and constitute the universe of U.S. establishments. We will use these data to develop a longitudinal database on coastal oil and gas producer services. We have budgeted for database coverage of all states adjacent to the Gulf of Mexico; this has been approved by MMS.

Working at CES, we are developing models of the coastal division of industrial labor, comparing socioeconomic outcomes for coastal areas with varying industrial and service sector compositions over time. We are especially interested in the extent to which industrial divisions of labor similar to that of Abbeville exist in other coastal communities. Assuming that we can identify areas with similar industrial profiles, we will analyze socioeconomic outcomes and compare those to the results we have in hand for Abbeville. For MMS resource management purposes, it would be very useful for us to explore the extent to which the Abbeville case is unique or whether there are other, similar areas whose industrial mix appears to buffer them from episodes of increasing and decreasing oil and gas industry activity.

OUTLINE OF CES ANALYSIS

Objectives

1. Employ confidential, longitudinal establishment data to analyze the Gulf coast industry mix over time and space and its relationship to income levels and income volatility.

2. Identify target industries with emphasis on producer services sector. Search for areas with industrial compositions similar to that of Abbeville, Louisiana (i.e., substantial involvement in oil and gas activity through service industries, as opposed to fabrication and extraction).

3. Explore variations in formation/dissolution (churning) of establishments coinciding with episodes of increased and decreased oil and gas industry activity. Compare rates of change for producer services versus other industries.

4. Explore use of 1990 long-form microdata to compute selected socioeconomic outcome measures and to estimate hierarchical linear models.

Units of Analysis: This analysis employs data for roughly 80,000 persons who work in approximately 900 incorporated places in the states of Texas, Louisiana, Mississippi, Alabama, Florida, and Georgia. All the incorporated places have populations of at least 2,500 persons. This permits us to match the place geography on the 1990 decennial information with the place geography found in the Economic Census of 1987 and 1992.

ANALYSIS

The analysis of enterprise data over time and space involves dealing with both a static and a dynamic issues. To evaluate oil and gas involvement of communities across space, we need to evaluate the degree of oil and gas involvement at a point in time, a static issue. When we evaluate across time, we need access to dynamic data to capture both the amount of change and the components of change. We will first discuss the static issue, oil and gas involvement at a point in time. Then we will discuss our analysis of the dynamic processes across time to evaluate change ant the components of change.

Evaluating the Oil and Gas Involvement of Communities

This section of our presentation consists of a cautionary note about public data sources based on economic census data collection procedures such as the widely used *County Business Patterns*. In our work with the *Census of Minerals,* we have discovered that substate geographies (e.g., metropolitan area, county, place) are not available. They are available neither in public data nor in the confidential establishment microdata that we employ at CES. Upon further investigation, we have learned that there are circumstances for which the Bureau does not collect or retain information other than state of operation. This is particularly the case for large enterprises that may have establishments in multiple locations. As a result, we omit minerals industries (SIC code 13) from our employment volatility analyses at the place level (at least temporarily).

This problem regarding information on minerals industries from *County Business Patterns* is further compounded by the Bureau's suppression of certain data in published reports. This suppression is done to ensure the confidentiality of data for specific establishments. Most often, suppression is used to avoid disclosing data on a single, dominant firm in an area. But, there are other reasons that data are suppressed. Suppression flags appear in data fields of the *County Business Patterns* for establishment employment and payroll. More often than not, the flag references a range of possible data values (say, 500-1,000 employees). Experienced users know to observe the suppression flags in public versions of the data and will typically derive an estimate of employment or payroll by using the midpoint of the interval.

Table 2G.3 illustrates how these two data problems interact to limit substantially the inferences that can be made from such published data sources as *County Business Patterns*. Each of the columns represents one of the Gulf-coast states that are the focus of our ongoing work. The data for Alabama indicate that 23 Alabama counties are identified as having one or more minerals industries establishments. In 20 of those 23 counties, however, employment and/or payroll data are suppressed. There are minerals establishments in other counties of Alabama, but the counties are not identified (the balance of the data are grouped into a single residual geographic category - code 999). Because establishment counts are not suppressed, we can report 90 minerals industry establishments for which counties are identified and 41 establishments in the non-identified geographic unit. This sums to the 131 found in the state total section. Payroll and total employment are suppressed for the generic geographic category in Alabama. What do we miss because of this? Because the state total payroll (in $1,000s) is $67,792 and the identified county payroll is $10,357, we do not have substate geography for $57,435, which is 85% of Alabama's minerals industries' payroll. Similarly, we cannot identify a location within the state for 84% of the employment in the industry. We know only that the place of work is somewhere in Alabama. Although Alabama may be the extreme case, there is substantial unaccounted information for all states in Table 2G.3. In Louisiana, 58% of the payroll and 49% of the employment information is not identified at the county level (county code = 999) and another 15% of payroll and 19% of employment information is suppressed at the county level. Thus there is no county level identification for 73% (58 + 15) of payroll and 68% (49 + 19) of employment information. For Texas, 46% of payroll and 47% of employment information has no county-level identification.

Among the datasets available at Census is the underlying establishment microdata for *County Business Patterns*. Because there is no suppression in these data, we are able to work with precise figures rather than estimates. This enables us to resolve the suppression problem. But, we have yet to resolve the geography problem in the minerals data. Thus, using the restricted access establishment microdata, we can identify county level information for the 15% of suppressed payroll and

Table 2G.3. Limitations of county business patterns data on mining.

	Alabama	Florida	Louisiana	Mississippi	Texas
State Totals					
Number of Identified Counties (Valid FIPS) With Mining Establishments	23	27	54	34	205
Number of Identified Counties (Valid FIPS) With Suppressed Mining Data	20	22	28	26	119
State Total Payroll in Mining	67792	16229	1551169	95173	3913068
State Total Employment in Mining	2016	501	42696	3539	104151
State Total Establishments	131	101	1451	345	6714
Identified Counties (Valid FIPS Code)					
Total Payroll in Mining	10357	1280	409970	21151	2113276
Total Employment in Mining	322	58	13828	743	56021
Number of Establishments	90	85	1284	284	6487
Total Information in Unidentifiable Geographic Unit (State Total-Identified)					
Payroll (% of State Total in Unidentifiable Geographic Units)	57435 (85%)	14949 (92%)	1141199 (73%)	74022 (78%)	1799792 (46%)
Employment (% of State Total in Unidentifiable Geographic Units)	1694 (84%)	443 (88%)	28868 (68%)	2796 (79%)	1664 (47%)
Non-Identified Counties (999)					
Total Payroll in Mining	X	6898 (43%)	902555 (58%)	36233 (38%)	X
Total Employment in Mining	X	191 (38%)	20776 (49%)	1132 (32%)	X
Number of Establishments	41	16	167	61	227
Suppressed Information (State Total-(Identified+Non-Identified))					
Payroll (% of State Total Unaccounted for by County Data)	57435 (85%)	8051 (50%)	238644 (15%)	37789 (40%)	1799792 (46%)
Employment (% of State Total Unaccounted for by County Data)	1694 (84%)	252 (50%)	8092 (19%)	1664 (47%)	1664 (47%)
X=Total Data Suppressed in CBP					

19% of suppressed employment data for Louisiana. But we are not able to identify county-level information for the 58% of payroll and 49% of employment data for Louisiana that has county coded "999."

We have attempted to use several related datasets including the Standard Statistical Establishment List (SSEL)—the Bureau's national establishment register. None of the business data sets has provided a solution for the geography problem. The best solution that we have been able to identify involves using the restricted-access 1990 population census long-form microdata. These data have place of work coded at a sufficient level of geographic specificity. Using the industrial classification also present in these data, we are able to derive a reliable community-level estimate of minerals industry employment activities. We construct a percentage share of total employment for oil and gas employment as our indicator of community involvement in the oil and gas industry. Currently, this is our best answer to our static question that compares communities across space on their level of oil and gas involvement. This solution does not provide us with such establishment-level information as size of establishment (based on either employment, payroll, or revenues), form of establishment (multi- establishment firm, ownership structure), and other information in the establishment microdata from the economic census. In a new project, we will investigate other solutions, including ES-202 data and proprietary data sources, which might expand the breadth of information available.

Employment Volatility

One of the primary concerns about the social impacts of ties to the oil and gas industry involves the potential employment volatility due to fluctuations in oil and gas industry activity. To evaluate the differences between oil- and gas-dependent and other communities, we developed several measures of employment volatility. These measures may also be called gross job flows or job churning. We first constructed a measure of *net employment change*: total employment at some time 2 (T2) minus total employment at a time 1 (TI) divided by total employment (TI). Data to construct this measure are readily available from public sources (i.e. economic censuses or county business patterns). Such economists as David Birch(1979) and Steven Davis, John Haltiwanger, and Scott Schuh (1996) have pointed out that a tremendous amount of job reallocation is not captured by a gross net change measure such as this one. Net job change is composed of jobs that existed at both time points, jobs that were created between TI and T2, and jobs that were lost between TI and T2. The job creation and job destruction each have two sources: (a) establishments that existed at both points in time and either expanded or contracted and (b) establishments that were created or dissolved.

Economists, like David Birch, have pointed out that the underlying turbulence in the labor market may indicate a highly innovative economic system. Many new businesses are formed due to innovation at the same time as the dissolution of businesses with outmoded technology. This brings great turbulence to the job market as jobs are created by the innovating businesses and eliminated by business failures. The Progressive Policy Institute has a new Economy Index to assist policy makers in developing economic strategies (*http://www.neweconomyindex.org/index.html*). The site shows this index for New Orleans (*http://www.neweconomyindex.org/metro/neworlenas.html)*. Under the grouping "Aggregated Economic Dynamism Scores," "job churning" and its importance is discussed (*http://www.neweconomyindex.org/metro/part3_page2.html*). They note that churning has increased over the last three decades and is “a major driver of economic innovation and growth.” The job churning scores, for the 50 metropolitan areas analyzed are reported. Although New Orleans’ overall rank was 30, its rank on the job churning is 23.

The Progressive Policy Institute makes note of the “increased economic risk faced by workers, companies, and even regions” in this environment of high job churning. Sociologists have long recognized that the social impact of this type of situation reaches beyond just economic risk. Citing Durkheim’s *Suicide* (1897), Smelser and Warner (1976) write:

> Under ordinary circumstances society provides moral norms, norms that are regarded by the majority as legitimate, to restrain and discipline the individual. ‘But when society is disturbed by some painful crisis or by beneficent but abrupt transitions, it is momentarily incapable of exercising this influence,’ and that is the painful condition that Durkheim called ‘anomie.’

It is not only bad times (recessions, busts) that may bring social instability; boom times (the late 1990s) may also be a destabilizing influence. As there are heightened levels anomie in a community, the old rules (norms) lose their ability to generate conforming behavior (restrain and discipline the individual). Nonconforming, disruptive behavior becomes more prevalent. This lack of community stability and cohesion has been linked to delinquency (Shaw and McKay 1969), crime (Sampson and Groves 1989; Crutchfield 1989), adolescent sexual activity (Brewster, Billy, and Grady 1993), and negative health consequences (Aneshensel and Sucoff 1996; Ross 2000; Ross and Jang 2000; Ross and Mirowsky 2001). Based on an analysis of young white men, Bernhardt *et al*. (1999) confirm a significant increase in job instability and that the wage returns to job changing have declined as a result of ob changes.

It is one thing to have community instability during periods of innovative advances. However, to the degree that this instability results from fluctuations in global commodity prices (in this case, oil), a community may have to bear the burden of instability without the benefit of economic development. Although there is significant innovation in the oil and gas industry, it would appear that the boom and bust cycle experienced in the Gulf Coast area is more a function of fluctuations in commodity prices. It is possible that the excessive volatility associated with this cyclic process may facilitate the development of a more anomic social environment and the social disorders that are associated with this environment.

The questions that we address in this paper are

1. Does Louisiana appear to have elevated levels of job churning or volatility?

2. Is volatility in the oil and gas industry higher than for the economy as a whole?

3. Does the level of oil and gas involvement in communities along the Gulf Coast appear to be related to the level of volatility? and

4. Can we identify characteristics of oil and gas involved communities that may mitigate the volatility?

Measuring Employment Volatility

To correctly evaluate employment volatility, we need to consider all of the sources of employment change. To build such measures, we need dynamic data—establishment-level data for employment for at least two points in time. To address our first two questions, we will use data developed by the Census Bureau and the Office of Advocacy of the Small Business Administration. The Business Information Tracking System (BITS) is a longitudinal file that links establishments over time. We can use the information on job loss due to establishment dissolution (death) and contraction, job gains from establishment creation (births) and expansion, and surviving jobs to create measures of employment volatility (see *http://www.neweconomyindex.org/metro/part_3page2.html* ; *http://www.census.gov/csd/susb/susb.htm*).

Because there are no dynamic aggregate data at the sub-state level, we need dynamic microdata to answer the last two questions. These "microdata" data are not available from public sources. They are available to us, however, at CES. We use microdata from the economic censuses of 1987 and 1992 to construct our employment volatility measures. However, we are limited to those sectors of the economy in which data are available at both points in time. We used data from the manufacturing, wholesale, retail, and service sectors to construct our measures. Although we planned to include the minerals census data also because of our interest in oil and gas employment, problems with local (substate) geography precluded doing so. In all other respects, the economic census microdata are ideal because we want to gauge employment volatility in local communities. The establishment microdata have a suite of geography items, including information on the name of the incorporated place in which the establishment is located. This permits us organize the data by locality or community. In all, we use data about 900 incorporated places of 2,500 persons or more from the five states that border the Gulf of Mexico (Florida, Alabama, Mississippi, Louisiana, and Texas).

We report information on a number of measures of employment volatility or turbulence in coastal communities in this presentation. These measures are defined in Table 2G.4. We use only one measure to address questions 1 and 2. This is measure 13, which addresses *total employment volatility*. It is constructed by summing the jobs that were created either in existing or new establishments and the jobs that were lost either from existing or dissolved establishments. These are jobs that existed at either 1987 or 1992, but not 1987 *and* 1992 . The sum is then divided by this total plus the jobs that existed at both 1987 and 1992. The remaining measures will be used in the analysis for questions 3 and 4. The first measure indicates net employment growth. This is the measure that is most often reported. As noted above, a substantial amount of job creation and destruction remains untapped by this measure. In theory, we could have zero net growth and a score of 100% on the volatility measure. For that score to occur, all old (1987) jobs would be eliminated and a whole new (1992) set of jobs would be created. This, of course, does not happen in practice. But, among our 900 places, the correlation of employment volatility and net growth is only .23. The next five measures (2, 3, 4, 5, and 6) focus on the components of employment volatility. Measures 7, 8, and 9 look at establishments, rather than employment. The name turbulence is used as a surrogate for volatility. Measures 10 and 11 focus separately on *job creation* and *job destruction*;

Table 2G.4. Definitions of dependent variables.

1. Total Employment Growth-Calculated as the change in employment between 1987 and 1992 divided by the total employment in 1987.
2. Gain Volatility-Calculated as the employment generated through survivor employment growth divided by the total employment in both time periods.
3. Lost Volatility-Calculated as the employment loss generated through survivor employment loss divided by the total employment in both time periods.
4. Same Volatility-Calculated as the employment generated through survivor employment staying constant across 1987 and 1992 divided by the total employment in both time periods.
5. Birth Volatility-Calculated as the employment generated through establishment birth divided by the total employment in both time periods.
6. Death Volatility-Calculated as the employment lost through establishment death divided by the total employment in both time periods.
7. Establishment Turbulence 1987-Calculated as the number of establishment deaths divided by the total establishments in 1987.
8. Establishment Turbulence 1992-Calculated as the number of establishment births divided by the total establishments in 1987.
9. Total Establishment Turbulence-Calculated as the number of establishment births and deaths divided by the total establishments existing either in 1987 or 1992.
10. Employment Turbulence 1987-Calculated as the total employment lost from establishment death divided by the total employment in 1987.
11. Employment Turbulence 1992-Calculated as the total employment gained from establishment birth divided by the total employment in 1992.
12. Total Employment Turbulence-Calculated as the total employment generated by births and deaths divided by the total employment from births, deaths, and survivor employment (1992 only for survivor employment).
13. Employment Volatility -Calculated as the total employment generated by births, deaths, survivors gaining employment, and survivors losing employment divided by the total employment resulting from births, deaths, survivors gaining employment, survivors losing employment, and survivors with no employment change.
14. Employment Volatility 1987-Calculated as the total employment lost due to deaths and survivors losing employment divided by the total employment in 1987.
15. Employment Volatility 1992-Calculated as the total employment gained due to births and survivors gaining employment divided by the total employment in 1992.

they are slightly different versions on measures 6 and 5. Measures 14 and 15 are, once again, slightly different versions of measures 6 and 5.

The same volatility measure is used for Tables 2G.5 through 2G.9. This is based on dynamic data obtained from the Small Business Administration web site (*http://www.sba.gov/advo/stats/data.html*). These data trace establishment employment between 1997 and 1998. These data are reported at the state and national levels. I will demonstrate the calculation of the volatility measure with the Table 2G.4 data and then report the measure for the remaining tables. To calculate the number of jobs that existed in 1987 or 1992 but not in 1987 and 1992, we sum the absolute values of the numbers for change in employment due to births, deaths, expansions, and contractions.

6309177 + 5660505 + 11781834 + 9617329 = 33368845

This number, 33368845, represents the number of jobs for which there was discontinuity across the time period. To calculate the number of jobs for which there was continuity across the period we subtract from the initial year employment, employment loses from deaths (dissolutions) and contractions.

105266491 - 5660505 - 9617329 = 89982657

Adding the two totals we just calculated produces the total number of jobs that existed at some point in this period.

89982657 + 33368845 = 123351502

Our volatility measure is calculated by dividing the first calculated total (33368845) by the last calculated total (123351502) and multiplying by 100.

33368845 / 123351502 * 100 = 27.1

This number is interpreted as the percent of jobs that existed at some point in this period that did not exist at both points in the period—in other words, the percent of jobs which for which there was not continuity across the time period. For 27.1% of the jobs that existed at some point in the period, there was not continuity across the time period. This is the figure for total employment in the United States. Table 2G.6 reports the data for total employment in the state of Louisiana. The employment volatility measure for Louisiana is 27.9%. This (279%) is somewhat higher than the national measure (27.1%). To put this in perspective, if the national measure had been 27.9%, there would have been an additional 1,046,244 jobs that lacked continuity. Or if Louisiana had been at the national level (27.1%), 15,113 additional jobs would have had continuity. These are not trivial differences. Thus, the answer to question 1, “does the Louisiana appear to have elevated levels of job churning or volatility?” appears to be “yes.”

Tables 2G.7 through 2G.9 address question 2, is volatility in the oil and gas industry higher than for the economy as a whole? Tables 2G.7 and G.8 consider national patterns. Table 2G.7 evaluates data for SIC Code 1300, the Oil and Gas Extraction Industry. Table 2G.8 addresses a subset of this

Table 2G.5. Establishment and Employment changes from births, deaths, expansions, and contractions by employment size of the enterprise for the United States, totals: 1997 – 1998.

DATA TYPE	TOTAL	1-4	5-9	10-19	20-99	100-499	500+	<500
Initial year establishments	6120714	2637864	1021084	637784	678236	302053	843693	5277021
Change in establishments	66363	44678	5754	-3511	-9191	4189	24444	41919
Percent change in establishments	1.1	1.7	0.6	-0.6	-1.4	1.4	2.9	0.8
Establishment births	719616	445989	82888	37473	29309	23004	100953	618663
Establishment deaths	653253	401311	77134	40984	38500	18815	76509	576744
Establishment expansions	1824454	578779	325777	236952	278649	118312	285985	1538469
Establishment contractions	1582321	352310	354761	250163	253849	103941	267297	1315024
Percent change in establishments due to births	11.8	16.9	8.1	5.9	4.3	7.6	12	11.7
Percent change in establishments due to deaths	-10.7	-15.2	-7.6	-6.4	-5.7	-6.2	-9.1	-10.9
Initial year employment	105260491	5538319	6602147	7955300	19101104	15312188	50751433	54509058
Change in employment	2813177	954468	261566	170259	230746	117537	1078601	1734576
Percent change in employment	2.7	17.2	4	2.1	1.2	0.8	2.1	3.2
Change in employment due to births	6309177	801861	532531	487922	892355	730969	2863539	3445638
Change in employment due to deaths	-5660505	-703481	-488438	-497028	-1001709	-715096	-2254753	-3405752
Change in employment due to expansions	11781834	1299057	932578	996201	2164860	1635689	4753449	7028385
Change in employment due to contractions	-9617329	-442969	-715105	-816836	-1824760	-1534025	-4283634	-5333695
Percent change in employment due to births	6	14.5	8.1	6.1	4.7	4.8	5.6	6.3
Percent change in employment due to deaths	-5.4	-12.7	-7.4	-6.2	-5.2	-4.7	-4.4	-6.2
Percent change in employment due to expansions & births	17.2	37.9	22.2	18.7	16	15.5	15	19.2
Percent change in employment due to contractions & deaths	-14.5	-20.7	-18.2	-16.5	-14.8	-14.7	-12.9	-16

Table 2G.6. Establishment and employment changes from births, deaths, expansions, and contractions by employment size of the enterprise for Louisiana, totals: 1997 – 1998.

DATA TYPE	TOTAL	1-4	5-9	10-19	20-99	100-499	500+	<500
Initial year establishments	91,110	36,687	15,572	9,796	10,935	4,597	13,523	77,587
Change in establishments	679	366	152	-24	-181	277	89	590
Percent change in establishments	0.7	1	1	-0.2	-1.7	6	0.7	0.8
Establishment births	10,152	5,828	1,369	583	506	556	1,310	8,842
Establishment deaths	9,473	5,462	1,217	607	687	279	1,221	8,252
Establishment expansions	27,837	8,160	4,976	3,737	4,518	1,832	4,614	23,223
Establishment contractions	23,289	4,749	5,276	3,717	4,006	1,538	4,003	19,286
Percent change in establishments due to births	11.1	15.9	8.8	6	4.6	12.1	9.7	11.4
Percent change in establishments due to deaths	-10.4	-14.9	-7.8	-6.2	-6.3	-6.1	-9	-10.6
Initial year employment	1,530,944	78,294	101,029	121,552	311,379	238,787	679,903	851,041
Change in employment	44,611	14,385	4,913	3,710	4,373	8,522	8,708	35,903
Percent change in employment	2.9	18.4	4.9	3.1	1.4	3.6	1.3	4.2
Change in employment due to births	93,602	10,899	8,942	7,588	16,523	19,376	30,274	63,328
Change in employment due to deaths	-87,063	-9,856	-7,696	-7,275	-18,627	-14,061	-29,548	-57,515
Change in employment due to expansions	180,813	19,220	14,174	15,505	36,864	29,028	66,022	114,791
Change in employment due to contractions	-142,741	-5,878	-10,507	-12,108	-30,387	-25,821	-58,040	-84,701
Percent change in employment due to births	6.1	13.9	8.9	6.2	5.3	8.1	4.5	7.4
Percent change in employment due to deaths	-5.7	-12.6	-7.6	-6	-6	-5.9	-4.3	-6.8
Percent change in employment due to expansions & births	17.9	38.5	22.9	19	17.1	20.3	14.2	20.9
Percent change in employment due to contractions & deaths	-15	-20.1	-18	-15.9	-15.7	-16.7	-12.9	-16.7

Table 2G.7. Establishment and employment changes from births, deaths, expansions, and contractions by employment size of the enterprise for the United States, industries (to 3 digit SIC) : 1997 - 1998. SIC CODE 1300 - oil and gas extraction.

DATA TYPE	TOTAL	1-4	5-9	10-19	20-99	100-499	500+	<500
Initial year establishments	16180	8092	2342	1567	1657	628	1894	14286
Change in establishments	-326	-151	15	-35	-55	-5	-95	-231
Percent change in establishments	-2	-1.9	0.6	-2.2	-3.3	-0.8	-5	-1.6
Establishment births	1614	1010	177	78	76	74	199	1415
Establishment deaths	1940	1161	162	113	131	79	294	1646
Establishment expansions	4302	1393	716	579	731	252	631	3671
Establishment contractions	3594	908	737	595	563	209	582	3012
Percent change in establishments due to births	10	12.5	7.6	5	4.6	11.8	10.5	9.9
Percent change in establishments due to deaths	-12	-14.3	-6.9	-7.2	-7.9	-12.6	-15.5	-11.5
Initial year employment	326655	15911	14492	18388	45826	36349	195689	130966
Change in employment	4232	2834	698	190	3569	96	-3155	7387
Percent change in employment	1.3	17.8	4.8	1	7.8	0.3	-1.6	5.6
Change in employment due to births	19430	1770	1129	963	2605	3578	9385	10045
Change in employment due to deaths	-28527	-1956	-972	-1329	-3023	-5812	-15435	-13092
Change in employment due to expansions	57367	4137	2104	2605	8348	6987	33186	24181
Change in employment due to contractions	-44038	-1117	-1563	-2049	-4361	-4657	-30291	-13747
Percent change in employment due to births	5.9	11.1	7.8	5.2	5.7	9.8	4.8	7.7
Percent change in employment due to deaths	-8.7	-12.3	-6.7	-7.2	-6.6	-16	-7.9	-10
Percent change in employment due to expansions & births	23.5	37.1	22.3	19.4	23.9	29.1	21.8	26.1
Percent change in employment due to contractions & deaths	-22.2	-19.3	-17.5	-18.4	-16.1	-28.8	-23.4	-20.5

Table 2G.8. Establishment and employment changes from births, deaths, expansions, and contractions by employment size of the enterprise for the United States, Industries (to 3 digit SIC) : 1997 - 1998. SIC CODE 1380 - oil and gas fieldservice.

DATA TYPE	TOTAL	1-4	5-9	10-19	20-99	100-499	500+	<500
Initial year establishments	8480	3918	1320	1039	1152	349	702	7778
Change in establishments	-138	-4	28	-26	-50	5	-91	-47
Percent change in establishments	-1.6	-0.1	2.1	-2.5	-4.3	1.4	-13	-0.6
Establishment births	966	619	135	53	49	56	54	912
Establishment deaths	1104	623	107	79	99	51	145	959
Establishment expansions	2650	811	461	428	535	160	255	2395
Establishment contractions	1905	467	410	363	393	109	163	1742
Percent change in establishments due to births	11.4	15.8	10.2	5.1	4.3	16	7.7	11.7
Percent change in establishments due to deaths	-13	-15.9	-8.1	-7.6	-8.6	-14.6	-20.7	-12.3
Initial year employment	175631	[i]	[i]	11827	32924	24397	90714	84917
Change in employment	9353	(D)	(D)	489	2603	191	3027	6326
Percent change in employment	5.3	(D)	(D)	4.1	7.9	0.8	3.3	7.4
Change in employment due to births	12749	1136	(D)	(D)	1988	(D)	4913	7836
Change in employment due to deaths	-20027	(D)	(D)	(D)	-2569	(D)	-9866	-10161
Change in employment due to expansions	39386	2805	1461	2097	6204	5498	21321	18065
Change in employment due to contractions	-22755	(D)	(D)	-1348	-3020	-3553	-13341	-9414
Percent change in employment due to births	7.3	(D)	(D)	(D)	6	(D)	5.4	9.2
Percent change in employment due to deaths	-11.4	(D)	(D)	(D)	-7.8	(D)	-10.9	-12
Percent change in employment due to expansions & births	29.7	(D)	(D)	(D)	24.9	(D)	28.9	30.5
Percent change in employment due to contractions & deaths	-24.4	(D)	(D)	(D)	-17	(D)	-25.6	-23.1

Table 2G.9. Establishment and employment changes from births, deaths, expansions, and contractions by employment size of the enterprise for Louisiana, mining: 1997 – 1998.

DATA TYPE	TOTAL	1-4	5-9	10-19	20-99	100-499	500+	<500
Initial year establishments	1,576	523	207	150	247	108	341	1,235
Change in establishments	-40	-5	-2	-5	-5	-2	-21	-19
Percent change in establishments	-2.5	-1	-1	-3.3	-2	-1.9	-6.2	-1.5
Establishment births	147	81	19	7	8	10	22	125
Establishment deaths	187	86	21	12	13	12	43	144
Establishment expansions	533	99	70	65	128	50	121	412
Establishment contractions	390	60	59	49	84	32	106	284
Percent change in establishments due to births	9.3	15.5	9.2	4.7	3.2	9.3	6.5	10.1
Percent change in establishments due to deaths	-11.9	-16.4	-10.1	-8	-5.3	-11.1	-12.6	-11.7
Initial year employment	54,253	[f]	1,217	1,685	7,078	[i]	35,598	18,655
Change in employment	3,909	(D)	132	100	2,076	(D)	2,267	1,642
Percent change in employment	7.2	(D)	10.8	5.9	29.3	(D)	6.4	8.8
Change in employment due to births	2,345	147	115	70	527	453	1,033	1,312
Change in employment due to deaths	-3,593	-148	-109	-149	-309	-1,818	-1,060	-2,533
Change in employment due to expansions	12,830	326	255	322	2,350	1,540	8,037	4,793
Change in employment due to contractions	-7,673	(D)	-129	-143	-492	(D)	-5,743	-1,930
Percent change in employment due to births	4.3	(D)	9.4	4.2	7.4	(D)	2.9	7
Percent change in employment due to deaths	-6.6	(D)	-9	-8.8	-4.4	(D)	-3	-13.6
Percent change in employment due to expansions & births	28	(D)	30.4	23.3	40.6	(D)	25.5	32.7
Percent change in employment due to contractions & deaths	-20.8	(D)	-19.6	-17.3	-11.3	(D)	-19.1	-23.9

industry, SIC Code 1360 Oil and Gas Field Services. Table 2G.9 considers the data available for Mining in Louisiana which is dominated by Oil and Gas activities. The employment volatility measures for the national data (Tables 2G.7 and 2G.8) are 37.0% for SIC 1300 Oil and Gas Extraction and 41.7% for SIC 1380 Oil and Gas Field Services. Both of these measures indicate a considerably greater amount of employment volatility in oil and gas activity. The employment volatility measure for Louisiana (Table 2G.9) is 38.1%. This exceeds slightly the national figure for Oil and Gas Extraction (38.1%) just as the total Louisiana measure (27.9%) was a little above the total national measure (27.1%). Furthermore, mining volatility (38.1%) is considerably higher than the overall employment volatility (27.9%) in Louisiana. It would appear that the answer to question 2 (is volatility in the oil and gas industry higher than for the economy as a whole?) receives a strong affirmative answer. Oil and gas employment has considerably higher volatility than the economy as a whole does. This conclusion is supported both by the national comparison and by the within Louisiana comparison. The elevated level of oil and gas employment volatility is very evident even in an economy with a high level of oil and gas activity.

Table 2G.10 address question 3: “does the level of oil and gas involvement in communities along the Gulf Coast appear to be related to the level of volatility?” In this table, we compare communities with above-average scores on an oil and gas factor developed from share measures (proportion of local employment in an extensive list of industries) of local economies. We used factor analysis to evaluate the pattern of industrial sector employment. Among our final factors was one that primarily tapped oil and gas activity. This analysis is based on those communities that had a positive score on this factor. This group is then divided into communities that are less than one standard deviation above the mean (medium activity) and those communities that are at least one standard deviation above the mean (high activity). The last row in Table 2G.10 reports the average percent of the local (community) employment that is within the oil and gas industry. For communities with medium oil and gas activity, 1.23 % of local employment is in the oil and gas industry; for communities with high activity, 7.128% of employment is in oil and gas.

The other rows in this table report t-tests between these two groups for volatility differences. Exact figures are not reported for Lost volatility and Death volatility for disclosure reasons. The row labeled Employment Volatility is the same measure reported in the analysis for questions 1 and 2. This measures indicates considerably higher levels of volatility than in the previous analysis. These data evaluate volatility over a five-year period whereas the earlier analysis looked at volatility over a one-year period. Thus, an establishment had to survive only one year to be considered a survivor (be continuous); for this analysis the establishment has to last five years to be classified as a survivor. A great deal of short-term volatility is not captured in this analysis. A number of establishments, especially small establishments, will come into and go out of business during the intervening years. We capture them only if they are present at one or the other points in time. However, the economic censuses are conducted only every five years. Therefore, we were constrained to use a five-year period for this analysis. Annual datasets are being developed that we will be able to use in future work.

There are statistically significant differences on 10 of the 14 volatility comparisons in this table. If one examines comparisons involving employment, 9 of the 11 comparisons have significant differences. There does appear to be considerably more volatility in the high oil and gas group. The

Table 2G.10. Means, standard deviations, and t-test for differences in means for oil and gas intensive places (category 3 and 4).

Turbulence and Volatility Measures	Oil Gas Factor >=0 and <1	Oil Gas Factor >=1
Total Employment Growth	12.334 (26.328)	13.280 (38.029)
Gain Volatility*	11.004 (5.503)	9.648 (3.454)
Lost Volatility	Lower	Higher
Same Volatility*	41.082 (10.465)	37.683 (10.758)
Birth Volatility*	21.605 (9.139)	24.362 (9.972)
Death Volatility	Lower	Higher
Establishment Turbulence 1987*	43.895 (6.679)	46.069 (6.786)
Establishment Turbulence 1992	44.290 (9.449)	44.822 (9.353)
Total Establishment Turbulence	61.117 (7.042)	62.472 (6.524)
Employment Turbulence 1987*	28.601 (11.320)	31.774(12.246)
Employment Turbulence 1992*	29.694 (12.583)	34.154 (12.745)
Total Employment Turbulence*	43.716 (13.276)	48.622 (12.616)
Employment Volatility *	58.918 (10.465)	62.323 (10.758)
Employment Volatility 1987*	39.231 (12.005)	43.026 (12.987)
Employment Volatility 1992*	44.416 (11.953)	47.753 (12.298)
Oil Extractive Activities*	1.240 (1.143)	7.128 (5.187)

*indicates p<.05 two-tailed test; Standard Deviation in Parentheses

first comparison in this table is our net growth measure. This difference is not statistically different. The next five comparisons focus on the components of volatility. Three of the five comparisons are statistically significant. Two of these comparisons show the medium activity group with statistically higher levels. One of these comparisons is really the opposite of volatility. Some volatility is really stability: the percent of the jobs that were present at both points in time. This is the volatility component that only appears in the denominator of the measure. The medium-activity group has a higher level on this stability measure. It is also higher on gain volatility. This measure is the percent of jobs that were added through expansions to existing establishments—new jobs in establishments that are present at the beginning and end of the time period. The medium-activity group is more likely to hold existing jobs and to add jobs to existing establishments. All other significant comparisons favor the high-activity group. A greater percent of their jobs came from jobs at new establishments. The Establishment Turbulence 1987 measure indicates that the high activity group is more likely to have firm dissolutions. The remaining significant comparisons all involve a form of employment volatility and indicate more volatility in the high activity group. Thus, these data do support the contention that the level of oil and gas involvement in communities along the Gulf Coast is related to the level of volatility: As oil and gas activity increases so does employment volatility.

Finally, we turn to Table 2G.11 for information about question 4: Can we identify characteristics of oil- and gas-involved communities that may mitigate the level of volatility in their economies? The first thirteen rows of this table report comparisons of selected industrial sector factors that were created through a factor analysis of our industrial share of employment data from the 1990 census micro data. The final nine rows look at detailed industrial sectors. Two community characteristics, population and proportion nonmetropolitan population, are between these two groups of indicators. Because of disclosure considerations, we are not able to report precise figures for these comparisons, but we are able to report direction and statistical significance.

Based on considerable exploratory analysis of data from various sources, we concluded that the presence of significant professional service and public administration sectors in a community would mitigate the volatility that may occur in communities with significant oil and gas involvement. In particular, the presence of significant legal, financial, and medical services along with public administration appear to be the key. The significant presence of these sectors in the local community appears to be associated with places that are able to buffer the swings of the commodity price cycle that disrupt other oil- and gas-involved communities so significantly. Although this analysis is still in the exploratory stage, we believe that the answer to question number 4 will be that we can identify these characteristics.

We began this analysis with the following questions:

1. Does Louisiana appear to have elevated levels of job churning or volatility?

2. Is volatility in the oil and gas industry higher than for the economy as a whole?

3. Does the level of oil and gas involvement in communities along the Gulf Coast appear to be related to the level of volatility? and

4. Can we identify characteristics of oil and gas involved communities that may mitigate the volatility?

We have answered both questions 2 and 3 with an unequivocal “yes.” Employment in the oil and gas industry does exhibit more volatility than the economy as a whole, both for national and within-Louisiana comparisons. Oil and gas involvement in communities along the Gulf of Mexico is associated with higher levels of employment volatility. The answer to question 1 is also “yes,” but the answer may be more equivocal than it is for the other two questions. Louisiana does appear to have a somewhat higher level of volatility (27.9% to 27.1%) than the overall economy does. Question 4 receives a qualified “yes” because the analysis is exploratory at this point.

This analysis addresses the first part of a broader question. It is possible that the excessive volatility associated with this cyclic process may produce a more anomic social environment and the social disorders that are associated with this environment. We have been able to confirm that excessive

Table 2G.11. T-test for differences in means for significant professional service sector and smaller professional service sector places with significant oil and gas involvement.

Measures of Occupation and Industry Structure	Significant Professional	Smaller Professional
Business Services Factor	Higher	Lower
Wholesale Factor *	Higher	Lower
Real Estate, Hotels Factor	Higher	Lower
Professional Services Factor *	Higher	Lower
Retail Factor	Higher	Lower
Refineries Factor *	Lower	Higher
Ship Related Factor +	Lower	Higher
Transportation Factor	Lower	Higher
Agriculture/Personal Services Factor	Lower	Higher
Welder Factor	Higher	Lower
Military/Public Administration Factor *	Higher	Lower
Education and Testing Factor	Lower	Higher
Construction Factor	Lower	Higher
Population, 1990	Higher	Lower
Proportion Nonmetro	Lower	Higher
Legal Services *	Higher	Lower
Insurance *	Higher	Lower
Banks *	Higher	Lower
Medical Services *	Higher	Lower
Engineering, Architectural, and Surveying	Higher	Lower
Accounting, Auditing, Bookkeeping	Higher	Lower
Management and Public Relations	Higher	Lower
Public Administration *	Higher	Lower
Oil and Gas Extraction	Lower	Higher

+ indicates p<.05, one-tailed test; *indicates p<.05 two-tailed test employment volatility is associated with the level of oil and gas involvement in a community. It is still a question whether this employment volatility does facilitate the development of a more anomic social environment and the social disorders that are associated with this environment. Is this volatility a function of the commodity price cycle of oil? Or does it just reflect an innovation process associated with the healthy development of the industry? We hope to address these issues in our future work.

Having access to the confidential micro data from the decennial and economic censuses has provided us with a means of addressing a research issue that we had not been able to tackle with existing publicly available data. We are interested in the impact of a small sector of the economy (oil and gas) at a low level of geography (places). The data at CES permit us to develop useful information about the relationship between oil and gas employment in local communities along the Gulf of Mexico. A number of these communities are small non-metropolitan places for which limited, if any, information is available. We were able to gain a greater understanding of the dynamics of the labor market for these areas through our analysis of the components of employment change.

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Charles M. Tolbert, II, obtained his Ph.D. from the University of Georgia in 1980. After holding faculty positions at Florida State and Louisiana State University, he is presently Professor and Chair of Sociology and Anthropology at Baylor University. He is also a senior scientist at Baylor's Center for Community Research and Development and a Research Associate with Special Sworn Status at the Center for Economic Studies, U.S. Census Bureau. Previously, he was Head, Departments of Sociology and Rural Sociology, Louisiana State University and Senior Research Scientist with the Louisiana Population Data Center. Dr. Tolbert has longstanding interests in labor markets, social inequality, and applied social demography. He is the author of three books and numerous agency reports. His research has appeared in social science journals such as the *American Sociological Review*, *American Journal of Sociology*, *Rural Sociology*, *Social Forces*, *Social Science Quarterly*, *Environment and Planning A* and in policy outlets such as *American Demographics*. Dr. Tolbert's research has been funded by the National Science Foundation, U.S. Departments of Agriculture (Economic Research Service and National Research Initiative), Commerce (Census Bureau, Economic Development Administration, and National Marine Fisheries Service), Interior (Minerals Management Service), and Labor (Employment and Training Administration), as well as the Louisiana Universities Marine Consortium (LUMCON) and the Louisiana Office of Community Services. He has also provided expert testimony in voting rights, school desegregation, and annexation cases on behalf of the U.S. Department of Justice and other parties.

MIGRATION AND COMMUTING IN LOUISIANA: THE CASE OF EXTRACTIVE INDUSTRIES

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This presentation summarizes some findings regarding commuting and migration patterns in Louisiana, with special emphasis on coastal areas and extractive industries.

COMMUTING PATTERNS 1960-90

In general, the proportion of commuters among workers in Louisiana has steadily increased during the period 1960-90 as the number of commuters grew faster than that of workers. The number of commuters has increased four-fold during this period, from 104,485 to 412,605 persons, while the number of total workers almost doubled, from 943,217 to 1,630,341. In terms of growth rates, the number of commuters increased substantially during the periods 1960-1970—83%—and 1970-1980—99%—and modestly between 1980 and 1990 at 9%. Total employment, in comparison, had the largest increase between 1970 and 1980 and showed practically no growth during the period 1980-90. As a result, the proportion of commuters among total workers increased from 11.1% in 1960 to 24% in 1980, and it continued to increase to 25% despite a decline in the growth rates in commuting during the recent period.

Throughout this period, the eleven coastal parishes in Louisiana consistently received more commuters than the state's 53 non-coastal parishes combined. The proportion of commuters among workers, as a result, has been much higher in coastal areas than in non-coastal areas. In 1960, 16% of all workers in coastal areas were commuters, compared to only 7.8% in non-coastal areas. By 1990, while the difference between coastal and non-coastal areas slightly narrowed, 32% of workers in coastal areas were commuters versus 21% in non-coastal areas. The smaller difference between coastal and non-coastal areas in the percentage of commuters resulted mostly from the differential growth in commuting during the period 1970-80. During this decade, total and mining-related employment grew more in non-coastal areas than in coastal areas, as noted previously.

In summary, commuting has been an important source of workers in coastal areas during the period 1960-90. Commuting appears to be also sensitive to the growth of the economy as reflected in the growth of employment. The importance of commuting as a source of labor increased during this period, but the gap between the coastal and non-coastal areas somewhat diminished, owing to a greater increase of commuting in non-coastal areas in response to a greater employment growth between 1970 and 1980 in those areas.

COMMUTING PATTERNS BY INDUSTRY

The importance of commuting in coastal areas is generally in line with our prediction that commuting is an important source of workers for coastal parishes that rely on off-shore mining activities. However, the data presented above do not allow us to conclude that the mining industry *per se* attracts more commuters than other industries; it may be other industries that are actually attracting these commuters. Consequently, it is necessary to disaggregate the commuting flows in terms of industry. For 1980 and 1990, the *Journey-to-Work* data from the 1980 and 1990 Census provide a further breakdown of commuting workers in terms of the major industrial categories at the one-digit industrial classification.

Our results show that mining, which combines agricultural services, forestry, fisheries and mining, includes the highest proportion of commuting workers for both periods. In 1980, 39% of workers in mining were commuters; only the construction industry had a comparable percentage of commuters in that year. In 1990, the proportion of commuting in mining industries increased to 43%. In comparison, workers in trade, public and private services and government employees are more likely to be residents of the area where they work. A further breakdown by coastal and non-coastal areas reveals that for all industry categories, workers in coastal areas are more likely to be commuters than is the case for workers in non-coastal areas. This applies especially to mining: about one-half of mining employment in coastal areas (47% in 1980 and 52% in 1990) is comprised of commuters.

These findings clearly demonstrate that (1) coastal areas depend heavily on commuting workers as a source of employment, and (2) the mining industry especially attracts workers who commute from elsewhere. The assessment of the impact of non-resident workers in coastal areas, however, must include the areas from which workers are recruited. Of particular interest here is the distance of commuting as an indication of the geographical spread of the attraction of mining employment in coastal areas.

We, therefore, carried out an analysis of commuting networks to learn (1) how far the impact of commuting involving coastal areas extends in general and (2) which parishes in particular are involved in commuting networks for sending mining-related workers.

COMMUTING DISTANCE

Coastal areas, regardless of industry, rely much more on commuting workers than do non-coastal areas. It is possible that a substantial portion of commuters observed in coastal areas originate in a few non-coastal areas that are adjacent to coastal parishes. However, it is more likely that a greater number of non-coastal parishes are involved to meet a demand for commuting workers in coastal areas as the pool of potential workers in adjoining parishes is exhausted. In view of the particular work schedule of OCS activities requiring the presence of workers on the platforms for one to three weeks at a stretch and followed by at least one week off work, we expect many more workers in coastal areas to originate in distant places than in non-coastal areas. Such a work schedule allows for much longer-distance commuting than would be feasible with a daily 8-5 work schedule.

Employers in coastal parishes recruited workers from slightly more distant parishes in every period than did non-coastal parishes. The difference between coastal and non-coastal areas during this period increased from 3.9 miles in 1960 to 12 miles in 1990. Thus, not only do businesses in coastal parishes recruit workers from more distant places than do those in non-coastal parishes but also this difference has increased over time.

The same data are tabulated in terms of a 10-mile radius to investigate the distribution of commuters, which is another important aspect of the spatial dimension of commuting. Since there are no parishes adjacent to coastal parishes whose distance to coastal parishes is less than 20 miles, the frequency for the category of 10-19 miles is zero for coastal parishes. Given the definition of "commuting," we expect short-distance commuting to dominate a majority of all commuting within 30 miles. Indeed, during the period 1960-90, about 60-70% of all commuters traveled from residences that were less than 30 miles away from their place of work.

In 1960 and 1970, the coastal parishes attracted a slightly larger percentage of commuting workers from parishes within 30 miles compared with non-coastal areas, but in 1980 and 1990, they attracted fewer workers from nearby parishes than did non-coastal areas. This pattern becomes even more pronounced when longer commuting distances are considered. In 1960, slightly more workers in non-coastal areas than coastal areas (4.0% vs. 3.8%) were commuting from 60 miles and beyond. Since 1970, however, this pattern has reversed: the percentage of commuting beyond this range in coastal areas compared with non-coastal areas is 6.2% versus 3.5% in 1970, 12.4% versus 10.1% in 1980, and 10.0% versus 6.9% in 1990. Thus, while long-distance commuting has gained more popularity in general in both areas, the coastal areas since 1970 have always topped the non-coastal areas in terms of proportion of workers traveling long-distance. This difference in commuting distance accounts for the greater increase in average commuting distance in coastal areas.

COMMUTING DISTANCE BY INDUSTRY

The findings presented above suggest that coastal parishes receive commuters from more distant counties than do non-coastal parishes. Since coastal areas are characterized by mining-related activities, at least part of long-distance commuting can be ascribed to the mining industry. Our findings show average distance in commuting by industry for coastal and non-coastal areas. The industry "mining" in this table includes, as before, agricultural services, forestry, fisheries and mining. Data show that between 1980 and 1990, the average commuting distance slightly shortened, although the difference between coastal and non-coastal areas in commuting distance increased.

The differentiation of commuting by industry shows that in both 1980 and 1990, mining attracted the longest-distance commuters, and mining workers to coastal parishes traveled much longer distances than those to non-coastal areas. For example, mining workers, regardless of destination, commuted an average of 64.2 miles in 1980 and 59.1 miles in 1990, which is over 20 miles more than traveled by construction workers who also tend to be longer-distance commuters. Furthermore, the comparison of coastal and non-coastal areas reveals that while mining workers commuted the longest distance in both types of areas, their commute to coastal parishes was even longer than to non-coastal parishes.

A greater proportion of mining workers than non-mining workers in 1980 and 1990, and in both coastal and non-coastal areas, come from areas located beyond 90 miles. In addition, a comparison of coastal and non-coastal parishes indicates that in coastal areas, 27.8% of mining workers in 1980 and 25.8% in 1990 originate in this furthest location. Less than 3% of coastal-area commuters in all other industries combined came from residences that far away. A differentiation by industry shows that the extreme commuting distance is specific to the mining industry in coastal parishes, for no other industry received more than 8% of commuters from areas beyond 90 miles away.

CONCLUSIONS

All data examined clearly indicate that commuting patterns in general, and long-distance commuting in particular, are affected strongly by the combination of two factors. Those factors are (1) the industry effect, whereby the mining industry attracts relatively more commuters than does any other industry, and (2) location effect, whereby coastal parishes attract relatively more commuters than do non-coastal parishes. Coastal parishes with a heavy dependence on mining, as a result, attract many more long-distance commuters than does mining in non-coastal areas, or than other industries in either type of area.

These results send a note of caution to use net in-migration as a proxy for the employment effects of OCS activities. Our findings show that in this industry, labor demand often is met by commuting and not by migration. Estimates of net migration as a sole indicator of labor demand, thus, is likely to underestimate the effects of OCS activity on labor markets.

Dr. Joachim Singelmann, David J. Kriskovich Distinguished Professor of Sociology at Louisiana State University, has directed numerous research projects addressing issues of poverty, development, urban-rural differentials, and employment. Many of his projects have been international and national in scope, but he has also done extensive work on Louisiana, especially in the Lower Mississippi Delta and in the Gulf of Mexico region. He built a longitudinal database for the U.S. Department of the Interior’s Mineral Management Service covering the GOM states for the period 1930-1990. While his research is mostly quantitative and uses complex statistical modeling, he has also done ethnographic work to supplement statistical information. He has been funded by major private and public foundations such as NSF, and has held contracts with state (La DHH, DSS, and DOL) and federal (DHHS, Department of the Interior, Department of Labor, USDA) agencies. His work has been published in leading social science journals.

SESSION 2H

EXPLOSIVE REMOVAL OF OFFSHORE STRUCTURES (EROS) II

Chair: Ms. Judy Wilson, Minerals Management Service
Co-Chair: Mr. Jeff Childs, Minerals Management Service

Date: January 10, 2002

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Ms. Simona Perry Roberts and Mr. Ken Hollingshead, NOAA Fisheries, Office of Protected Resources, Marine Mammal Conservation Division

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Mr. Gregg R. Gitschlag, NMFS Galveston Laboratory

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Dr. David J. Leidel, JRC - Halliburton Energy Services

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MARINE MAMMAL REGULATORY ISSUES AND THE EXPLOSIVE REMOVAL OF OFFSHORE STRUCTURES: THE SMALL TAKE AUTHORIZATION PROGRAM

Ms. Simona Perry Roberts
Mr. Ken Hollingshead
NOAA Fisheries, Office of Protected Resources
Marine Mammal Conservation Division

WHO ARE WE?

The MMPA Small Take Authorization Program is one of many programs implemented by NOAA Fisheries (referred to as Fisheries here; aka National Marine Fisheries Service) Office of Protected Resources' Marine Mammal Conservation Division. The Division also develops, implements, and administers marine mammal status assessments, recovery plans, commercial fishery interactions, marine mammal health, marine mammal stranding response, as well as direct harvest co-management and international conservation agreements. The overall mission of the Office of Protected Resources is to conserve protected marine species and maintain marine biodiversity.

BRIEF LEGAL HISTORY AND IMPORTANT DEFINITIONS

With passage of the Marine Mammal Protection Act (MMPA) in 1972, Congress established a moratorium on the "taking" of marine mammals. In order to allow "taking" under certain conditions (a provision primarily envisioned to acknowledge the problem of marine mammal by-catch in commercial fisheries) the Secretaries of Commerce & Interior were authorized to adopt suitable regulations, issue permits, and make determinations on exceptions to this moratorium. These exceptions included: (1) "take" during scientific research, public display, and photography; (2) "take" during commercial fishing operations; and (3) "take" during specified activities (other than commercial fishing) within specified geographical regions (MMPA Sections 101.a.5.A-D). In 1996, the Fisheries published general regulations (50 CFR 216, Subpart I: General Regulations Governing Small Takes of Marine Mammals Incidental to Specified Activities) to implement the sections of the MMPA regarding the "take" of marine mammals during specified, non-fisheries, activities.

After passage of the MMPA, "take" was defined in the MMPA implementation regulations (50 CFR 216.3-Definitions) as: "to harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal." In addition, these same regulations define two levels of "harassment":

- Level A: "any act of pursuit, torment, or annoyance which has the potential to injure a marine mammal or marine mammal stock in the wild"; and

- Level B: "any act of pursuit, torment, or annoyance which has the potential to disturb a marine mammal or marine mammal stock in the wild by causing disruption of behavioral patterns, including, but not limited to, migration, breathing, nursing, breeding, feeding, or sheltering but which does not have the potential to injure a marine mammal or marine mammal stock in the wild."

The MMPA Small Take Authorization Program was created to implement sections 101. a. 5. A-D of the MMPA allowing for the incidental take of small numbers of marine mammals by U.S. citizens engaging in specified non-fisheries maritime activities within a specified geographic region. Implementation is currently carried out through the processing (including external public review) of authorization requests received from U.S. citizens. It was under this program that Fisheries issued 5-year regulations (50 CFR 216, Subpart M) for the take of bottlenose dolphins and spotted dolphins incidental to oil and gas structure removal activities in 1995. In November 2000, these regulations expired.

MMPA SMALL TAKE AUTHORIZATIONS

Before authorization requests are submitted, requestors must analyze their activities in enough to decide:

1. the type authorization that best suits the activities;

2. operationally realistic mitigation measures that may reduce the amount and extent of marine mammal “take”; and

3. how much time will be necessary to process the request given the complexity of the activity and the type authorization being requested.

TYPES OF AUTHORIZATIONS

There are two types of authorizations administered through the Small Take Program, the Letter of Authorization of “LOA” and the Incidental Harassment Authorization or “IHA.” In deciding the type of authorization to be requested, the requestor should consider the following factors:

1. the potential type of marine mammal take (e.g., Level A or Level B harassment) that will result from the activity;

2. mitigation measures that could be incorporated into operations to reduce the amount and extent of take; and

3. the time it will take to finish the project.

An LOA is required when there is a potential for serious injury or mortality, and there are no mitigation measures that could be taken to prevent injury death. In some cases, when the project has a 5-year or longer timeframe or is an on-going activity, the requestor and Fisheries may agree to proceed with the LOA even if there is no potential for serious injury or mortality. To obtain an LOA, Fisheries must first promulgate 5-year regulations, including two 30-day public comment periods. This process can take between 6 months to one year and longer in certain complex cases. Once these regulations are finalized, one-year renewable (upon request) LOAs are issued to requesting parties.

An IHA is required when there is no potential for serious injury or mortality or the potential for injury and mortality can be prevented through mitigation measures. No regulations are created before issuance of the IHA; however, there is one 30-day public comment period. The IHA process takes between three and six months to complete and results that expire one year from the date of issuance. Requestors wishing to extend the authorization beyond one year must submit a lull request to Fisheries at least three months prior to expiration along with results of any behavioral, feeding, or population studies that were conducted supplemental to the monitoring program required under the IHA.

Issuance Determination

Authorizations are issued to requestors after adequate scientific/technical and public review and if the activities are determined by Fisheries to

1. Have a "negligible impact" on the species or stock of marine mammal(s);

2. Take only "small numbers" of marine mammals; and

3. Not have an "unmitigable adverse impact" on the availability of marine mammals intended for subsistence uses.

To better understand how Fisheries makes these three determinations, one must look at the regulatory definitions key to these three factors: negligible impact, small numbers, and unmitigable adverse impact. The third factor of unmitigable adverse impact is only of concern in areas where subsistence communities rely on marine mammal products as a primary source of protein or for maintaining cultural integrity, so it will not be detailed in this Gulf of Mexico-focused paper.

Negligible impact is defined as "an impact resulting from the activity that cannot be reasonably expected to, and is not reasonably likely to, adversely affect the species or stock through effects on annual rates of recruitment or survival." Therefore, when Fisheries analyzes requests for authorizations we must first analyze how the activity may impact the ability of the species of concern to reproduce annually and survive into the future. This is no easy task given the lack of baseline data on annual rates of recruitment and survival for most marine mammal species (particularly those inhabiting pelagic, deep-water environments). An important point to remember is that the focus of an analysis of incidental take impacts is on the stock or population of animals. This differs from the analysis of directed take impacts for marine mammal scientific research permits, where the analysis of impacts focuses more on individual animals Therefore, short-term and geographically discrete behavioral modifications (i.e., Level B harassment) by marine mammals as a result of maritime industrial activities *may or may not* have a negligible impact on marine mammal stock(s) depending on many factors. Examples of these factors include, but are not limited to

- the inherent vulnerability of the marine mammal species to human disturbance;

- the availability of alternative habitat to the stock;

- other potential threats in the same area or in other areas of critical importance to the stock's life history; and

- the current conservation status of the stock.

In making this negligible impact determination, Fisheries is required to consider the number of marine mammals that could be taken in the course of the activity relative to population estimates of the entire marine mammal species or stock. This is the second "small numbers" determination (and the determination from which the Small Take Program takes its name). In making this "small" determination, Fisheries uses the most current and statistically reliable baseline population estimates available.

Information Needed to Process An LOA or IHA Request

Fisheries to make appropriate determinations on issuance of small take authorizations, we must receive detailed and accurate information on the activities from each requestor. There are 14 specific types of information (outlined in 50 CFR 216.104), including a mitigation and monitoring plan, that must be submitted to Fisheries by the requestors for either an LOA or an IHA. This information must also be complete enough to meet NEPA requirements (i.e., what potential is there for a significant negative or positive impact on the environment as a result of the specified activities). Probably the most challenging parts of the request to develop are the proposed mitigation measures and monitoring plans. This requires not only a good understanding of the operational aspects of the activity but also an understanding of wildlife science and marine mammal biology.

Mitigation and Monitoring Plans

The Small Take Authorization Program requires mitigation to be put in place for all maritime activities receiving an LOA or IHA. In general, these mitigation measures are operational techniques designed to reduce the adverse impact on the species or stock and its habitat. Examples of such measures used for explosives in the marine environment include

- safety and buffer zones established around explosive source(s) based on the best available information (e.g., propagation models, marine mammal hearing thresholds);

- use of explosives only during daylight hours;

- attenuation devices that reduce the noise resulting from the explosive source(s);

- passive acoustic arrays; and

- sonar systems specifically designed for marine mammal detection.

The MMPA requires that all U.S. citizens obtaining an LOA or IHA also have a Fisheries-approved monitoring plan. These plans are proposed by the requestor and are subject to scientific peer-review and public review prior to being approved and accepted. In general, monitoring plans should be

- site-specific;

- developed using the most recent biological baseline data at the appropriate species, subspecies, or stock level; and

- provide a detailed description of the survey techniques that will be used to determine the movement and activity of marine mammals, including migration and feeding, relative to the activity site.

A successful monitoring plan will quantify the level of taking or impacts on marine mammal stock(s) that may be attributable to specified activities as well as encourage and coordinate research opportunities, plans, and activities relating to reducing incidental takes and evaluating impacts from similar activities.

CLOSING REMARKS AND POSSIBLE FUTURE DIRECTIONS

In recognition of the potential regulatory burden that the small take authorization process can impose on maritime industries, program staff are available to provide guidance on the biological aspects in designing appropriate marine mammal mitigation and monitoring plans and in navigating the legal requirements that must be met under the MMPA, ESA, and NEPA. In equal recognition that the small take authorization process can provide an incentive for regulated industries to become better stewards of the marine environment, program staff are dedicated to working with scientists and the environmental advocacy community on identifying non-regulatory means of reducing the impacts of human disturbance, particularly noise on marine mammals and other living marine resources.

The future direction of the program depends on the success of continual multi-disciplinary communication, something that can only be done with equal cooperation between the regulating, regulated, non-regulated interests. With successful communication between all parties, one could envision a day when jointly developed regulatory marine mammal mitigation, monitoring, and reporting programs are not perceived as a burden on the industry or lacking in environmental sensitivity. Imagine instead that the Small Take Authorization Program has the potential to promote marine stewardship in the industrial sector while encouraging appropriate technological innovation to improve the quality of marine ecosystems.

Simona Perry Roberts received her B.S. wildlife biology from University of Massachusetts and her M.A. in marine policy from the University of Washington. In fulfillment of her marine policy degree, she developed an ecological risk assessment framework for status reviews of threatened and endangered marine vertebrate species. She began work as an independent contractor with NOAA in 1994 conducting large whale sighting surveys in the North Atlantic Ocean. Since that time she has participated in a diverse array of field projects, from harbor porpoise sighting surveys and American mink foraging studies in Washington State to right whale aerial surveys off Florida. Since joining NOAA's Office of Protected Resources in 2000, her duties have not only included implementation of the MMPA small take authorization program, but also advising marine mammal researchers on the regulations surrounding MMPA scientific research permits. She is currently the U.S. federal representative to the North American Marine Species of Common Conservation Concern Initiative—a collaborative effort between Mexican, Canadian, and U.S. governmental agencies and non-governmental entities to identify a North American conservation strategy for trans-boundary marine species. She authored the 1999 large whale five-year status review published in the journal Marine Fisheries Review. In addition, she has co-authored several publications, including an article in *American Scientist* on the successes and failures of large whale recovery efforts in the United States and an invited paper in the *Journal of Mammalogy* on the interactions of marine mammals and commercial fisheries in the 21st century.

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THE ENDANGERED SPECIES ACT AND GULF OF MEXICO MARINE SPECIES

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This paper provides an overview of the Endangered Species Act (ESA) and of how the statute shapes the responsibilities of all the players who may be affecting endangered and threatened marine species in the Gulf.

PLAYERS

The ESA's requirements for managing listed species include a wide range of players. The National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (FWS) are the federal agencies charged with primary management responsibility for listed species. In the Gulf of Mexico (GOM), six species of great whales, five species of sea turtles, and the Gulf sturgeon are listed as endangered or threatened and under NMFS jurisdiction. All other federal agencies with activities in the Gulf also have duties within their own range of authorities to conserve listed species and to minimize the impacts of their actions on listed species. The MMS, U.S. Army Corps of Engineers, the Air Force, and the Navy are some of the major federal actors in the Gulf. Other federal agencies, such as the U.S. Coast Guard, the Environmental Protection Agency, the U.S. Geological Survey, the National Park Service, and the Federal Energy Regulatory Commission, also have roles in studying or protecting listed marine species or conducting or permitting activities that may affect them. Section 6 of the ESA allows states to form cooperative agreements with NMFS to protect and manage endangered and threatened marine species: none of the coastal Gulf states has yet done so. Industry, of course, is also heavily involved with protected species activities, both through their regulatory requirements and through their own initiatives. We also depend on academia to conduct much of the critical scientific research to understand these species' threats and needs. Lastly, the ESA has special provisions that allow "any person" to become involved in endangered species issues.

ENDANGERED SPECIES UNDER NMFS JURISDICTION IN THE GOM

The listed marine species that may occur in the GOM include six great whales: blue, fin, humpback, right, sei, and sperm whales. Sperm whales are perhaps the greatest concern as it appears that these whales may have an endemic population in the GOM. Listed also are five species of sea turtles: the green, hawksbill, Kemp's ridley, leatherback, and loggerhead turtles. Finally, there is the Gulf sturgeon. The sea turtles are under joint jurisdiction with the U.S. Fish and Wildlife Service with the Fish and Wildlife Service having management authority on the nesting beaches and NMFS in the water. Gulf sturgeon are also jointly managed with Fish and Wildlife, with NMFS responsible for marine areas.

IMPORTANT PARTS OF THE ESA

Summarized below are some of the more important sections of the ESA.

Section 4 - Determination of Endangered and Threatened Species

Section 4 is the starting point for the protection and recovery of a species. It specifies the procedures and requirements for listing a species as threatened or endangered. It also lays out how to designate critical habitat for a species. Critical habitat, as used in the ESA, has a particular meaning, and then only has meaning in relation to one other section of the ESA. No critical habitat has been designated for listed marine species in the Gulf. Once species are listed, section 4 requires that recovery plans be created for most species. The recovery plans set out goals to be achieved to bring about a species recovery and de-listing, and they recommend the tasks needed and who is to accomplish them. For the Gulf marine species, recovery plans have been completed for the five species of sea turtles, the Gulf sturgeon, and the blue, humpback, and right whales. Lastly, when species are listed as threatened (but not endangered), special regulations can be enacted under section 4(d). A 4(d) rule lays out what protections these threatened species require. These 4(d) rules are commonly used to extend most of the ESA's full protections for endangered species to threatened species, while carving out a few exceptions. One well-known application of a 4(d) rule in the GOM is the exception that allows shrimpers to incidentally capture threatened sea turtles, as long as they use turtle excluder devices.

Section 9 - Prohibited Acts

This section provides a lot of the teeth of the ESA. Perhaps of most importance is the blanket prohibition of any kind of "take" of an endangered species. The definition of "take" in the ESA includes "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect" or to attempt to do any of those. Importantly, the take prohibition includes non-intentional, or incidental, takes as well. Section 9 also prohibits any violations of the special protective regulations for threatened species (4(d) rules).

Section 7 - Interagency Cooperation

The ESA includes special duties and responsibilities for all federal agencies to help carry out the purposes of the ESA. These are spelled out in section 7. Section 7 applies only to federal agencies.

All federal agencies have a duty to take positive actions to conserve endangered and threatened species. Section 7(a)(1) of the ESA provides that "…federal agencies shall, in consultation with and with the assistance of [NMFS or FWS], utilize their authorities in…carrying out programs for the conservation of threatened and endangered species… ." This language has long been considered to represent simply a generalized policy, rather than a concrete obligation, as the statute does not have an "or else" clause if an agency does not undertake listed species conservation activities. A recent court ruling, however, has emphasized that federal agencies do have an affirmative responsibility to take action to conserve listed species (see *Sierra Club vs. Glickman*, U.S. 5th Circuit Court of Appeals, Sept. 1998). My understanding of that ruling is that, where agencies have relevant programs in place that can benefit listed species, they are supposed to have *some* form of endangered species program, rather than completely ignore this section of the Act. For an agency like MMS, an extensive set of endangered species research activities, would meet the standard in that opinion.

Federal agencies have a further duty to examine the effects of their actions on listed species; this process is called section 7 consultation. Section 7(a)(2) of the ESA requires every federal agency, in consultation with NMFS and/or FWS, to ensure that any action it authorizes, funds, or carries out is not likely to jeopardize the continued existence of any listed species. As part of the consultation process, NMFS would review the agency action and issue a "biological opinion" whether jeopardy to any listed species is likely. If a "no-jeopardy" finding is reached, then the biological opinion would also include an incidental take statement (ITS) that would authorize a small level of incidental take of listed species, while requiring the federal agency or their permit applicant to take specified measures to reduce the impact of the take. For listed species of marine mammals, incidental take can only be authorized if the more stringent requirements of section 101(a)(5) of the Marine Mammal Protection Act (MMPA) have been met as well. An ITS provides an important exception to the prohibition on takes in section 9, as long as the terms and conditions of the ITS are implemented. If an agency action *is* determined likely to jeopardize any listed species, then the activity may not proceed and no incidental take would be authorized, unless a no-jeopardy alternative is specified. Very few agency actions result in jeopardy biological opinions, however. The section 7 consultation process actually provides for a great deal of flexibility and cooperation between the action agency and NMFS or FWS, so impacts can be identified and minimized in advance, avoiding jeopardy to listed species and adverse changes to the project.

Some Important Consultations: NMFS and MMS have completed important consultations relating to GOM marine species for explosive structure removals and the overall lease/sale process. In a July 1988 biological opinion, NMFS concluded a no-jeopardy opinion on explosive structure removals in the OCS that considered the effects of a "generic" explosive structure removal. The requirements of the ITS focus on monitoring and minimizing the impacts of individual removals. The opinion is over 10 years old and is still in effect. The 1988 opinion also does not apply to structure removals in the territorial sea, where removal permits are issued by the states or the Corps of Engineers.

The intent of the 1988 NMFS biological opinion was to describe and cover the removals that were considered typical then and were thought to be relatively safe for marine animals. It was not the intent to require all removals to be done only according to that description. Removals that do not meet that generic description can still be authorized, but they require separate consultation. In my time at NMFS, I can not recall that MMS or an oil company has ever gone through the process to request a variation from the generic procedures, so to say that NMFS requires all removals to be done the same way is false. The consultation process does take a long time—up to 4-1/2 months for us to issue a biological opinion—so perhaps the time required and the desire for regulatory certainty has led industry to crystallize all the removals, but that has been their choice.

NMFS and MMS have been discussing "reinitiating" the consultation on structure removals. There is a need to address changes in industry, particularly the move into deeper waters. In 1988, we certainly did not consider the possibility of explosive removals in ultra-deep waters and the measures in the ITS make no sense in that deep-water context. We also want to provide more flexibility to industry and provide guidelines for removals that do not meet the current generic requirements. We would like to consider alternative blasting and monitoring techniques and try to create built-in incentives to use lower explosive weights than the current generic opinion.

NMFS and MMS have also consulted on the overall lease sales for oil and gas development. In January 1998, NMFS issued a no-jeopardy biological opinion on MMS 5-year lease sale plans for the Western and Central Gulf Planning Areas. Biological opinions have to consider all the direct and indirect effects of an action, so this opinion considered all OCS oil and gas exploration and development activities (except structure removals). Since the scope of the opinion was so wide, the requirements of the ITS focus more on monitoring the Gulf-wide status of affected species (specifically their overall numbers and health) and on addressing data needs. The upcoming lease sale in 2002, number 182, is the last one covered under this opinion, so we will have to do a new consultation for lease sales beyond that. For the Eastern Planning Area, we have done a separate no-jeopardy opinion for MMS lease sale 181 in June 2001. In that opinion, the ITS requirements are more focused on minimizing the risk of take, for example, through reductions in marine debris and avoiding vessel strikes through training of OCS vessel operators.

Incidental Take Statements: Incidental takes statements are issued as part of a biological opinion and can authorize a specified level of taking of a listed species. To be authorized, the taking must be (a) incidental to the purpose of the action; that is, they cannot be directed takes; (b) they must be the result of an otherwise lawful activity; and (c) they must be not likely to jeopardize a species or destroy critical habitat. This "incidental to an otherwise lawful activity" is important because the biological opinion needs to consider the effects of all resulting activities, but ITS can only authorize takes from lawful activities. For example, an oil spill is a foreseeable consequence of oil and gas development and can injure listed species. But since oil spills are illegal under the Clean Water Act and OPA 90, incidental take for an oil spill cannot be authorized in an ITS. The takings authorized in an ITS are exempt from the ESA section 9 prohibitions. An ITS must then include measures to minimize the impact of the action on listed species with specific terms and conditions that must be carried out for the incidental take authorization to be valid. Although we would not necessarily agree with the characterization, recent court cases have said that the ITS and its terms and conditions essentially amount to a permit that applicants must have.

REINITIATION OF CONSULTATION

Biological opinions are not permanent documents or permits with an indefinite life-span. They are subject to reinitiation, that is, to review and possibly re-opening and a complete re-do of the process. Reinitiation occurs

(a) if the authorized take levels in an ITS are met or exceeded

(b) if the subject activity is changed in a way that would change the effects to listed species

(c) if new information indicates that the action may affect species in a way or to an extent that was not previously considered

(d) if a new species is listed or critical habitat is designated that may be affected by the activity

Section 10 - Exceptions

Section 7 consultation can provide for an important exception to the prohibition on incidental take of listed species, but section 7 does not apply to non-federal activities, nor to cases of directed take of listed species. Section 10 of the ESA provides for permits that can authorize those types of takes. Permits can be granted for the directed take of a listed species for scientific research purposes and for activities to enhance the species' survival (10(a)(1)(a) permits). Permits can be granted to non-federal applicants, who do not have access to section 7, to incidentally take listed species during the course of an otherwise lawful activity (10(a)(1)(b) permits). The applicants are required to minimize and mitigate their impacts, often by setting aside habitat, and these permits are commonly called Habitat Conservation Plans (HCPs). HCPs are not widely used in the marine environment, because many activities are federally authorized and section 7 would apply. From time to time, we have done consultations with a federal agency for an activity with a regulated industry or a particular applicant, and the applicant has requested a section 10 permit rather than go through the section 7 process with their regulating agency. The application requirements, including public notice and comment, for the section 10 permit are much more rigorous than the section 7 process, however. The companies have ultimately opted in all the cases to just go through section 7 consultation.

Section 11 - Penalties and Enforcement

The ESA allows violators to be fined through civil proceedings or to be criminally prosecuted, with maximum penalties of $25,000 or $50,000, respectively. In addition to penalties that can be sought by the government, the ESA includes a citizen suit provision in section 11(g). Any person may sue any other person, including the U.S. government, for violating any section of the ESA. These suits may seek an injunction to stop an activity that violates the ESA. A common use of these suits is to compel federal agencies to conduct section 7 consultation. The citizen suit provision has been heavily used in the courts, primarily by environmental NGOs. It is probably the main reason that the ESA is considered such a strong and, at the same time, controversial law.

Section 17 - Construction with the MMPA

Probably the most obscure section of the ESA is section 17, but it is very relevant to our discussions, since one of the more important marine mammals in the Gulf—the sperm whale—is protected by both the MMPA and the ESA. Section 17 states that the ESA does not take precedence over the MMPA, where the MMPA's provisions are more restrictive. In other words, for listed species of marine mammals, both acts must be complied with, including the most restrictive requirements. In a biological opinion, then, an incidental take statement can not authorize take of a marine mammal under the ESA until an MMPA small take authorization is also given.

THE NATIONAL MARINE FISHERIES SERVICE PLATFORM REMOVAL OBSERVER PROGRAM

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INTRODUCTION

The National Oceanic and Atmospheric Administration/National Marine Fisheries Service (NOAA/NMFS) Platform Removal Observer Program (PROP) officially began in 1987. Origination of the PROP was a direct result of a requirement in the Incidental Take Statement (ITS) prepared under the Endangered Species Act (ESA) to protect sea turtles at the explosive removal of offshore oil and gas structures in the Gulf of Mexico. The ITS requires qualified observers approved by NMFS to monitor the area around the removal site prior to, during, and after detonation of charges. A requirement in the now-expired Letter of Authorization for the Taking of Marine Mammals prepared in 1995 under the Marine Mammal Protection Act also mandates the use of observers to perform monitoring at explosive structure removals.

The purpose of the PROP is twofold. First, the PROP functions to protect sea turtles and marine mammals from impacts of underwater explosives used in the structure removal process. Second, the PROP assesses the impacts of underwater explosives on these protected species. Observers document sightings of sea turtles and marine mammals both before and after detonations, recommend delays in detonating explosives when sea turtles and marine mammals are present, record the condition of observed animals, and coordinate retrieval of impacted animals for medical examination, rehabilitation, and necropsy.

INCIDENTAL TAKE STATEMENT FOR SEA TURTLES

The ITS for sea turtles authorizes a take (by injury or mortality) of one Kemp's ridley, green, hawksbill or leatherback sea turtle or ten loggerhead sea turtles for all removal operations conducted under the terms and conditions of this ITS. Take is cumulative for all covered removals. If the take level is met or exceeded then the Minerals Management Service (MMS) must reinitiate consultation with NMFS to review the incidents and determine the need for developing further mitigation measures. The following is a summary of the ITS.

1. Observer monitoring is performed before, during and after detonations. If sea turtles are observed and thought to be resident, then pre- and post-detonation diver surveys are required.

2. A 30-minute aerial survey must be conducted within 1 hour before and after detonations. If bad weather makes it unsafe to fly, then aerial surveys may be waived. However, there is no guarantee that waivers will be granted.

3. Blasting will be delayed until attempts are successful in removing sea turtles observed within 1,000 yd of the blast site. When a sea turtle is observed, the aerial surveys must be repeated prior to blasting.

4. Detonations are prohibited between one hour before sunset and one hour after sunrise.

5. Divers must report sightings of sea turtles and marine mammals and attempt to recover any that are injured or killed.

6. Detonation of charges must be staggered at least 0.9 sec to minimize the cumulative effect of the blast.
   a. When multiple structures are being removed, the interval between detonations should be minimized to reduce the "chumming effect" (attraction of protected species feeding on animals killed by earlier detonations).
   b. When the interval exceeds 90 minutes then the aerial survey must be repeated.

7. Scare charges are allowed only when approved by NMFS/MMS.

8. A report summarizing results and mitigation measures must be submitted to MMS with a copy to NMFS within 15 working days after removal.

LETTER OF AUTHORIZATION (LOA) FOR MARINE MAMMALS (EXPIRED 13 NOVEMBER 2000)

Requirements in the LOA for the taking of Atlantic bottlenose and spotted dolphins are nearly identical to those in the sea turtle ITS with notable exceptions. There is no provision for the waiver of pre- and post-detonation aerial surveys. Also, if a marine mammal is observed, special post-detonation surveys must be conducted to assess impacts. Either a diver survey of the sea floor can be performed within 24 hours after detonation or an aerial or vessel survey can be conducted within two to seven days after detonation.

The LOA for taking marine mammals expired on 13 November 2000. Until a new LOA is issued, operators planning to perform explosive removals are offered certain options. If the operator follows all procedures in the expired LOA, then NMFS agrees this should provide reasonable and prudent protection to marine mammals. Since the LOA has officially expired, the operator is not required to follow listed protocols, but the operator will be fully liable should a marine mammal be injured or killed. During this interim period, no operator has elected not to follow listed protocols. Some operators have elected not to use explosives until a new LOA is issued.

REMOVING SEA TURTLES AND MARINE MAMMALS FROM THE IMPACT ZONE

The ITS specifies that blasting will be delayed until sea turtles are removed at least 1,000 yd from the blast site. There are currently no methods available to perform this activity other than capture of sea turtles by divers, which is an uncommon occurrence. In the case of marine mammals, vessels motoring through the impact zone are sometimes successful in leading dolphins out of the area as they ride bow or stern waves. Alternatively, a small scare charge consisting of 6 ft of detonation cord is occasionally successful in scaring dolphins out of the area.

TAKE TO DATE

From1987 through December 2001 the total take of sea turtles includes four loggerhead sea turtles. Of these, one was killed, one was stunned but recovered sufficiently to avoid capture, and two were injured, recovered, rehabilitated and later released. Both injured sea turtles had more than a half-meter crack in the top of their shell. In contrast, no marine mammals were observed to be killed or injured during the same period. This indicates not an absence of marine mammals, but superior detection of marine mammals versus sea turtles within the impact zone shortly before explosives were detonated.

CRITIQUE OF EXISTING MONITORING PROTOCOLS

Existing protocols are almost entirely based on monitoring the sea surface. Observers view the sea surface from vessels, platforms, and helicopters to detect the presence of sea turtles and dolphins within a 1,000 yd radius around the detonation site. Most of the sea turtles identified by the PROP are loggerheads which have been shown to spend about 90-95% of their time underwater (Renaud & Carpenter 1994). Consequently, current monitoring procedures are limited in their effectiveness at detecting sea turtles. In contrast, dolphins spend much more time at the sea surface and are easier to detect than sea turtles. However, dolphins can and do remain submerged for extensive periods and, at times, are difficult to detect within the 1,000 yd impact zone.

Aerial surveys are superior to observers monitoring from vessels and platforms by about an order of magnitude. Comparison of annual sea turtle observation rates from aerial vs. daytime surface based surveys ranged from 6-29 (Gitschlag & Herczeg 1994; Gitschlag *et al*. 1997). However, surface monitoring by observers may be superior to aerial surveys in detecting the presence of sea turtles that make long dives in excess of 30 minutes.

Diver surveys are required if sea turtles are observed and thought to be resident. The effectiveness of pre-detonation diver surveys for sea turtles is limited by the diver’s available bottom time at depth and by in-water decompression time. Consequently, the area recommended for the diver survey is generally limited to the platform footprint. Post-detonation diver surveys for sea turtles and marine mammals are also restricted by bottom time at depth. In both cases a diver’s effectiveness can be severely limited by underwater visibility. A thorough survey around the entire platform at any distance beyond the footprint is usually severely limited due to time constraints. In contrast, post-detonation aerial and vessel surveys conducted for marine mammals from two to seven days after detonation include an expanded survey area. Generally, these surveys include seven parallel seven nm transect lines spaced 1 nm apart. While this covers a much larger region than diver surveys, even moderate currents may carry carcasses beyond the survey area. Although present monitoring protocols are useful, they are far from infallible at detecting protected species.

Monitoring requirements were not designed with deep water removals in mind because none were being conducted years ago when the requirements were prepared. Deep diving whales can and commonly do remain submerged for periods far exceeding the 30-minute pre-detonation aerial survey. There is a high probability that these whales will not be detected given current monitoring requirements. Thus far, there have been few deep water removals. However, these are expected to increase in the future.

SUGGESTED IMPROVEMENTS

There are several ways in which current monitoring protocols to detect the presence of sea turtles and marine mammals may be improved. The requirement to begin monitoring 48 hours prior to detonation of explosives can be reduced to 24 hours without any negative impact to protected species. In deep water areas where whales may occur, pre-detonation, passive acoustic monitoring may enable detection of marine mammals within the impact zone. This procedure may also be a useful option in shallow water areas when sporadic dolphin sightings sometimes cause extensive blast delays. Duration of aerial surveys conducted at deep water sites should be increased so survey times are longer than the dive duration of whales. Further research may identify active acoustic signals that can move marine mammals out of the impact zone. Other than the “hit or miss” capture by diver, no methods are currently available to remove sea turtles from the impact zone. Past suggestions include trawling which cannot be done effectively in close proximity to platforms due to increased risk of entanglement on bottom obstructions and pipelines. While common fish finders may detect sea turtles as objects on a display screen, they cannot effectively distinguish sea turtles from other objects of similar size such as fish. Since sea turtles are far less dependent on sound than marine mammals, acoustic solutions to move sea turtles from the impact zone are highly unlikely.

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Gregg Gitschlag has worked for NOAA’s Southeast Fisheries Science Center, Galveston Laboratory for over 20 years as an oceanographer and fishery biologist. His research interests include sea turtle behavior and migration as well as recreational and commercial fishery impacts on red snapper. Gregg holds a B.S. in zoology from the University of Michigan and a M.S. in biological oceanography from Florida State University. He has been a manager of the Platform Removal Observer Program since its inception in 1987.

A CRITIQUE OF EXISTING AND ALTERNATIVE MITIGATION MEASURES

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INTRODUCTION

The detonation of an explosive charge underwater results in considerably more effective transmission of energy into the surrounding medium than, for example, the detonation of the same charge in air due to the relatively low compressibility of liquids in comparison to gases. While explosive charges can be used to perform many steel cutting and structure removing operations offshore in a safe and effective manner, the effects of these chemical explosive charges on the environment cannot be ignored. The potential damage to marine life, offshore pipelines, divers, and nearby surface and sub-surface vessels must be considered in terms of possible deleterious effects.

In regard to marine life, aside from the obvious lethal effects which is relatively easy to detect, serious injury to marine animals rendering their survival in the wild doubtful is equally as undesirable and far more difficult to detect. Furthermore, human activity resulting in marine animals deviating from their normal behavior can be construed as harassment and is illegal in the case of some species.

On the other hand, in comparison to diver burning of offshore structures, explosive severing of underwater structural members has been established as a safe and cost effective removal method for abandoned offshore oil/gas production installations.

Mitigating the effects of open water and sub-seabed explosive blasting has become an issue with the continued removal of offshore oil and gas facilities in the Gulf of Mexico combined with forthcoming rulemaking by the National Marine Fisheries Service concerning incidental takes of marine mammals. In reference to the current rules on this issue, a review of the definitions concerning impacts on marine mammals is included.

Definitions:

A) Take – To harass, hunt, capture, or kill, or attempt to harass, hunt, capture or kill any endangered wildlife. “Taking” includes “harming”. Taking does include fish and wildlife but not plants.

B) Incidental Take – A take defined as one not for the express purpose of some intended activity.

C) Harm – Any act which kills or injures wildlife. Such an act may include habitat modification which results in behavior pattern alteration affecting breeding, feeding or sheltering.

D) Harassment – An act of pursuit, torment or annoyance.

E) Level A Harassment – Harassment which has the potential of injury.

F) Level B Harassment – Harassment with the potential to disturb by causing a disruption in behavior patterns such as migration, breathing, nursing, breeding, feeding, or sheltering.

G) Mitigation – The cornerstone of marine life protection, mitigation is the ongoing effort to lessen the impact of manmade offshore activity on marine life. This may be accomplished by avoiding the impact altogether or by minimizing the impact by limiting the magnitude of the environmental effects.

For the purpose of describing the threat to marine life, the following section, summarizes the principal characteristics of the underwater shock wave with particular emphasis on the incident shock.

Overview of Underwater Blast Effects

The release of kinetic and thermal energy from an underwater detonating chemical explosive or explosive device consists of two major phenomena, an initial shock wave or pressure discontinuity directed into the surrounding medium and the later expansion, oscillation and buoyant rise of a gas bubble containing the gaseous products of detonation of the explosive. Although the energy partitioning between the two events is approximately equal, the gas bubble is responsible for damage to structures at very close distances to the explosive detonation. The initial shock wave is of primary concern as a threat to marine life as injury or lethal effects can be felt at considerable distances from the detonation source.

Since most underwater detonations occur in close proximity to nearby rigid complex structures, the seabed, the water surface, are buried beneath the seabed, or consists of non-spherical or multiple shots, the shape of the pressure discontinuity deviates greatly from the theoretical decaying exponential waveform associated with an underwater shock.

Shock Wave Peak Pressure

In the most simplistic case of a perfectly spherical explosive charge detonating in open water in the absence of nearby reflective, refractive, or release surfaces, the incident shock approaching a point of observation is of the form:

$$P(t) = P_{max}\, e^{-t/\theta}$$

where:

P_{max} = peak shock pressure
e = base of natural logarithms
t = time
θ = blast wave time constant

The detonation of a charge near to the water surface will result in a sharp cutoff of the shock due to the nearby presence of a free surface, (boundary condition normal stress s ~ 0). The presence of multiple charges would non-linearly sum the contributions of each of the charges to the shock wave, (linear acoustic theory leads to underestimation of shock strength), adjusted for the appropriate time delays as determined from the relative distances of the shots to the point of observation. Non-spherical or line charges result in shocks where the contribution to the shock of each element of the charge, (dx in the case of a straight line charge), is summed numerically.

Reflective or refractive surfaces further complicate the shock waveform by the addition of semi-rigid boundaries which can strengthen and re-direct the shock in other than straight line paths.

Confined charges or charges detonated below the seabed expend a considerable portion of the shock energy release in the nearby confining material or seabed strata. Charges detonated below the seabed drive considerable energy into the seabed strata resulting in seismic energy transmitted through the seabed. Ground vibration effects on nearby pipelines, submarine cables and communication cables must be considered as a result of explosive shots near the bottom or buried charges where energy transmission coupling to the seabed is good. One significant advantage of buried explosive charges is that the substantial attenuation of the underwater shock wave is obtained from burying the charge a few meters below the mudline. This burial completely confines the gas bubble and sharply reduces the shock strength.

The peak pressure of the leading edge of the pressure discontinuity is a function of the inverse of the distance from the shot to the observer and a function of explosive weight to the one-third power for the case of a spherical charge. In the most simplistic case, for a spherical charge:

$$P_{max} = K_1 \left(W^{1/3} / R\right)^{\alpha}$$

where:

K_1, α are constants
W = explosive weight
R = straight line distance from the shot to the observer

The constants K_1 and α are determined by the type of explosive used.

The peak pressure is a very significant factor in determining the impact on nearby structures, (particularly air-backed structures such as ship’s shellplating) and marine life, but is not the only factor of significance. It must be noted that two underwater shocks with nearly identical peak pressure levels can have very different impacts on nearby objects since the time constant of the two pressure waves may be much different. A parameter which includes the *duration* of the shock as well as its peak pressure is the specific impulse.

Shock Specific Impulse

The shock wave specific impulse is, (in effect), the area under the pressure-time curve, P(t), of the initial shock wave as:

$$\text{Incident Specific Impulse} = \int P(t)dt$$

over the time interval from initial pressure rise to the point where the shock is too weak to have a significant impact on its surroundings. The specific impulse is directly proportional to the momentum acquired by a nearby object struck by the shock for structural loading where the time constant is much smaller in magnitude than the natural period of vibration of the object. The dynamic structural loading is termed impulsive and the magnitude of the specific impulse is a major parameter determining the dynamic response of the structure. For the form of a scaling law for impulse, the following equation approximates the numerical value for impulse:

$$\text{Incident Specific Impulse} \sim K_2 (W^{1/3})(W^{1/3}/R)^{\beta}$$

For most air-backed structures, the threshold which determines the difference between survival and permanent damage from an underwater shock is a function of both peak pressure and specific impulse. Unless otherwise determined, it might be assumed that the same would hold for organic structures as well.

Example of a Failure Criterion for a Clamped-clamped Plate Under Impulsive Loading

To provide an example of the relationship between peak shock pressure and incident specific impulse as parameters governing the survival or damage of a structure, it may be useful to consider the case of a thin elastic rectangular air-backed plate, (for example the shellplating of a surface vessel), subjected to a exponentially decaying shock wave. It is mathematically possible to model the two-dimensional elastic structure as a one-dimensional equivalent oscillator as:

$$m_e\, d^2x/dt^2 + k_e\, x = C_e P_{emax} e^{-t/\theta}$$

where:

m_e = mass equivalent
k_e = one dimensional “spring” constant
C_e = constant, (load equivalent noting that shocks increase in magnitude upon reflection from nearly rigid surfaces

The above differential equation is solved with the initial conditions at time t=0 being X(0)=0 and dx/dt =0. If $(k_e/m_e)^{1/2}\,\theta > 40$, the loading decays very little before the structure achieves its maximum deflection and the deflection is not strongly dependent on the structure’s mass but becomes strongly dependent on the peak pressure. This is not generally the case with underwater explosions since small or moderate explosive charges exhibit blast waves with time constants of magnitudes less than a millisecond. On the other hand, for situations where the product of the blast wave time constant and the natural period of the structure is very small, (much less than 40), the loading is considered impulsive and the shock wave impulse and the structure's mass become the dominant parameters in determining structural response. For many cases such as, for example, the response of steel shellplating, both peak pressure AND specific impulse should be considered where the product of the natural period of vibration and the blast wave time constant lie between 0.4 and 40. Using an energy solution for the structural response where the work done on a structure can be equated to a change in the structure's kinetic energy, (after assuming a reasonable displacement function for the structure, a descriptive plot, (see Figure 2H.1), can be created depicting the quasi-steady and impulsive loading asymptotes and the survival and damaged response of the structures.

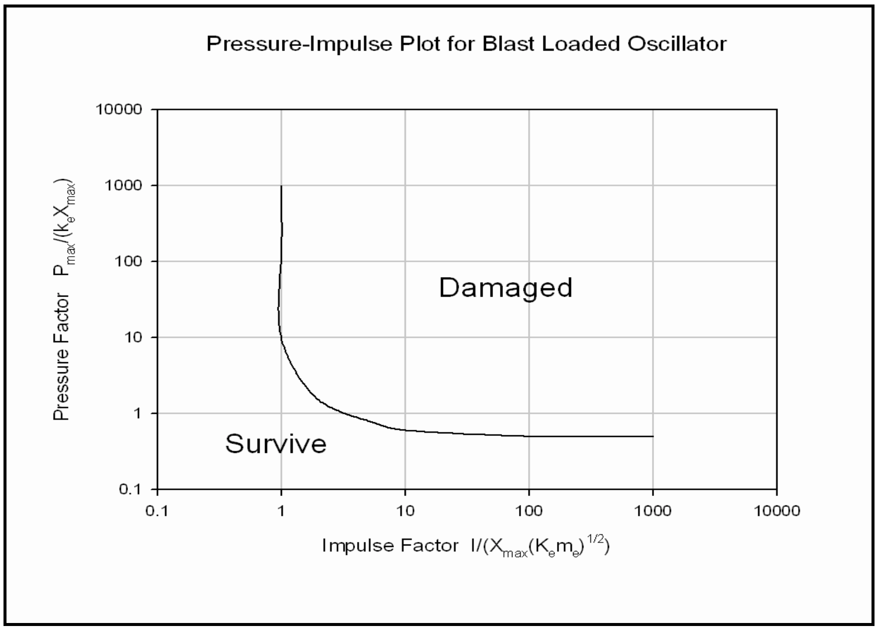

Figure 2H.1. A descriptive plot depicting the quasi-steady and impulsive loading asymptotes and the survival and damaged response of the structures.

The horizontal asymptote observed in Figure 2H.1 is the solution for quasi-steady dynamic load while the vertical asymptote is the impulsive solution. Many structural loadings due to underwater shock are found in the lower left of the plot where both impulse and peak pressure must be considered to determine structural response. The major point to be made is that peak shock overpressure alone is not an adequate descriptor of an underwater disturbance whose source is the detonation of a conventional explosive. Clearly the above represents a very simplistic analysis of the impact of an underwater shock originating from the detonation of a chemical explosive on a nearby object. The actual response of the structure is also complex since the initial displacement response of the structure results in cavitation of the water adjacent to the impact surface causing subsequent unloading and re-loading of the structure. Multiple shots result in multiple impacts, which results in a complex loading function that does not add algebraically but in a more complex fashion, Shock velocity is also not constant, but a function of shock strength, water temperature gradients, (water density gradients), and water salinity.

Shock wave transmission of kinetic energy is a very efficient mechanism to transmit energy long distances, particularly in dense media, (liquids and solids). As a result, the effects of underwater explosions can be felt at long distances from the source, and mitigation of these effects is of prime importance. The next section summarizes the various methods available to minimize the impact of underwater explosions on their surroundings.

SUMMARY OF SHOCK MITIGATION METHODS

Many methods have been considered or employed to mitigate the effects of underwater explosions on the environment. It must be considered that during a detonation of a chemical explosive, a single gram of a high explosive releases as much as 1.4 kilocalories of energy, (over 1.8 kilocalories per gram for aluminized explosives), at elevated temperature and extremely high pressure. True physical attenuation of shock waves requires the absorption or re-direction of the shock energy released into a harmless direction. That is not an easy matter, particularly when the attenuation or re-direction of the shock must be accomplished close to the charge itself.

Mitigation by Reduction in Net Explosive Weight

The most obvious solution to reduction in underwater blast effects is simply reduce the net explosive weight of the cutting or severing charges used to remove the platform or structure. Very serious effort is currently being devoted to obtaining more cutting effectiveness from explosive charges of lower weight. A number of technologies are available or are under development to accomplish meet this goal. The following sub-sections summarize a few of them.

Use of Directed Energy Devices: The use of shaped charge devices, particularly linear shaped charge cutters to sever underwater steel structural members has been employed in offshore structure removals and salvage operations for several decades. Recently the mast of the Ehime Maru was cut using an ROV deployed “horseshoe” shaped cutter using 3,200 grain/ft linear shaped charge assembled in a watertight housing. The mast had to be removed to avoid interference with the lifting slings used to move the vessel to shallow water. The purpose of the charge was to sever the mast with the least amount of explosive possible to avoid further damage to the ship and its contents. Linear shaped charge consists of a “chevron” shaped copper jacket containing very brisant explosive fills, (usually RDX), which when detonated collapses a portion of the jacket to form a high-speed jet of copper capable of penetrating distances into steel targets approximately equal to the width of the “chevron.” Linear shaped charge does not significantly reduce the blast wave in directions other than the jet propagation direction, but chiefly serves as a means to do a lot of steel cutting for a relatively small amount of explosive. Roll-formed linear shaped charge is limited to a maximum explosive loading of 3,200 grains per linear foot of charge. Larger charges are generally cast using Composition B, TNT, or Octol explosive fills. When 3,200 grain per foot linear shaped charge is formed into a circular shape for cutting circular members and then installed in a water-tight housing, (water would prohibit the jet from forming), a limiting cutting depth in mild steel is approximately 1.5 inches. Thicker members become a problem without resorting to larger cast charges. In addition, shaped charges should be installed on the member to be cut at an optimal or nearly optimal standoff distance to permit the jet to form properly and not have to propagate through too much water prior to impacting the member. Running a shaped charge cutter into the interior of a jacket leg or pile is not an easy matter. Ovality of the member, scale, and obstructions, (usually unknown beforehand), can make the use of linear shaped charge cutters difficult without prior preparation of the member to be cut.

External cutting for the purpose of pipeline repair has been accomplished in very deep water, (>5,000 feet), using ROV deployed cutters.

Cost is a factor where linear shaped charge cutters are more expensive than bulk charges, but are a useful tool for certain applications.

Waveshaping and Shock Reflection Induced Fracturing: Recognizing the cutting thickness limitations of copper jacketed linear shaped charges or 3,200 grain per foot or less, other techniques are being studied and tested to increase the steel thickness to be severed while maintaining the explosive fill weight near to that of linear shaped charge. The use of re-combinant shocks and their release waves if timed very precisely may result in very ductile steels behaving in a brittle fashion and fracturing and spalling along a pre-determined plane. This technique has applications in caisson removal where the steel wall thickness often exceeds the limits of linear shaped charge. These techniques have been demonstrated in the laboratory and are approaching the stage of trials on actual members. Thus this technique is currently an experimental one, but shows great promise, particularly for shallow water protected wellheads.

Collision Charges: A simple improvement to the conventional bulk explosive charge that could assist in reducing the net explosive weight in the charge is to initiate the charge from both ends at the same instant, resulting in detonation waves meeting at a plane in the charge approximately equidistant from the two detonators. Usually exploding bridgewire detonators are used due to their very low jitter, (less than a microsecond). This method is a fairly conventional design technique for warheads used in air-to-air missiles to alter the fragment throw of the warhead and to increase its lethality.

Years ago when the typical maximum surface conductor size was 30 inches in diameter, it was common to sever three to four conductor strings in a wellhead fifteen feet below the mudline and remove the wellhead and guidebase using a 27-pound net explosive weight nitromethane collision-type cutting charge. Conductor size has subsequently increased, but there is a possibility that even bulk shots could be reduced in weight if collision waveshaping were used.

Shock Waveshaping – Bubble Curtains

A solution to mitigate the effects of the initial shock wave as it propagates outward through the water from the explosive source is to increase the compressibility of the water surrounding the charge with a curtain of air, and force the outward propagating shock to pass through a very compressible medium, namely aerated water. A pipe is deployed on the seabed completely surrounding the explosive charge or charges. Holes are drilled in the pipe, and compressed air pumped from surface air compressors permit air to bubble out of the holes, essentially releasing a “curtain” of air bubbles around the charge. For example, two-inch pipe is typically used with 1/8" diameter holes drilled on six-inch centers permitting flow of approximately 2.5 cubic feet per minute per linear foot of pipe. The air compression requirements can be enormous: one job on a jackup in Kachemak Bay, Alaska, required eight compressors with a total flow capacity of 7,600 cubic feet per minute. The reduction in shock wave intensity for a well-designed bubble curtain is substantial in terms of peak blast overpressure reduction, less so in terms of reduction in specific impulse. Bubble curtains tend to “stretch out” the shock pulse, reducing the peak pressure but increasing the pulse duration. However, there have been a number of studies performed indicating the benefits of bubble curtains in improving the survivability of marine life close to the blast source. Bubble curtains are less effective in reducing shock energy for charges close to the curtain where the bubble pattern is not fully formed. Strong water currents are dispersive to the bubble pattern, making it less effective during tide changes and strong currents. The bubble curtain is also less effective close to the piping system, as the curtain has not had time to properly form, rendering the curtain less effective in protecting bottom-dwellers.

The major disadvantage is the tremendous cost associated with bubble curtain deployment. However, for extremely sensitive environmental regions such as spawning grounds for fish or known habitats for marine mammals or reptiles, bubble curtains are a possible solution for blast wave mitigation.

When bubble curtains of higher flow volumes have been used to protect explosive metal-forming tanks, flow rates of 8.7 cubic feet per minute have reduced to the tank wall hoop stress by 69%, while increasing the flow to 13.7 cubic feet per minute reduced the tank wall hoop stress by 83%.

Shock and Bubble Energy Absorption in Sacrificial Structures: Sacrificial structures are those structures used to surround the explosive charge and permitted to absorb shock energy in the form of elastic-plastic strains thereby reducing the shock wave energy emitted to the surrounding water. The most effective sacrificial structure is one consisting of a double-wall ductile steel shell with the inner wall backed by air.

An example of this type of structure is a double-wall steel shroud mounted on a rig’s fairleader assembly and used to contain the blast of a 1.5 pound net explosive weight stud link anchor chain cutter for emergency release of semi-submersible mooring systems. The shroud permitted the explosive shaped charge cutter to be detonated on an eighteen-inch center to the rig’s columns without permanent deformation of the columns.

Sacrificial structures can be expensive and as the nomenclature implies, are generally used only once.

The State of Connecticut required the use of water-filled or, in some cases, a de-watered cofferdams to protect endangered species of fish.

Shock Wave Absorption in Porous Media

Charges Emplaced Internally: Explosive charges run in the interior of structural members to be cut display initial shocks significantly attenuated from open water explosions. The granular material of the seabed, even though water saturated, is an effective absorber of shock energy. Concentration of the blast energy by running the cutting charge inside the member to be cut also makes more effective use of the bubble energy to sever the member; the oscillating gas bubble of detonation products contains nearly half of the energy released by the explosive and can do a significant amount of cutting if it attached itself to a structure when first formed.

Stemming: Stemming is a common term used in drilling and blasting and refers to the loading of inert materials on top of borehole charges to delay the release of the high pressure products of detonation and increase the crushing or break of the overburden surrounding the borehole. Likewise, the use of stemming in internally contained charges run below the seabed can also serve to direct the gas bubble energy radially outward instead of up the hole. This will improve severing effectiveness and reduce the blast released up the hole. For example, in designing wellhead severing charges, a cement filled ballast can was attached to the top of the charge container to render the charge negatively buoyant and also provide a degree of stemming to the charge. In terms of peak pressure, from actual measurements, the 27-pound nitromethane charge run fifteen feet below the mudline was equivalent, (in terms of peak overpressure only), less than 2 pounds net explosive weight detonated in open water.

De-watering the Structure and Shooting "Dry": When explosive severing charges are run internally in the member to be cut, it may be possible to "de-water" the interior of the member and shoot the charge "dry." Surrounding the charge by air instead of water increases the likelihood of fragment throw up the pile or leg, but significantly de-couples the shock from the surrounding water. Combined with some form of stemming, this would be an effective way to decrease the shock driven into the water. Precise measurements of shock intensity would be required to quantify the shock attenuation.

Delays: Projects requiring multiple shots should delay the shots sufficiently to avoid combining shocks and producing pressure rises in the surrounding water of very high peak pressures. Shot patterns and delays should be carefully designed to avoid damaging emplaced charges prior to their initiation and creating a hazardous situation with dudded or unfired damaged charges that require removal to the surface.

Mitigation Methods as Found in 50 CFR Part 216, Subpart M

In regard to the Code of Federal Regulations, Title 50, Part 216, "Regulations Governing the Taking and Importing of Marine Mammals", Subpart M, "Taking of Bottlenose Dolphins and Spotted Dolphins Incidental to Oil and Gas Structure Removal Activities", Section 216.143, 144 & 145 lists a number of mitigation measures that must be utilized when using explosives to sever structural members. The following lists those mitigation steps.

1) Ceasing blasting activities if dolphins are observed within 3,000 feet from the detonation site or leading the animals away from the platform using small boats, permitting the dolphins to “bowride” the boats away from the blast site.

2) Requiring aerial surveys. A good method of mitigation but aerial surveys have limited capability in detecting all forms of marine life of concern.

3) Restricting detonations to a time period from one hour after sunrise to one hour before sunset. This restriction is useful for permitting aerial and surface surveys of the blast area, but also assists in maintaining control over the blast site and therefore reduce the risks associated with offshore blasting. Only under the most dire emergency circumstances should blasting be permitted at night.

4) Restricting detonations to times when sea state and weather conditions permit aerial, surface or sub-surface animal surveillance to take place. This is good policy, however, under unusual or emergency circumstances, there should be provisions for exception.

5) Restricting time delays for groups of shots to a minimum of 0.9 seconds for each group of charges. Time delays or staggered detonations when properly designed avoid reinforcement of shocks from more than one charge. However, it must be noted that if time delays are too long, it’s possible for the shock from one charge to damage a nearby charge prior to detonation leading to misfires or damaged charges or charges dislodged from location. This becomes a safety issue. The 0.9 second delay may not be appropriate under all circumstances.

   In point of fact, some offshore blasting operations should not use delays. A jackup with its legs stuck in the mud and suffering from a broken jacking mechanism was freed by severing the legs; but the legs had to be severed simultaneously.

6) Using explosive charges having an impulse and pressure less than or equal to that generated by a 50-pound net explosive weight charge detonated outside the rig piling.

7) Conducting a second post-detonation survey no sooner than 48 hours after the shot and no later than one week after the shot to assess the impact on marine mammals and sea turtles unless an underwater survey has been conducted within 48 hours of the shot. This requirement may be waived if no marine mammals were sited on the pre-detonation survey. This does not constitute a reliable assessment of injury or mortality to marine life as all those injured or killed do not necessarily float. Even attempting to project or estimate mortality levels from observed “floaters” is uncertain.

8) Filing within thirty days of the explosive operation a report must be filed with the Director of NMFS detailing the blasting activities, monitoring and mitigation operations.

Alternative or Experimental Mitigation Methods

Alternative mitigation methods are being considered such as ROV surveys, sonar, and ultrasound techniques, but these are experimental and no evidence of their success in locating marine life has been forthcoming. Studies with these devices are necessary before employing them on a wholesale basis. Visual identification of marine life by ROV is sharply limited by the viewing range of the systems in murky water or at long distances.

"Scare" Charges

Detonating small underwater charges around the blasting site prior to firing the actual blast was once thought to be a means to frighten away marine life from explosive operations. Unfortunately, it has been found that "scare" charges can kill small fish and attract predators. "Seal bombs" were once used to drive away seals from fishing locations, but it was soon found that after time, the seals were no longer frightened and ignored the charges. There also has been one recorded human diver fatality from a detonating "seal bomb."

Noise from Non-Explosive Sources

Acoustic sources have been used by fishermen to drive fish into nets. Sirens have been used to repel fish in rivers. Some investigators have determined that pulsed broadband sound was effective as a repelling source for some types of fish. Pingers are also a possible source for driving marine life from blasting areas, but much work is required to ensure satisfactory results.

Seasonal Moratorium on Blasting

In regions where migration, spawning or other group activities of marine life take place on a seasonal basis, exposure and endangerment could be limited by avoiding blasting during certain times in the calendar year.

EFFECTIVENESS OF VARIOUS MITIGATION METHODS

Elasmobranchs

A recently proposed rule by the National Marine Fisheries Service would declare the Smalltooth Sawfish endangered. Only limited data appears to be published concerning their numbers and rate of population decline, although it is suspected that entanglement in fishing nets is a major cause of the reduction in numbers.

Bottom Feeders

The Gulf Sturgeon was listed as a threatened species by the National Marine Fisheries Service on 30 September 1991. As the Sturgeon is a bottom-feeder, the choices of mitigation methods are limited, but bottom surveys by ROV could be applied.

Marine Reptiles and Marine Mammals

As air-breathing marine animals requiring surfacing, marine reptiles and marine mammals are probably more easily spotted by aerial and surface surveys than other types.

Dr. David J. Leidel completed his doctoral studies at Drexel University in 1979 and joined Jet Research Center, a division of Halliburton Company, as a senior research engineer in shaped charge mechanics for aerospace and oilfield applications. He was responsible for the design of high density high temperature tubing conveyed shaped charge perforators, supported the defense and aerospace group in experimental heavy metal shaped charge warhead fabrication, provided technical support for the development and fabrication of several missile destruct systems, and supervised operations in the company's test range and flash x-ray laboratory. Dr. Leidel also supported offshore blasting and demobilization operations on offshore oil and gas production platforms by providing blast effects data to the field engineers. From 1989 to 1995, Dr. Leidel was employed by BEI Defense Systems Company as chief engineer on the tri-service Hydra 70 Rocket System while BEI was the rocket system's prime contractor. Dr. Leidel returned to Jet Research Center where he is currently a scientific advisor and research team leader in oilfield explosive systems. Over the last twenty years, Dr. Leidel has authored or co-authored a number of technical publications and participated in a wide variety of research programs in energetic systems.

THE MMS/NMFS/INDUSTRY WORK PLAN

Mr. Jeff Childs
Minerals Management Service

Subpart M Regulations (50 CFR § 216) under the Marine Mammal Protection Act (MMPA) allowing incidental harassment of dolphins while removing oil and gas structures on the Outer Continental Shelf in the Gulf of Mexico (GOM) expired on 13 November 2000.

The goal of this document is to set a "course" for the Minerals Management Service (MMS), the offshore oil and gas industry (Industry), and the National Marine Fisheries Service (NMFS) to navigate to achieve resolution to the Explosive Removal of Offshore Structures (EROS) issue. Specific objectives of the document include (1) identifying the starting point for petitioning NMFS, (2) describing the petitioning cycle, (3) presenting a dynamic solution to the EROS issue, and (4) identifying future work required to achieve the dynamic solution.

THE STARTING POINT

The NMFS requires a petition from either the oil and gas industry or the MMS to consider the development of specific regulations and incidental take authorization while removing offshore structures in the GOM. NMFS requires a synthesis of information as specified in Subpart I (50 CFR §216.104) including new information gathered since the former Subpart M regulations were issued. That information would be the basis for the petition. The information requirements include a detailed description of the activities expected to result in incidental taking of marine mammals; the duration of such activities; a description of the status and distribution of marine mammals likely to be affected by such activities; the type of incidental take authorization that is being requested (i.e., takes by harassment only; takes by harassment, injury and/or death); the anticipated impact of the activity upon the marine mammal and its habitat; and the suggested means of accomplishing the necessary monitoring and reporting that will result in increased knowledge of the species.

MMS will petition the NMFS to promulgate regulations under the MMPA allowing for the incidental take (harassment only) of marine mammals inhabiting shelf and slope waters of the GOM in conjunction with the explosive removal of offshore oil and gas structures. NMFS recently established new criteria (based on peak pressure and acoustic energy flux properties) to determine when a marine mammal would be subjected to harassment. MMS must consider the "take" criteria in its petition and use it as a basis for mitigating measures. Once NMFS accepts the petition they can begin the rulemaking process.

At the same time MMS is preparing the petition for MMPA regulations, it will also be preparing documents for an Endangered Species Act (ESA) Section 7 Consultation. The consultation will also address explosive removal of oil and gas structures on the shelf and slope. Threatened and endangered species covered in the ESA consultation will include the Kemp's ridley, green, hawksbill, loggerhead and leatherback sea turtles and the sperm whale. MMS' goal is to have the ESA consultation results mirror the MMPA petition results. Only after MMPA regulations are implemented for marine mammals can NMFS provide for incidental take of the endangered sperm whale, under the ESA.

THE PETITIONING CYCLE

The reason that Subpart M regulations expired is that neither Industry nor MMS petitioned NMFS for new rulemaking. Small take regulations under the MMPA may be effective for as many as five years. In the past, NMFS has issued Subpart M regulations with a five-year life span. To effectively address the lapse of Subpart M regulations, Industry, MMS, and NMFS need commit to the petitioning cycle (Figure 2H.2) which can be summarized as petitioning, rulemaking, studies, monitoring, assessment, and re-petitioning. Each component of the petitioning cycle is interdependent with the others. It is not enough to simply re-petition for regulations every five years without conducting additional studies, monitoring, and analysis of data. For example, upon issuing Subpart M regulations in 1995, NMFS specified the need to collect data concerning the alleged dampening effects of detonating explosives inside a tubular member and below the mudline. This study was not performed; consequently, the petition must be based on a model using open-water blast parameters. Such a model will likely generate an impact zone that is considerably more conservative than one that incorporates the alleged dampening effects.

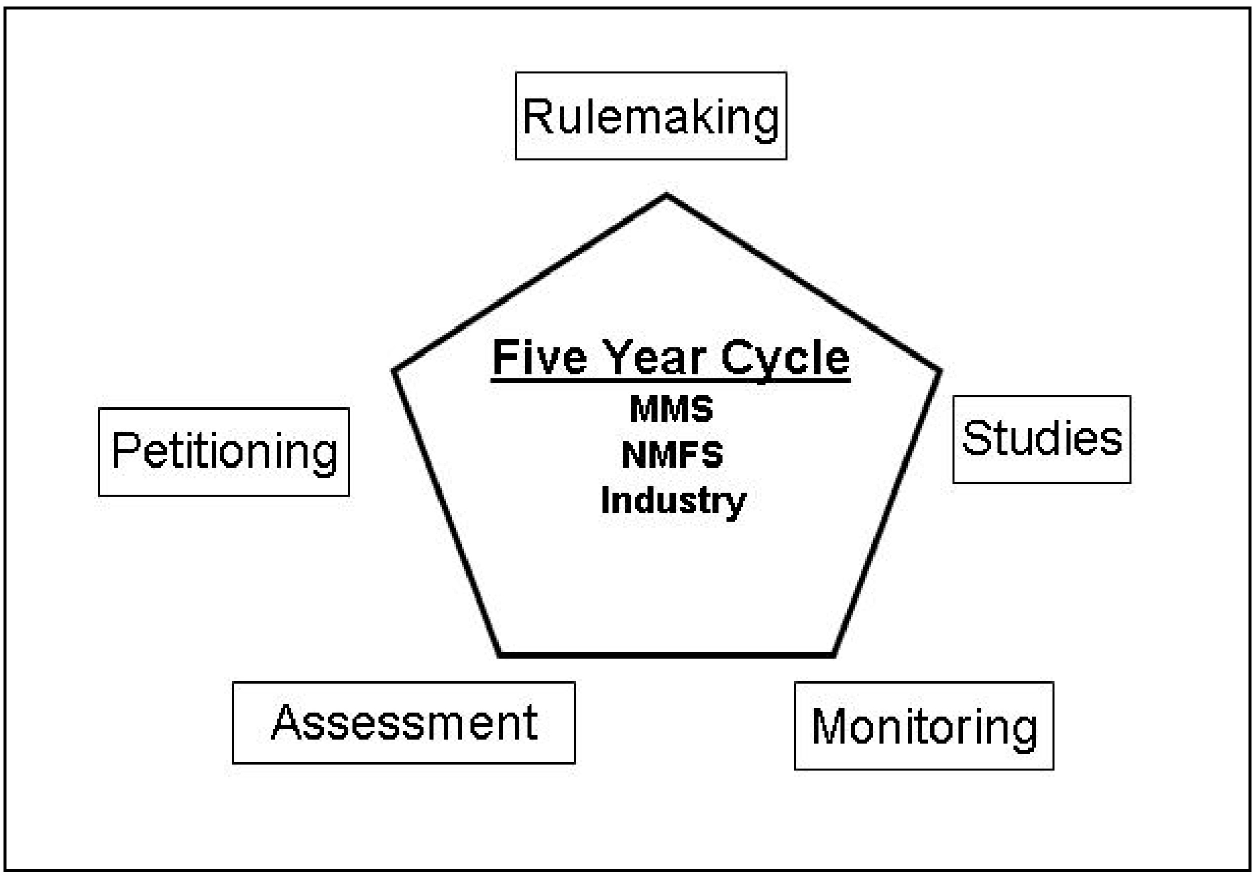

Figure 2H.2. Managing the EROS issue: committing to a petitioning cycle.

A DYNAMIC SOLUTION

The opportunity to establish new regulations for EROS activities is of great importance to Industry, MMS, and NMFS. The results will also be of interest to the U.S. Navy, the U.S. Coast Guard, and the U.S. Army Corps of Engineers. The existing and expired requirements are fraught with problems. Firstly, they are only practical in waters where divers can safely perform underwater surveys; structures in waters greater than approximately 50 m (160 ft) fall outside the safe limits of performing these diver surveys. Secondly, in some cases the requirements are excessive. The National Research Council (1996) and Pulsipher *et al.* (1996) recommended that pre-detonation surveys performed by NMFS observers be reduced from the required 48 hr period to no more than 24 hr of observation time. Thirdly and perhaps most importantly, the existing requirements limit the weight of individual explosive charges to 50 pounds. As predicted by the NRC (1996), the requirements have become a *de facto* industry standard that discourages the development of alternative explosive technology. Essentially, there are no economic incentives for Industry to use smaller charges or to design new mitigation measures that will minimize the shock wave and acoustic properties associated with an explosive removal project. For example, an operator that uses a single 20-pound shape charge to remove a structure is saddled with the same mitigation measures as an operator that uses a series of 50-pound bulk charges. Additionally, because the existing "generic plan" is limited to the use of 50-pound charges, operators with structures requiring explosive charges exceeding 50 pounds are faced with a permitting obstacle course under both the ESA and MMPA that may take months to complete. All teams can benefit from the establishment of a flexible and dynamic approach that encourages new solutions to the problems posed by explosive removals.

The MMS has drafted such a "dynamic plan." Not only does the dynamic plan allow for new solutions to the problem, the plan also facilitates the petitioning cycle that is required by the MMPA (Figure 2H.2). To meet our National Environmental Policy Act (NEPA) obligations, the MMS will prepare a Programmatic Environmental Assessment (PEA) on Structure Removal Operations in the Gulf of Mexico. The PEA will be drafted to include the information required to petition the NMFS for new MMPA rulemaking and complete our Formal Section 7 Consultation under the ESA. It will be structured such that it will champion the "dynamic plan."

The conceptual application of the dynamic plan begins with an operator consulting with engineers and explosives experts to determine the methodology to remove the structure. Given the decision to use explosives, the operator would prepare a plan that identifies the appropriate impact zone and mitigation measures to be performed for the removal. The impact zone would be calculated from models or equations prepared and approved by the MMS and NMFS. Similarly, the mitigation measures would be selected from a MMS-NMFS list of mitigation measures appropriate for the site, proposed charges, etc. The operator would also be encouraged to nominate or propose experimental mitigation measures to MMS and NMFS for consideration. MMS would review the operator's plan and approve, modify, or disapprove it following communications with the operator and NMFS as necessary. Once the plan is approved, the operator would then be responsible for carrying it out and reporting the results to MMS and NMFS.

THE WORK LIST

There is much to be done before the Dynamic Plan can be submitted to NMFS for consideration. In concept, NMFS has communicated to MMS that they support the plan. However, they have also stressed the need to gather credible scientific data to support its implementation. To start, we will need to model the impact zone for explosive removals. According to NMFS, such a model must use open-water blast criteria. The PEA will include an analysis of the dynamic plan using the open-water blast model (the PEA will be the vehicle for petitioning NMFS for new small-take rulemaking). It is expected that new rulemaking would conclude approximately 12 months after petitioning NMFS. Any new plan (dynamic or otherwise) approved by NMFS during rulemaking is expected to be based on open-water blast modeling.

To factor the supposed dampening effects of setting off explosives within a tubular 15 feet (or more) below the mudline into the model, Industry and MMS must demonstrate to NMFS with credible scientific data that the shock wave and acoustic noise generated by the action does in fact experience a dampening effect. Therefore, during the period that MMS is preparing the PEA and petitioning for rulemaking, the MMS will fund a study to collect shock wave and acoustic properties data from explosive removals. The study is crucial to move from an open-water blast model to one that mirrors the methods by which offshore structures are removed with explosives. The study is expected to conclude in approximately three years. Upon completion of the study, MMS will revise the dynamic plan model and submit it with the results of the shock wave study to re-petition NMFS for new MMPA rulemaking. To be clear, Industry will not have a dynamic plan that incorporates the hypothesized dampening effects until MMS and Industry collect credible data and present it to NMFS as a petition.

Although the MMS is preparing the PEA to petition for new MMPA rulemaking and funding the shock wave study, the MMS will need the assistance of both Industry and NMFS to bring this issue to some resolution. For example, the process would benefit from an Industry-prepared document that describes in detail the methods used to decommission offshore structures, and more specifically, the methods of explosive removal. The MMS and NMFS will use this information in their analyses required by the NEPA, ESA, and MMPA. Additionally, the shock wave and acoustic properties study will require the proactive, unbiased support and participation of Industry. Without such support, Industry will continue to be beleaguered with the use of open-water blast criteria. At the same time, since NMFS has the final responsibility for approving the dynamic plan, it is in the best interest of MMS and Industry to draw upon the biological and acoustic expertise that NMFS can offer throughout the development of the PEA and shock wave study. Similar proactive partnerships with the U.S. Corps of Engineers, U.S. Coast Guard, and U.S. Navy may also be prudent to obtain a pragmatic and dynamic solution to the explosive removal of offshore structures.

The course to resolving the problems facing Industry, MMS, and NMFS concerning the explosive removal of offshore structures lies before us to navigate. It is in the best interest of all teams to work proactively together to achieve our goals of removing offshore structures while also meeting our responsibilities of protecting marine life and their habitats under the NEPA, ESA, and MMPA.

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The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.