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MMS 2000-030

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Eighteenth Annual Gulf of Mexico Information Transfer Meeting

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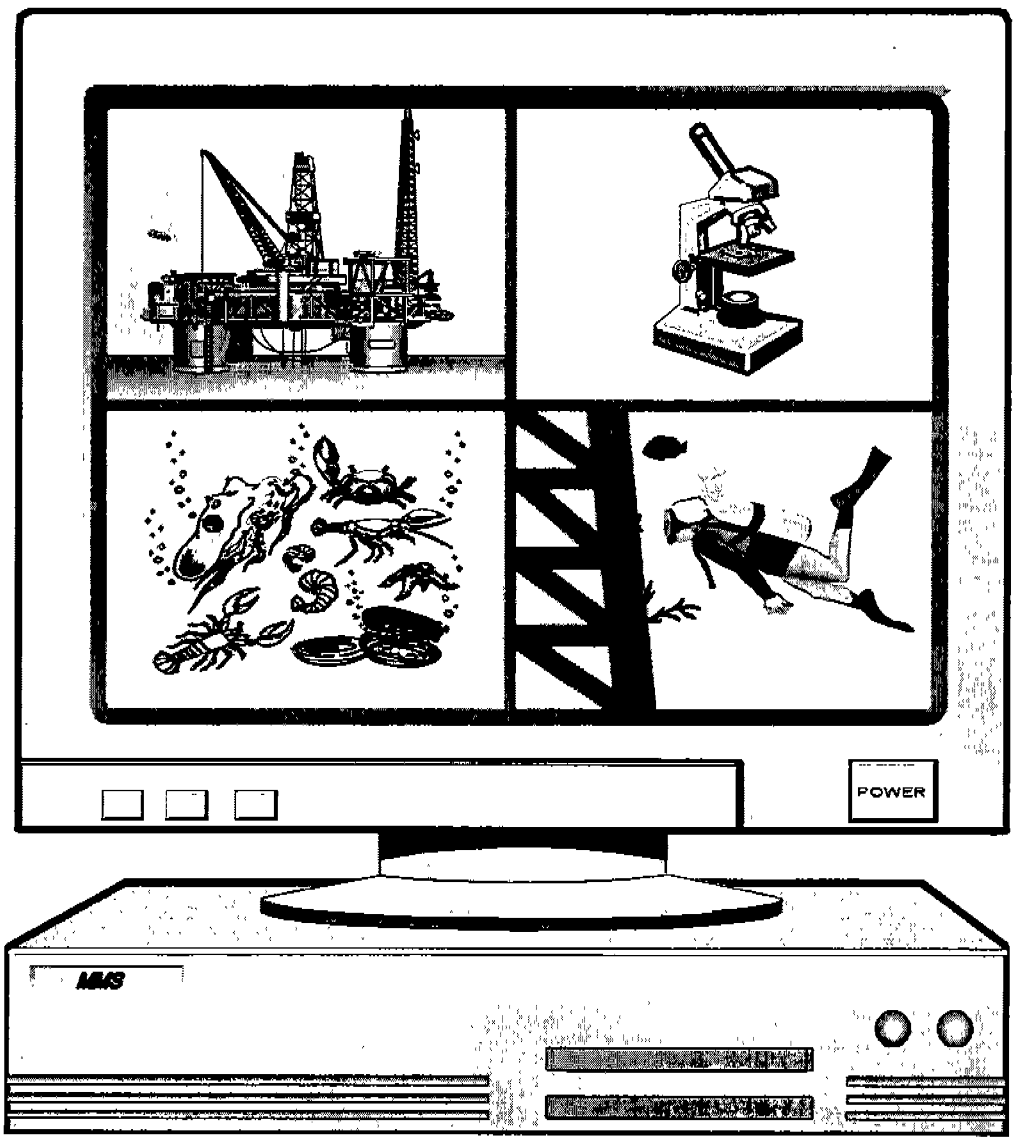

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Minerals Management Service
Gulf of Mexico OCS Region

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MMS 2000-030

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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. Authors are listed by name with their articles and again in an index at the back of this publication.

We are grateful to the chairs and co-chairs for the many hours spent in organizing and chairing the sessions and for spending time gathering presentation summaries. They are listed by name in the table of contents as well as at the beginning of each session.

Special recognition is given to staff who contributed immensely to the overall success of the meeting: Rose Hampton and Vita Jones, administrative support; Donna Bourg, Internet and administrative support; Joe Perryman, computer technical support.

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The staff of the Airport Hilton were personable and accommodating to our countless requests.

INTRODUCTION

Ms. Debra L. Vigil
Environmental Sciences Section
Minerals Management Service
Gulf of Mexico OCS Region

The primary purposes of the ITM are (1) to provide a forum for interchange on topics of current interest relative to environmental assessments in support of offshore oil and gas activities in the Gulf of Mexico OCS Region; (2) to present the accomplishments of the MMS Environmental Studies Program for the Gulf of Mexico and of other research programs or study projects; and (3) 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 and to encourage opportunities for these attendees to meet and nurture professional acquaintances and peer contacts.

The ITM agenda is planned and coordinated by the MMS staff of the Gulf of Mexico OCS Regional Office around the three themes mentioned above—issues of current interest to the Region or MMS oil and gas program; accomplishments of the agency; and regional information exchange. Presentations are by invitation through personal contacts between session chairpersons and speakers who have demonstrated knowledge or expertise on the subject.

The ITM is considered a meeting of regional importance and is one of the Region's primary outreach efforts. Attendance in recent years has been 300-400 people, including scientists, managers, and laypersons from government, academia, industry, environmental groups, and the general public.

Support funding is provided through the MMS Environmental Studies Program. Logistical support for the ITM is provided by a contractor and subcontractors selected through the Federal procurement process. A proceedings volume is prepared for each ITM based on summaries of brief technical papers submitted by each speaker and on each session chair's added comments.

SESSION 1A

OIL SPILL RESPONSE, RESEARCH, REGULATIONS, AND DRILLS

Co-Chairs: Mr. Joe Mullin and Mr. Michael Tolbert

Date: December 8, 1998

Presentation	Author/Affiliation
Regional Oil Spill Response Plans and 30 CFR Part 254	Mr. David M. Moore Minerals Management Service Gulf of Mexico OCS Region
Unannounced Oil Spill Drill Program	Ms. Angie D. Gobert Minerals Management Service Gulf of Mexico OCS Region
The Minerals Management Service Cutting Edge Oil Spill Response Research	Mr. Joseph V. Mullin Minerals Management Service Engineering and Research Branch
Availability and Capabilities of "Ohmsett": the National Oil Spill Response Test Facility	Mr. Michael E. Whitehead Mr. William T. Schmidt MAR, Incorporated Diamondhead, Mississippi

REGIONAL OIL SPILL RESPONSE PLANS AND 30 CFR PART 254

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One facet of the Oil Pollution Act of 1990 (OPA), passed in August of that year, was the amendment of section 311(j) of the Federal Water Pollution Control Act (FWPCA) which strengthened provisions concerning oil-spill prevention efforts and spill response capability. Under Executive Order 12777, the Minerals Management Service (MMS) is responsible under FWPCA for issuing regulations requiring owners or operators of offshore facilities to prepare and submit oil spill plans. The FWPCA requires that owners or operators of offshore facilities, including associated pipelines, prepare and submit response plans. They must also ensure the availability of private personnel and equipment to contain discharges of oil and hazardous substances. The new authorities apply to all offshore areas including state submerged lands but not to deep-water ports subject to the Deep Water Port Act.

On 12 August 1992, MMS published an advance notice of proposed rulemaking (ANPR) in the Federal Register. That notice informed the public that MMS was developing regulations governing 1) the establishment of procedures, methods, and equipment to prevent and contain discharges of oil and hazardous substances; 2) the preparation and submission of response plans; and 3) the periodic inspection of containment booms and response equipment. The notice solicited information concerning the development of these requirements.

MMS reviewed and analyzed the comments received from the ANPR and published a notice of proposed rulemaking covering these requirements on 13 January 1995. To allow owners and operators of facilities to continue to operate beyond 18 February 1993, the established date for submittal of spill response plans, MMS developed an interim final rule. The interim final rule ensured that spill response plans were in place at the earliest possible date and that the beneficial environmental effects of spill response plans were realized while more extensive regulations to implement OPA were being developed. The interim final rule, which was set to expire on 18 February 1995, was subsequently extended to the effective date of the final rule.

On 25 March 1997, MMS published its final rule governing Oil Spill Response Plans (OSRPs) and related requirements for facilities located seaward of the coastline, including those facilities located in both state and federal offshore waters (30 CFR Part 254). These regulations became effective on 23 June 1997. Interim guidance on the preparation of regional oil spill response plans based upon the new regulations was provided through a Notice to Lessees and Operators (NTL) No. 97-15, dated 27 June 1997.

MMS has prepared the final guidance regarding the preparation of regional oil spill response plans, with publication tentatively scheduled for January 1999. The subject NTL was prepared by engineers and biologist from Field Operations and Leasing and Environment directly responsible for Oil Spill

Contingency Plan (OSCP) review and approval. During the development process, the draft NTL was forwarded for review and comment to staff at agencies in Alabama, Mississippi, Louisiana, and Texas responsible for spill response and management. Further, the draft NTL was forwarded to and reviewed by members of the American Petroleum Institute, the Offshore Operators Committee, the National Ocean Industries Association, and the Independent Petroleum Association of America. Recommendations for NTL revisions were presented both in written form and during an informal presentation by OOC representatives to MMS. Suggestions that clearly represented an improvement in the NTL were incorporated as appropriate.

One of the many features of the regional oil spill response plans that will be a product of the new NTL will be documents of similar formats that contain discreet plan components. Such an approach was chosen to help simplify plan development and long-term plan maintenance without compromising plan integrity and effectiveness in ensuring a prompt, efficient response to an oil spill. Additionally, this approach, in conjunction with MMS initiatives to standardize plan reviews, will reduce the amount of time required by MMS staff to review response plans for regulatory consistency and will thus result in quicker plan approvals. For owners and operators, the new approach should equate to a much clearer understanding of plan requirements and the elimination of numerous revisions brought about by MMS review to bring plans into compliance with the regulations. For both owners and operators and MMS alike, the new approach should mean improved staff productivity and reduced costs.

The Table of Contents for a typical OSRP to be prepared following publication of the forthcoming NTL is given below. As the NTL is undergoing final review in the NTL approval process, sections are subject to change.

Section 1. OSRP Quick Guide (Optional)

Section 2. Preface
- a. Table of Contents
- b. Record of Revisions
- c. Cross Reference Table

Section 3. Introduction
- a. Companies Covered
- b. Purpose and Use
- c. Types of Leases and ROW Pipelines
- d. Facility Information Statement
- e. Contract Certification Statement

Section 4. Organization
- a. Qualified Individual
- b. Spill Management Team
- c. Spill Response Operating Team
- d. Oil Spill Removal Organizations

Section 5. Spill Response Operations Center and Communications
a. Spill Response Operations Center
b. Communications

Section 6. Spill Detection and Source Identification and Control
a. Spill Detection
b. Pipeline Spill Detection and Location
c. Source Control

Section 7. QI, SMT, SROT, and OSRO Notifications
a. Reporting Procedures
b. Company Contact Information
c. SROT Contact Information
d. OSRO Contact Information
e. Internal Spill Reporting Forms

Section 8. External Notifications
a. Reporting Procedures
b. External Contact Information
c. External Spill Reporting Forms

Section 9. Available Technical Expertise

Section 10. Spill Assessment
a. Locating a Spill
b. Determining the Size and Volume of a Spill
c. Predicting Spill Movement
d. Monitoring and Tracking the Spill Movement

Section 11. Resource Identification

Section 12. Strategic Response Planning

Section 13. Resource Protection Methods

Section 14. Mobilization and Deployment Methods

Section 15. Oil and Debris Removal Procedures
a. Offshore Procedures
b. Shallow Water Procedures

Section 16. Oil and Debris Disposal Procedures

Section 17. Wildlife Rehabilitation Procedures

Section 18. Dispersant Use Plan
a. Dispersant Inventory
b. Toxicity Data
c. Application Equipment
d. Application Methods
e. Conditions for Use
f. Approval Procedures and Forms

Section 19. In Situ Burning Plan
a. In Situ Burning Equipment
b. Procedures
c. Environmental Effects
d. Safety Provisions
e. Conditions for Use
f. Decision Processes
g. Approval Procedures and Forms

Section 20. Alternative Chemical and Biological Response Strategies (Optional)
a. Product Inventory
b. Toxicity Data
c. Application Equipment
d. Application Methods
e. Conditions for Use
f. Approval Procedures and Forms

Section 21. Documentation

Appendix A. Facility Information
a. Table 1
b. Table 2
c. Table 3
d. Table 4

Appendix B. Training Information
a. OSRC/IC, SMT, and QI
b. Other SMT Members
c. SROT
d. Location of Records

Appendix C. Drill Information

Appendix D. Contractual Agreements

Appendix E. Response Equipment

a. Equipment Inventory
b. Inspection and Maintenance Programs

Appendix F. Support Services and Supplies

Appendix G. Notification and Reporting Forms

a. Internal Spill Reporting Forms
b. External Spill Reporting Forms

Appendix H. Worst Case Discharge Scenarios

a. Facility Information
b. Volume
c. Land Segment Identification
d. Resource Identification
e. Response

Appendix I. Bibliography

Items of significance noted in the NTL associated with MMS efforts to improve the plan while reducing requirements are the provision for a company-defined "OSRP Quick Guide," which is intended to serve as an abbreviated set of instructions for owners and operators on key actions, contacts, and requirements during the early phases of a spill response; the reduction of copies of initial response plans and subsequent modifications required by MMS from two copies, to one copy; the reduction of the plan update frequency from once a year, to every two years; the elimination of response time sheets and trajectory land impact probabilities, sensitive resource identification and protection strategies; and the option to certify that contracts are in effect with oil spill removal organization(s) instead of providing a fully executed contract.

With the effective date of the NTL to be sixty days following its publication, owners and operators will have a number of options on when they must submit a new OSRP. Owners and operators who have not filed a regional OSRP under existing interim requirements must submit a plan in compliance with the new NTL. Those owners and operators with approved oil spill contingency plans may either 1) amend the plan in compliance with the new NTL at the time of the next annual update, or 2) amend the plan using existing interim requirements at the time of the next annual update but then amend the plan in compliance with the new NTL at the time of the following annual update. Response plans submitted in various phases of revision or those that have never been approved will be reviewed on a case by case basis, with the status of the owner's or operator's worst case certification being a key factor in determining if the response plan must be submitted under guidance provided in the new NTL.

Following publication of the NTL, it will be forwarded by direct mail to those on the MMS NTL mailing list. Additionally, copies may be obtained from the MMS Web Site at *http://www.gomr.mms.gov/topic1/html*, or by contacting the MMS GOMR Public Information office at 504-736-2519 or 1-800-200-GULF.

David Moore works with MMS in the Gulf of Mexico region as a Petroleum Engineer in the Pipeline Section. His current responsibilities include review of pipeline applications and pipeline repair procedures. Additionally, he reviews oil spill response plans and conducts unannounced spill drills for companies with facilities limited to right-of-way pipelines.

UNANNOUNCED OIL SPILL DRILL PROGRAM

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Gulf of Mexico OCS Region

This paper discusses the history and evolution of the Minerals Management Service (MMS) Gulf of Mexico Outer Continental Shelf Region's (GOMR) Unannounced Oil Spill Drill Program. This paper also contains a few statistics regarding the GOMR Unannounced Oil Spill Drill Program.

The MMS is a regulatory agency within the United States Department of the Interior (DOI) charged with responsibility for administering the Outer Continental Shelf (OCS) oil, gas, sulphur, and minerals program. Its responsibilities include the regulation of operations to ensure safety, conservation of natural resources, and protection of the environment.

Of particular concern to the MMS and the general public is the prevention of and response to oil spills. The MMS has extensive regulations designed to minimize spill occurrences and to ensure that operators respond effectively to spills when they happen. To ensure an effective response, the MMS requires oil spill response plans, training of those persons responsible for the response, and periodic drills and other exercises. The MMS can also conduct unannounced oil spill drills as part of its regulatory approach.

The Unannounced Oil Spill Drill Program was launched by the GOMR in May 1989 via a Letter to Lessees and Operators (LTL). This program was instituted to test oil spill response preparedness of operators in the Gulf of Mexico. On 26 June 1989, the GOMR issued a second LTL to all oil and gas operators in the Gulf of Mexico. This LTL implemented the program and explained the procedures concerning the various types of oil spill containment and cleanup drills the GOMR would be conducting. In 1992, the MMS published Notice to Lessees and Operators (NTL) No. 92-04. One of the results was that holders of OCS right-of-way (ROW) pipelines in the Gulf of Mexico would be subject to unannounced drills.

On 3 February 1994, a Memorandum of Understanding (MOU) among the Department of Transportation, the DOI, and the Environmental Protection Agency became effective. This MOU established Federal jurisdictional boundaries for offshore facilities including pipelines. Under this MOU, the MMS is responsible for offshore facilities located seaward of the coastline, including those in state offshore waters.

The MMS has entered into MOU's with both the Louisiana Oil Spill Coordinator's Office (LOSCO) and the Texas General Land Office (TGLO). The MOU's are for the purpose of coordinating and implementing consistent requirements for oil spill prevention and response. Among the provisions of these MOU's is the conducting of joint drills with LOSCO and TGLO. These MOU's became effective in late 1994.

On 23 June 1997, the MMS published its final rule implementing the provisions of the Oil Pollution Act of 1990 (OPA 90). These regulations contain a provision in paragraph (g) of 30 CFR 254.42, *Exercises for Your Response Personnel and Equipment*, for the MMS to conduct unannounced oil spill drills. The GOMR Unannounced Spill Drill Program continues under this new authority.

As a result of OPA 90, the U. S. Coast Guard developed the National Preparedness for Response Exercise Program (PREP) to meet the intent of Section 4202(a) of OPA 90 as a workable exercise program. It was developed to provide a mechanism for compliance with the exercise requirements while being economically feasible for the government and oil industry to adopt and sustain.

The PREP is a unified Federal effort and satisfies the exercise requirements of Department of Transportation agencies (the U.S. Coast Guard and the Office of Pipeline Safety), the Environmental Protection Agency, and the DOI's MMS. These exercises, which we call drills, also may include the participation of State and local government agencies. Completion of the PREP exercises will satisfy all OPA 90 mandated oil spill response exercise requirements. Guidelines for the various types of PREP drills have in place since 1 January 1994.

The 1989 LTL outlined four types of unannounced drills and exercises. They are:

1) Unannounced Drill with Equipment Mobilization Only
2) Unannounced Drill with Equipment Mobilization and Deployment
3) Spot "Table-Top" Drill
4) Announced "Table-Top" Simulation of a Large Oil Spill (to date no drill of this type has been held)

The remainder of this paper describes how an unannounced oil spill drill is planned, conducted, and evaluated.

When the GOMR schedules an unannounced oil spill drill, the first step is to select an operator or pipeline ROW holder to drill. The selection is made by the Regional Supervisor for Field Operations, the Plans Section Chief, or the Oil Spill Program Administrator. The selection is made using criteria that includes: new operators, operators with new oil spill response organizations, operators who have exhibited past poor performance, operators with facilities storing or transporting large volumes of oil, and operators with facilities near highly sensitive areas.

The GOMR Oil Spill Program Administrator usually takes the lead in conducting the drill. The lead position is titled "Monitoring Team Leader." The Monitoring Team Leader develops a plausible scenario for the drill. He utilizes information gathered from various sources such as computer data and MMS files and records. After an oil spill trajectory analysis is performed, the Monitoring Team Leader arranges the logistics for the drill. This includes selecting a Monitoring Team from personnel in the GOMR Office of Field Operations, the GOMR Office of Leasing and Environment, and appropriate Federal or State agencies. This also includes arranging for the delivery of the scenario to the offshore facility (if possible) and briefing the Monitoring Team on the scenario and the expectations for the drill.

On the day of the drill, the Monitoring Team arrives at the operator's Command Center to monitor the response efforts of the Oil Spill Response Coordinator and the Spill Management Team. Upon arrival, the Monitoring Team Leader asks to speak with the Response Coordinator. The Monitoring Team Leader informs the Response Coordinator that the Monitoring Team is there to conduct an unannounced oil spill drill. After notification from the field, which is planned to happen simultaneously with the arrival of the Monitoring Team at the Command Center, the scenario is reviewed and the Ground Rules are established. The scenario sets up the situation for the drill, and the Ground Rules tell the operator what the GOMR expects of him.

During the course of the drill, the operator is expected to respond as if the scenario were real. The Ground Rules contain instructions on what can and cannot be simulated. The unannounced oil spill drills usually take place in real time, even for simulated actions. In other words, even if an action is simulated, the operator must behave as though the action were actually taking place and allow the necessary time to complete the action.

While the operator responds to the scenario, the Monitoring Team observes the actions of the Response Coordinator and his Spill Management Team. During these observations, the Monitoring Team may use prepared evaluation forms or just make notes. The Monitoring Team Leader usually concludes the drill after the operator has explored all of his response options, determined an appropriate and adequate response, initiated simulated response efforts, and calculated the times for response equipment and personnel to arrive at the site of the simulated spill.

The initial evaluation of the unannounced oil spill drill occurs at the onsite debriefing. At the conclusion of the drill, the Monitoring Team Leader asks the Response Coordinator to discuss his response actions. The discussion may include acknowledgments of what was done well and recommendations for improvement of what was not done so well. This discussion is open to the GOMR Monitoring Team as well as the other Spill Management Team members.

The second phase of the evaluation is the operator's written report. This report should include, but not be limited to, a chronology of all events, copies of each participant's log, a summary of the status of all response efforts at the time the drill is concluded, and any comments that will assist the GOMR in improving future unannounced oil spill drills. The operator must submit this report to the GOMR within 15 days of the date of the drill.

The GOMR will respond to the operator with a critique which includes the comments, observations, and recommendations of the Monitoring Team. It is the goal of the GOMR to transmit this critique to the operator approximately 30 days after it receives operator's evaluation.

The GOMR evaluates each unannounced oil spill drill based on the three major categories of the Response Plan Core Components outlined in the PREP guidelines. Only those Response Plan Core Components that are demonstrated during the unannounced oil spill drill will be considered for MMS drill component credit. The three major categories of PREP Response Plan Core Components are Organizational Design, Operational Response, and Response Support.

Organizational Design consists of three components:

1. Notifications
2. Staff Mobilization
3. Ability to Operate Within the Response Management System Described in the Response Plan.

The MMS expects operators to make all the necessary notifications, such as the National Response Center, the local U. S. Coast Guard Marine Safety Office, and other appropriate federal and state agencies. Staff mobilization encompasses the assembly of the Spill Management Team and other necessary field personnel to carry out response efforts. The ability to operate within the response management system described in the response plan pertains to the effectiveness of the organizational structure to accomplish an adequate response.

Operational Response consists of six components:

1. Discharge Control
2. Assessment
3. Containment
4. Recovery
5. Protection
6. Disposal

Operational Response relates to spill source abatement, spill assessment, identified cleanup strategies for the spill, protection of sensitive resources and involved personnel, and accommodations for disposal.

Response Support consists of five applicable components pertaining to the ability to

1. establish an effective communication system
2. provide effective transportation to facilitate the cleanup and support activities,

3. provide all personnel associated with the response necessary support, such as administrative management, overnight accommodations, and suitable feeding arrangements for a sustained response,
4. procure sufficient personnel, equipment, and support equipment to mount and sustain an organized response, and
5. document decisions and actions.

The GOMR recently instituted the Pass/Fail rating system. The system is designed to categorize an operator's performance in each of the three major PREP Response Plan Core Components categories (Organizational Design, Operational Support, Response Support). The rating received will then determine, based upon policy, the subsequent actions taken by the GOMR.

When an operator receives a Pass rating for any of the three categories, the GOMR evaluation letter contains commendations and recommendations for improvement. Following are examples of commendations: "The assembly of the Spill Management Team was quick," and "The Command Center was equipped with essential charts, maps, and other visual aids," and "Disposal was addressed early in planning the response." Examples of recommendations: "Your Spill Management Team should consider further training in the area of Dispersant Use"; "You should better utilize the services of oil spill experts"; "Consider all available forms of transportation in your response efforts."

When an operator receives a Conditional Pass rating for any of the three categories, the GOMR evaluation letter contains directives that are to be carried out by the operator within a specified time frame. These directives could include specific changes in his oil spill response plan, remedial training for response personnel in specific areas, or conferences with the Oil Spill Program Administrator and other appropriate officials. After these directives are accomplished, the GOMR may re-drill the operator to determine if the condition(s) can be removed.

An operator will receive a Fail rating if he or she is unsuccessful in carrying out an adequate response within an appropriate time in accordance with his oil spill response plan. The evaluation letter will contain directives that are to be carried out by the operator within a specified time frame. As with the Conditional Pass rating, these directives could include specific changes in the oil spill response plan, remedial training for response personnel in specific areas, or conferences with the Oil Spill Program Administrator and other appropriate officials. After these directives are accomplished, the GOMR will re-drill the operator to determine if he can now carry out an adequate response. Any operator receiving a Fail rating may be subject to receiving Incidents of Non-Compliance (INC's) and civil penalties.

A few statistics regarding the GOMR Unannounced Oil Spill Drill Program:

1. Of the approximately 155 oil spill response plans currently on file with the GOMR, approximately 130 candidates for the drills under the Unannounced Oil Spill Drill Program are OCS oil and gas operators and 25 candidates are pipeline ROW holders.
2. There have been 55 unannounced drills since 1989.
   a. Three of those were joint drills with the TGLO

b. One was a joint drill with the LOSCO
c. Thirty-nine have been table-top drills.
d. Sixteen drills involved mobilization of equipment.

3. There has been only one Fail rating given. (The operator who received this rating has since been re-drilled, and the GOMR has determined that he is now capable of carrying out an adequate oil spill response. The operator received a Pass rating in all three categories.)

Prior to the establishment of the GOMR Oil Spill Program Administrator position in November 1997, the GOMR averaged approximately six unannounced oil spill drills per year in keeping with the May 1989 LTL announcing the Unannounced Oil Spill Drill Program. However, in 1998 the GOMR has conducted 15 drills and has plans to average about 20 drills per year in the future.

Please contact Mr. Rusty Wright, the MMS GOMR Oil Spill Program Administrator, for any further information regarding the GOMR Unannounced Oil Spill Drill Program. He can be reached at Minerals Management Service, Gulf of Mexico OCS Region, Plans Section, MS 5231, 1201 Elmwood Park Blvd., New Orleans, Louisiana 70123-2394, office telephone: (504) 736-2529, fax: (504) 736-2960, E-mail address: *Harold.Wright@mms.gov*.

Angie D. Gobert is a Staff Petroleum Engineer in the MMS's Gulf of Mexico OCS Region, Office of Field Operations - Plans Section. She has worked in the Plans Section for 14½ years. She is primarily responsible for the approval of Plans of Exploration, Development Operations Coordination Documents, granting Rights of Use and Easements; and coordinating waiver requests. For the past nine years, she has been responsible for and involved with matters related to oil spill response. She has experience in reviewing and approving oil spill contingency plans and has assisted in the inspection of oil spill cleanup and containment equipment. She has served on the MMS Monitoring Team for approximately 30 of the 55 unannounced oil spill drills in the Gulf of Mexico and has acted as the MMS Monitoring Team Leader for approximately 12 of them.

THE MINERALS MANAGEMENT SERVICE CUTTING EDGE OIL SPILL RESPONSE RESEARCH

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ABSTRACT

The Minerals Management Service (MMS), is the principal U.S. Government agency funding offshore oil spill response research. The MMS, a bureau of the Department of the Interior, maintains a comprehensive Oil Spill Response Research program in support of oil spill prevention and response. Through funding provided by MMS, scientists and engineers from the public and private sectors worldwide are working to address outstanding gaps in information and technology concerning the cleanup of oil spills. Joint research projects with Environment Canada (EC) continue to focus on determining the physical and chemical properties of crude oil, the fate and behavior of spilled oil, remote sensing and mapping of oil slicks, chemical treating agents including dispersants, and innovative shoreline cleanup strategies. In joint projects with the National Institute of Standards and Technology (NIST), MMS continues to assess the capabilities of in situ burning as an oil spill response tool. Also discussed is Ohmsett —The National Oil Spill Response Test Facility. Ohmsett is the only facility in the world where government agencies, universities, and private companies can conduct full-scale oil spill response equipment testing, research, and training with oil under controlled conditions.

DISCUSSION

As the stewards of more than 1.4 billion offshore acres, the MMS is responsible for the environmentally sound management of the nation's undersea mineral resources. These include energy and other mineral resources on the Outer Continental Shelf (OCS). Through leases granted by the federal government to private industry for exploration, development and production, the OCS accounts for one-ninth of America's oil production and one-fourth of its natural gas production (Labelle 1997).

For more than 20 years, MMS has maintained a comprehensive international research program to improve oil spill response technologies and procedures. The MMS manages the Oil Spill Response Research Program (OSRRP) as part of its Technology Assessment and Research Program (TARP). Funds for the OSRRP are appropriated from the Oil Spill Liability Trust Fund (OSLTF). By making payments into the fund, as required by OPA-90, companies that produce and transport oil are supporting research to improve oil spill response capabilities. This paper has been prepared in an ongoing effort to keep responders and decision makers informed on our recent findings.

PROPERTIES AND BEHAVIOR OF SPILLED OIL

The MMS has jointly funded the *Catalogue of Crude Oil and Oil Product Properties* with EC since 1989. The catalogue contains physical and chemical information on more than 380 different types of crude oils and oil product properties. The current version online through EC's Internet web site (*http://www.etcentre.org/spills/*). The catalogue contains many new data points including adhesion measurements, evaporation equations, new form of distillation data, BTEX and C3 analysis, etc. It is now possible to generate more than 800 data points for each oil.

The BOSS—Behavior of Oil Spilled at Sea—project is designed to provide a comprehensive collection and review of data and ideas related to oil spill behavior. More than 6,500 scientific papers have been collected and reviewed. Topics include behavior of oil spilled at sea but will also include the lesser-documented topics of oil on land, on freshwater and oil in ground. A draft oil-in-ice volume is complete and under peer review.

REMOTE SENSING AND SURVEILLANCE

Laser Fluorosensors are active sensors, meaning they provide their own source of illumination and can therefore be used during the day or at night. Laser Fluorosensors detect a primary characteristic of oil, namely their characteristic fluorescence spectral signature and intensity. The Laser Environmental Airborne Fluorosensor (LEAF) was tested in two well-documented field trials and several test flights along inland waterways including Chesapeake Bay. In the summer of 1996, the LEAF participated in the recovery of the "Irving Whale" oil barge off the east coast of Canada (Brown 1997). Knowledge and experience gained from operation of the LEAF system have been applied to the design of the next generation laser fluorosensor. The new system, designated the Scanning Laser Environmental Airborne Fluorosensor (SLEAF), will be a fully operational system incorporating state-of-the-art laser and solid-state detector technologies. The SLEAF will provide spill response personnel with real-time oil contamination location information as hard copy maps. In 1998-99, work will consist of

- Mounting of the SLEAF in an aircraft
- Ground and flight tests of the prototype
- Demonstration and ground-truthing of the fluorosensor concept over known targets

OIL SPILL CHEMICAL TREATING AGENTS

Dispersants

The "swirling flask" test method for dispersant effectiveness was developed in this project. This test method has been modified to move away from visible measurement techniques to a GC technique (Fingas 1997). In the case of light and waxy oils, this technique improves accuracy by several orders of magnitude. The "swirling flask" method has been adopted by the US Environmental Protection Agency for use in testing products for inclusion in the revised National Contingency Plan. Testing of new commercial and experimental dispersants will continue to be conducted.

Surface Washing Agents and Solidifiers

Tests for the effectiveness of Surface Washing Agents and Solidifiers have been completed. Surface washing agents are those surfactant-containing agents used to clean beaches or man-made shore structures. A test for these agents has been developed and used to test more than 100 commercial products. Additional standardization of the test method will be conducted. New agents will be tested by EC as they arrive. A test for the effectiveness of solidifiers has been developed and used to test more than 28 commercial products.

Emulsion Breaking and Inhibition Agents

Work on developing a test for effectiveness will continue, but five tests are currently in hand. It was found that the test was very complex to develop (work has gone on for the past six years) because of the complexities of emulsions. Work is continuing on a test for emulsion stability. The new methods test separately for effectiveness in both closed and open systems and for inhibition or breaking.

Biodegradation Agents

Tests for these agents are being developed. In addition, several commercial products have been developed with an interim test, and their results are consistent. A test for freshwater has been published. This year's work will focus on salt water systems and starting development of a new soil test.

SHORELINE CLEANUP

Svalbard Shoreline Project

The Svalbard Shoreline Field Trials are part of a series of studies in a long-term program to better understand the behavior of oil on shorelines and apply appropriate response options. The Svalbard Shoreline Field Trials, in combination with its partner, the Oil and Fines Interaction (OFI) Basin Trials, are investigating both the effectiveness of mainstream in situ shoreline cleanup techniques and the natural processes for oil removal from shorelines, in particular by oil and fine particle interaction. The 1997 Svalbard Shoreline Field Trials were highly successfully. Oiling of the shoreline, treatment of oiled plots, and four sampling periods went as planned. Three shorelines were oiled and experimental plots were established within the continuous stretch of oiled shoreline at each site. A total of 5500 L of oil were used and applied to a 3m wide swath in the upper intertidal zone. Treatments were conducted a week after oiling and after wave and tidal washing and working of the oiled zone. Treatments included in-situ tilling (mixing), sediment relocation to the lower intertidal zone (surf washing) and application of fertilizers to enhance biodegradation. Early results look excellent for the surf washing treatment. Oil removal effectiveness was visually obvious. Initial results suggest that the addition of fertilizers (soluble and slow release) was successful in delivering nutrients to the intertidal waters on the oiled beaches, and that these nutrients stimulated microbial activity in the beaches. A 1998 summer sampling program is underway to determine changes in the oil content of the sediments due to natural or enhanced methods.

IN SITU BURN RESEARCH

In situ burning is a response technique that has been rarely used at sea but has been used for many years to cleanup oil spills on land. Results from the mesoscale burns in Mobile, Alabama (1991-94), the Newfoundland Offshore Burn Experiment, and the Alaska Clean Seas, Emulsion Burn Experiments, continue to indicate that burning is a rapid, effective and environmentally safe means for removing large quantities of oil from the surface of the water. In public and government forums, burning has become accepted as a first response method. However, questions remain about the effects of in situ burning on both water and air quality.

Fire Resistant Boon Technology

Most plans for burns at sea call for a fire resistant boom to contain and thicken the oil during burning. For the past two years MMS and the U.S. Coast Guard (USCG) have participated in a joint project to evaluate the performance of commercially available and prototype firebooms. Phase I evaluated the oil containment and towing ability at Ohmsett—The National Oil Spill Response Test Facility in Leonardo, New Jersey. Phase II evaluated the firebooms for thermal stress and mechanical performance when exposed to a liquid fuel fire in waves. These burn tests were conducted in a specially designed tank at the USCG Fire and Safety Test Detachment, Mobile, Alabama.

Smoke Plume Dispersion Modeling

The MMS funded the NIST to develop the ALOFT (A Large Outdoor Fire plume Trajectory model) model to compute and display smoke plume trajectories from in situ burning. The ALOFT smoke transport model can predict time-averaged downwind concentrations of particulate matter from a large fire. Two model versions now exist: the ALOFT-FT for flat terrain and ALOFT-CT for complex terrain. Both the flat terrain and three-dimensional complex terrain versions are operational on personal computers and both versions can accommodate multiple fire sources. Based on input from users, several significant new features have been added, including a fuel property's database that can be modified by the user, an optional user specified emission factors and the ability to specify different wind fluctuations over water and land. This version has been distributed to the response community and is available from the Internet.

LABORATORY TESTING TO DETERMINE OPERATIONAL PARAMETERS FOR IN SITU BURNING OF UNITED STATES OUTER CONTINENTAL SHELF CRUDE OIL SPILLS

Six U.S. Outer Continental Shelf (OCS) crude oils were selected by the MMS regional offices and subjected to a laboratory test program. Three oils were produced in the Gulf of Mexico (Amoco High Island, Green Canyon, and West Delta), and three were produced offshore California (Carpenteria, Santa Clara, and Santa Ynez). The objective was to determine the following:

- The effects of evaporation and emulsification on the ignition of spilled oil;
- The ability of commercially available emulsion breakers and alternative gelled fuel igniters to extend the window of opportunity for ignition of emulsions;
- The effects of wave action on the combustion of emulsion slicks and,
- The likelihood of the residues sinking after efficient burns of thick slicks of crude oils.

A final report has been completed. This study has shown that in situ burning is not a suitable response option for all crude oils. The stability of a water-in-oil emulsion and its response to emulsion breakers is highly dependent on the properties of the oil. Only three of the more widely available emulsion breakers were tested on the oils in this study. It is vital that other crude oils be tested to establish a catalog of in situ burning properties.

OHMSETT—THE NATIONAL OIL SPILL RESPONSE TEST FACILITY

Ohmsett is The National Oil Spill Response Test Facility, in Leonardo, New Jersey, on the grounds of Naval Weapons Station Earle. Ohmsett is the only facility in the world where clients can conduct full-scale oil spill response equipment tests with a variety of crude oils and refined petroleum products. Equipment tests are conducted under controlled, reproducible conditions and include the capability for variable, artificial wavemaking. Ohmsett provides a unique facility to conduct tests and develop new devices and techniques that detect, map, contain and clean up oil spills. Ohmsett is available on a reimbursable basis for use by Government agencies, private industry and academia. The primary feature of the facility is a pile-supported, concrete tank with a water surface 203 meters (667 feet) long by 20 meters (65 feet) wide and with a water depth of 2.4 meters (8 feet). The tank is filled with 9.84 million liters of crystal clear water. The tank can tow floating test equipment at graduated speeds up to 3.3 meters/second (6.5 knots) for at least 40 seconds. The towing bridge is equipped to lay oil on the surface of the water several meters ahead of the equipment being tested, so that reproducible thicknesses and widths of test oils are achievable with minimum wind interference.

In FY-96, eight tests totaling 114 days were completed. In FY-97, 15 tests totaling 91 days were completed. Final reports are available on all test series conducted to date. During FY-1997, Ohmsett underwent a major repair and refurbishments program that upgraded the condition of the facility and increased testing capabilities. Historically Ohmsett was used to test and evaluate mechanical oil spill response equipment (booms and skimmers). Based on clients requests, MMS has expanded the operations at Ohmsett to accommodate a broad spectrum of oil spill response technologies such as temporary storage devices, remote sensors, and sorbents. The U.S. Navy and USCG routinely use Ohmsett to train their response personnel using their own equipment, with oil, in calm and wave conditions. In FY-98 an extensive testing schedule has been completed that included evaluation of several boom and skimmer systems, tow force tests, decanting studies of temporary storage devices, evaluation of different sorbent materials, high speed boom tests, and oil containment and tow tests of five different firebooms.

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Joseph W. Mullin is Program Manager for Oil Spill Response Research with the U.S Department of the Interior, Minerals Management Service, Engineering and Research Branch. He is responsible for analyzing Outer Continental Shelf oil spill response operations, advising on appropriate spill response techniques and equipment, and for procuring and managing oil spill response contractual research. Mr. Mullin represents MMS on several national and international committees that deal with oil spill research. Mr. Mullin received both an A.S. and a B.S. in Oceanographic Technology from Florida Institute of Technology.

AVAILABILITY AND CAPABILITIES OF "OHMSETT": THE NATIONAL OIL SPILL RESPONSE TEST FACILITY

Mr. Michael E. Whitehead
Mr. William T. Schmidt
MAR, Incorporated
Diamondhead, Mississippi

OHMSETT REFURBISHMENT ENHANCES FACILITY'S CAPABILITIES

Newly refurbished and filled with 2.6 million gallons of sparkling, clear water, the tank at Ohmsett, the National Oil Spill Response Test Facility, is ready for the testing season. Ohmsett is the only place in the world where full-scale oil spill response equipment testing, research, and training with oil can be conducted in a marine environment under controlled conditions.

The Ohmsett facility is located on Sandy Hook Bay in Leonardo, New Jersey. Ohmsett has been operated and maintained by MAR Incorporated under contract to the U.S. Minerals Management Service (MMS), Department of the Interior since 1992.

Ohmsett is available to both the public and private sector for evaluation of oil response equipment such as booms, skimmers, temporary storage devices, dispersants and for research in remote sensing, oil characteristics, and controlled oil burns.

"The unique testing facilities at Ohmsett are essential if we hope to develop the technology and procedures required to effectively respond to future oil spills," says Joseph Mullin, MMS Program Manager for Oil Spill Response Research. "In the event of an oil spill, do we really want to rely on equipment and techniques that have not been properly tested?"

Ohmsett's concrete tank measures 667 feet long and 65 feet wide, with a water depth of eight feet. Conditions simulating actual spill situations can be created with the wave generating system and a wave dampening artificial beach. Moveable bridges can tow equipment at speeds up to 6.5 knots. Customers and technicians can view a test from the bridges or from the control tower above the tank, while state-of-the-art data collection and video systems record test results.

Use of the Ohmsett facility is available on a reimbursable basis to both the private and public sectors as a research center to test oil spill containment/clean-up equipment or techniques, remote sensing devices or to conduct training in oil spill response. Current testing at Ohmsett is being funded by MMS, U.S. Coast Guard, U.S. Environmental Protection Agency, Environment Canada, and the Marine Spill Response Corporation.

Funding and imagination are the only limits to the oil spill response research opportunities at Ohmsett. MMS stands ready to assist all public and private sector organizations in meeting their goals of developing superior oil spill response capability. For more information contact:

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FACILITY FEATURES AND CAPABILITIES

Ohmsett's main feature is an aboveground concrete tank measuring 203 meters long by 20 meters wide by 3.4 meters deep. The tank is filled with 9.84 million liters of brackish water from nearby Sandy Hook Bay.

The main facility features and capabilities are as follows:

- A main towing bridge capable of towing test equipment at speeds up to 6.5 knots;
- An auxiliary bridge oil recovery system to quantify skimmer recovery rates;
- A wave generator capable of simulating regular waves up to one meter in height, as well as a simulated harbor chop;
- A movable, wave-damping artificial beach;
- An oil distribution and recovery system that can handle heavy, viscous oils and emulsions;
- A control tower with a fully computerized 32-channel data collection system as well as above-and below-water video;
- A centrifuge system to recover and recycle test oil;
- Blending tanks with a water and oil distribution system to produce custom oil/water emulsions for testing;
- A filtration and oil/water separator system;
- An electrolytic chlorinator to control biological activity;
- Permanent and mobile storage tanks that can hold over 227,000 liters of test fluids;
- A vacuum bridge to clean the bottom of the tank; and staging and shop area for special fabrication.

Through a variety of mechanical, electrical, and chemical systems at Ohmsett, the following test parameters can be controlled or measured:

- Sea state (wave height, length, and period);
- Tow speed;
- Meteorological data;
- Water temperature and salinity;
- Volume of oil encountered and recovered by test equipment or protocol;
- Oil-water ratios;
- Physical characteristics of experimental oil; and Behavior of treated oils.

SPILL SCHOOL NOW IN SESSION

A recently forged relationship with the National Spill School at Texas A&M University helps make Ohmsett a premier training site for oil spill response personnel. The National Spill School is recognized as the leading specialist in hazardous material spill training. In 1997, instructors with the National Spill School teamed up with Ohmsett to conduct training sessions at the facility.

Ohmsett has scheduled two training sessions with Texas A&M for the summer of 1998, and can book more for public and private sector personnel. Another notable development—part of Ohmsett's recent refurbishment effort—is the addition of a 30-seat classroom with an array of audiovisual equipment. Students can receive classroom training and review and critique their videotaped performance on equipment in the tank.

Companies and agencies can also configure a training session to their own specific needs, using their own equipment. Strictly hands-on training sessions are also available without the classroom portions taught by Texas A&M.

The Coast Guard was first to take advantage of the opportunity to train with Texas A&M in July of 1997. Crew from buoy tenders WILLOW, JUNIPER, and KUKUI, and members of the Atlantic Strike Team trained to operate the USCG Vessel of Opportunity Skimming System (VOSS).

The training included an eight-hour OSHA refresher course. Upon completion of the five-day course, students received a certificate from the Texas A&M University National Spill Control School.

A valuable feature at Ohmsett is a half-hull that can be placed in the tank. The VOSS was placed alongside the hull as it would be in actual use, and the crew practiced recovering oil under conditions close to the real thing.

The Coast Guard returned in September 1997, when members of the Coast Guard Spill Response Strike Team came for practice training. The aim this time was to increase proficiency in use of a fence boom and weir skimmer. The recovered oil was collected and measured at each test and, by the end of the week, students had a clear picture of how their performance had improved.

"They know how to use their equipment already," says Phil Coyne, Ohmsett Test Engineer. "But they wanted to become more proficient at recovering oil. They wanted to practice. You can't rehearse with oil in the ocean. You can use popcorn and other biodegradable substitutes, but oil is a fluid and popcorn is a solid body and it behaves differently from oil. We plan to make spill training at Ohmsett part of our schedule."

Also in September 1997, the Navy put a belt skimmer in Ohmsett's tank to train the Navy crew charged with responding to oil spills in Sandy Hook Bay, New Jersey. After a half day of classroom training, the crew practiced rigging their equipment in the tank and the next day began practice runs recovering oil.

LT Chris Chadwick, NWS Earle Port Officer says, "Ohmsett is the only place I know of where you can train with oil. You can train all you want using substitutes, but there is no substitute for real spill experience."

LT Chadwick plans to send another group of Navy spill personnel to Ohmsett for two weeks—and maybe more—in 1998. "The Navy has such a high turnover in personnel, you need to train constantly," he says. "We plan to make spill training at Ohmsett part of our schedule."

For information on booking a training session date at Ohmsett, call Bill Schmidt at (732) 866-7183, e-mail: *ohmsettpm@monmouth.com*, or Michael Whitehead at (228) 255-1461, e-mail: *wxwizz@aol.com*.

TESTING VARIABLES AND MEASURED RESULTS

Ohmsett's size allows various oil spill recovery components (booms, skimmers, and temporary storage devices) to be combined into systems that can be realistically evaluated and compared with each other.

Testing Variables

- Oil Viscosity
- Wave Conditions
- Boom Testing Variables
- Skimmer Testing Variables
- TSD Testing Variables
- Mechanical Geometry

Measured Results

- First Loss Speed
- Gross Loss Speed
- Critical Speed
- Oil Recovery Rate
- Tow Tension
- Deployment/Retrieval Procedures

Ohmsett's size can also accommodate large full-scale skimmer systems that can be evaluated in a real-life environment.

Testing Variables

- Oil Viscosity
- Velocity through the Water
- Oil Encounter Rate & Volume
- Skimmer Speed
- Wave Conditions
- Mechanical Geometry
- Debris

Measured Results

- Oil/Water Volume Recovered
- Oil Volume Recovered
- Water in Oil
- Oil Recovery Rate
- Recovered Oil Characteristics
- First Loss Speed
- Gross Loss Speed

Ohmsett's 203 m long x 20 m wide x 3.4 m deep tow basin allows full-scale evaluation of oil containment booms using a wide range of oil viscosities. MMS has developed standard testing protocols for comparative performance evaluations.

Testing Variables

- Oil Viscosity
- Oil Volume Precharge
- Wave Conditions
- Tow Carriage Speed

Measured Results

- Towspeed for First Loss
- Towspeed for Gross Loss
- Critical Speed and Failure
- Wave Conditions
- Tow Tensions
- Above and Underwater Video
- Water Temperature and Salinity
- Meteorological Data

Ohmsett is an ideal facility to test and evaluate the practical effectiveness of Temporary Storage Devices (TSDs).

Testing Variables

- Oil Viscosity
- Oil Water Mixture
- Ratios
- Percent Capacity Load
- Pump Configurations and Methods
- Wave Conditions

Measured Results

- Offloaded Volume
- Pumping Rates
- Effectiveness of Cleaning Methods

Ohmsett can realistically evaluate the relative response characteristics of oil spill detection devices to a wide variety of controlled oil spills with known characteristics.

Testing Variables

- Oil Viscosity
- Emulsions
- Surface Area and Thickness
- Wave Conditions
- Detection Device Height over Water
- Detector Velocity

Measured Results

- Detector Response Profile
- Meteorological Conditions

Michael Whitehead is the Mississippi Group Manager and Principal Scientist for MAR, Incorporated's Meteorology and Oceanography (METOC) Center in Diamondhead and the Major Shared Resource Center located at Stennis Space Center, which supports the CRAY supercomputer operations. He is MAR's Senior Operational Meteorologist, directing environmental and mapping support of U.S. Navy missions, by providing detailed research studies and forecast products and services in support of World-Wide Fleet Operations. He has spearheaded the effort to convert traditional training materials into multimedia presentations and has expanded MAR's capabilities in the Geographic Information Services and the commercial weather arena. Before joining MAR, Commander Whitehead completed a 23-year Navy career in Operational METOC Support, concluding with an assignment as the Director of Training for approximately 4,000 government personnel. Commander Whitehead's academic background includes an M.S. in operations management from the University of Arkansas in Fayetteville and a B.S. in geography and meteorology from the University of the State of New York in Albany. Michael is also an experienced Total Quality Leadership Facilitator and is an American Red Cross-certified Community Disaster Education Instructor. In 1998 MAR and the Mineral Management Service called on Michael to represent Ohmsett as the facility's Marketing Coordinator.

William Schmidt is Program Manager at Ohmsett, The National Oil Spill Response Test Facility. MAR, Inc., the contractor to the U.S. Department of the Interior, is responsible for running the facility. Mr. Schmidt is responsible for the overall management and administrative responsibility for ensuring Ohmsett is operated and maintained as an environmentally and physically safe and secure facility. In addition, he is responsible for supporting and actively participating in marketing efforts to attract and retain clients by developing a marketing plan and attending technical committee meetings and conferences. He also presides over the Health and Safety meetings. Mr. Schmidt received a B.S. in engineering from the New Jersey Institute of Technology (1979).

SESSION 1B

FISHERIES ASSOCIATIONS WITH PLATFORMS

Chair: Mr. Gregory Boland
Co-Chair: Dr. Ann Scarborough Bull

Date: December 8, 1998

Presentation	Author/Affiliation
Cross-shelf Gradient of Larval Fish: Importance to Platform Productivity	Mr. James Ditty Dr. Richard F. Shaw Ms. Talat Farooqi Coastal Fisheries Institute Louisiana State University
Importance of Zooplankton to Platform Productivity	Mr. S.F. Keenan Department of Biological Sciences Louisiana State University Dr. M.C. Benfield Dr. R.F. Shaw Coastal Fisheries Institute Louisiana State University Ms. H.L. Haas Department of Oceanography and Coastal Sciences Louisiana State University
Effect of Depth on the Density of Fishes at Three Petroleum Platforms	Dr. David R. Stanley Dr. Charles A. Wilson Coastal Fisheries Institute Center for Coastal, Energy and Environmental Resources Louisiana State University
Fisheries Impacts of Underwater Explosives Used in Platform Salvage in the Gulf of Mexico 1993-1998	Mr. Gregg Gitschlag Galveston Laboratory National Marine Fisheries Service

Presentation	Author/Affiliation
Preliminary Surveys of Sessile Invertebrate Community on a Partially Removed Platform Reef off South Padre Island, Texas	Mr. Terry E. Riggs Dr. Quenton R. Dokken Mr. Carl R. Beaver Center for Coastal Studies Texas A&M University-Corpus Christi
Preliminary Observations of Fish Assemblages Associated with a Partially Removed Platform off the Texas Coast	Ms. Lisa D. Vitale Dr. Quenton R. Dokken Center for Coastal Studies Texas A&M University-Corpus Christi

CROSS-SHELF GRADIENT OF LARVAL FISH: IMPORTANCE TO PLATFORM PRODUCTIVITY

Mr. James Ditty
Dr. Richard F. Shaw
Ms. Talat Farooqi
Coastal Fisheries Institute
Louisiana State University

INTRODUCTION

The proliferation of offshore oil and gas structures (defacto artificial reefs) in the northern Gulf of Mexico since the 1940's has undoubtedly affected the marine ecosystem. With relatively little natural hard bottom, the introduction and structural complexity of nearly 5,000 petroleum platforms in the northern Gulf of Mexico has substantially increased hard-bottom habitat, thereby attracting a variety of reef and pelagic fishes to their reef-like structure. Since wetlands are nursery areas for a large number of commercially and recreationally important fish, continual loss of estuarine and wetland areas make knowledge of the potential nursery function of other habitats, such as artificial hard-bottom, critical. As nursery areas, offshore oil and gas platforms may be similar to shallow, soft-bottom estuarine wetlands in several important ways: 1) increased food availability; 2) potentially lower predation pressure; and, 3) spatial or structural complexity of habitat (i.e. many ecological niches, "nooks and crannies", and refugia). Thus, oil and gas platforms may serve as "essential fish habitat" for the early life history stages of a variety of reef and reef-associated fishes. Further-more, since reef fish assemblages are among the most diverse and taxonomically rich in the aquatic biosphere (Sale 1991), platform-associated communities may significantly enhance the biodiversity of the northern Gulf and serve as a migratory route for exotic species. Our objectives were to 1) provide information on the nursery ground/refugia role of platforms for postlarval/juvenile fish; 2) respond to specific fisheries management requests for basic biological information on reef fish seasonality and cross shelf distribution; and 3) begin cross-shelf characterization of the early life stages of fish utilizing offshore petroleum platforms off central Louisiana.

METHODS

We conducted sampling over a three-year period (1995-1997) along a N-S cross-shelf transect of oil and gas platforms off Louisiana to document the use of platform structure as nursery habitat by early life stages of reef- and other structure-associated fishes. Sites differed in depth, cross-shelf location (with differing exposures to nutrient-rich waters of the Mississippi River plume), and faunal assemblage. During Year One (1995-1996), we sampled at Green Canyon 18A (GC18A), a Mobile oil and gas platform located in oligotrophic, shelf break waters 225-m deep, located about 220-km south of Morgan City. During Year Two (1996), we sampled at Grand Isle 94B (GI94B), a Mobile platform located in mesotrophic, mid-shelf waters 60-m deep. During Year Three (1997), we sampled at South Timbalier 54G (ST54G), an Exxon platform located off Grande Isle in turbid, highly productive waters about 20-m deep. We sampled monthly at GC18A around the new moon.

GI94B was sampled twice monthly (both new and full moons) for three consecutive nights within a five-day period between April and August, times coinciding with either peak spawning or recruitment of most reef fish in the area. During May, however, we also sampled during both the first and third quarter moon phases for two consecutive nights. The sampling design at ST54G was similar to that at GI94B except there was no extra May sampling during quarter moon phases. Each set contained, when possible, a vertical plankton net tow (30-cm net, 0.063-mm mesh), surface and at depth (about 20-m) light trap samples within rig structure, a surface off-rig light trap sample, and a horizontal plankton net tow (60-cm, 0.333-mm mesh, 15 min duration) fished passively at the surface and at depth (20-m). Logistic constraints, weather, and gear failure resulted in restricted sampling during some months. Light traps fished for 10 minutes. Off-rig light traps floated at least 15-20 m downstream before turning on the light. We collected hydrographic data (current speed and direction, temperature, salinity, and turbidity) at each site, when possible. GC18A has a primarily tropical reef fish assemblage, GI94B a brown shrimp faunal assemblage, and ST54G a white shrimp faunal assemblage (Gallaway 1981).

RESULTS

The early life stages of fish collected at the various cross shelf sites closely approximate the adult faunal assemblages of Gallaway (1981). Larval and juvenile stages of coastal pelagic (e. g., engraulids, clupeids, and planktivorous carangids) and demersal/estuarine species (e. g., sciaenids and flatfishes) dominate catches at inner shelf ST54G. Catch per unit effort (CPUE) of reef-associated taxa (e. g., blennies, gobies, and snappers), predatory ocean pelagics (e. g., jacks, blue runner, most tunas and mackerels) and demersal/pelagic fishes (e. g., lizardfish) are greater at GI94B than either ST54G or GC18A, with CPUE generally low in all ecological-categories at GC18A (Figure 1B.1). Relatively abundant reef-associated species at GI94B include: vermilion snapper (*Rhomboplites aurorubens*) and snappers of the genus *Lutjanus* spp., several members of the family Blennidae, and various sea basses and groupers.

CPUE differed among sites and gear. Overall, catches were higher in surface light traps fished within rig structure than in traps floated away from the rig, while light traps fished at 20-m had the lowest CPUE. Occasionally, standardized catches in surface plankton nets were up to 5-10 times higher than in light traps. These high plankton net catches may be due to differences in gear selectivity and/or the differential mortality experienced by the larger specimens selectively captured by light traps. Differences in length frequencies of taxa caught with each gear support this observation. Plankton nets generally collect larvae <6 mm standard length (SL) whereas light traps generally collect fish >5 mm SL.

Preliminary analyses suggest that CPUE at ST54G was greater on the full than new moon. At GI94B, however, both density estimates from surface plankton nets and CPUE from light traps suggest higher catches during the first quarter moon. However, differences between sites and between moon phases may be taxa-dependent. Data also suggest that CPUE are generally higher when currents are toward the west and north than towards the south and east. Furthermore, CPUE is generally higher before than after midnight.

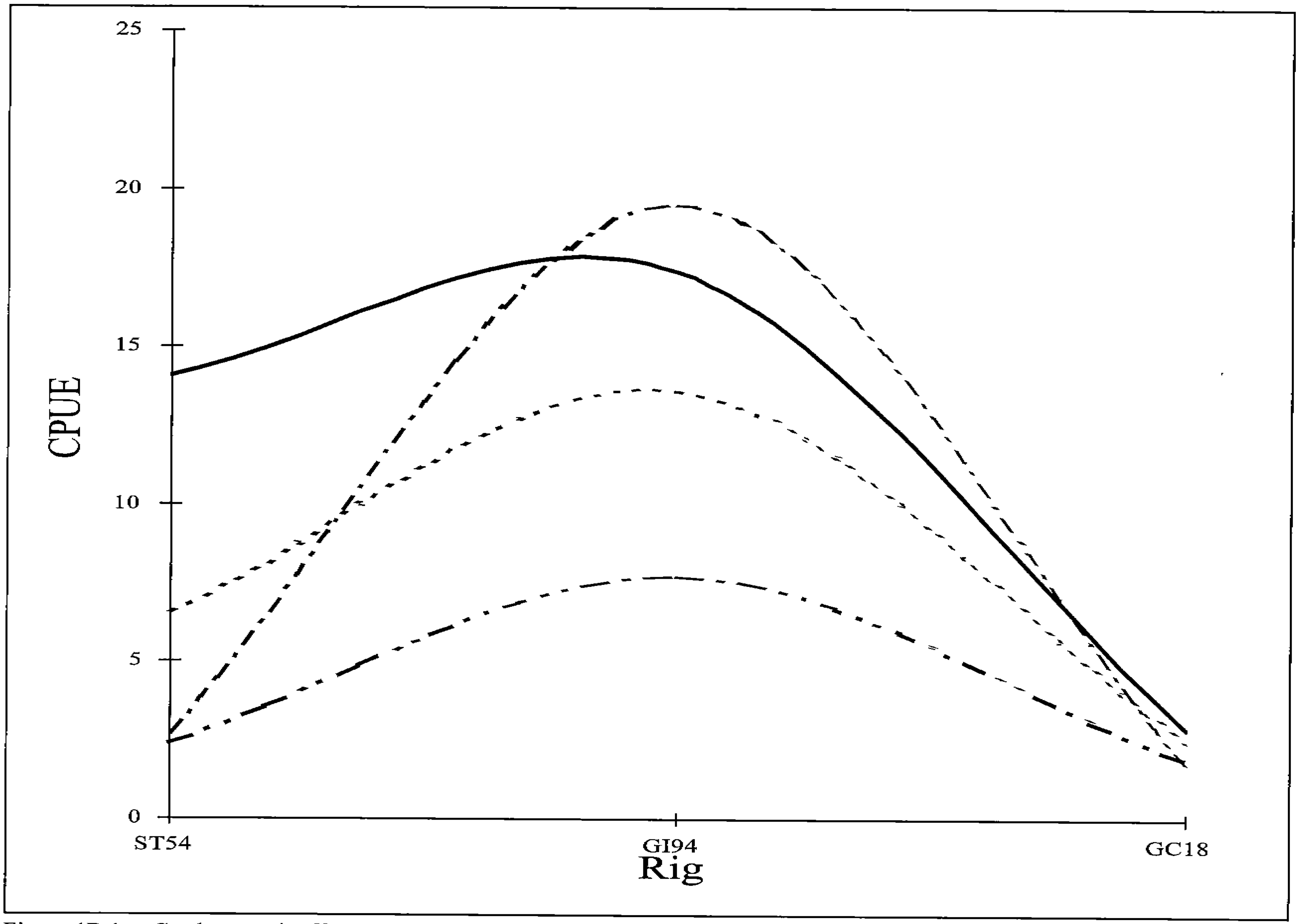

Figure 1B.1. Catch per unit effort (CPUE) by gear type and rig along a cross-shelf transect in the Gulf of Mexico off Louisiana. CP: coastal pelagic fishes; OP: ocean pelagic fishes; R: reef-associated taxa; and D/MP: demersal/pelagic fishes.

In summary, the early life stages of fish collected at the various cross shelf sites closely approximate the adult faunal assemblages of Gallaway (1981). We collected larvae/juveniles of most reef and reef-associated taxa known to frequent rigs and suggest that some reef fishes use oil and gas platforms as nursery areas. Because ocean pelagic and demersal/pelagic predators are abundant at all three rigs, predation pressure is probably high. Finally, light traps appear to effectively characterize most coastal pelagic, ocean pelagic, and some reef fishes that use petroleum platforms off Louisiana.

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Jim Ditty has conducted fisheries research in the Gulf of Mexico for 20 years, the past 12 at LSU's Coastal Fisheries Institute, and has authored over 20 articles on the taxonomy and ecology of larval and juvenile fishes. He now manages the Taxonomy and Ecology Lab for the Fish Ecology Section at NMFS's Galveston Lab, Texas. He received his B. S. in zoology from Marshall University, his M. S. in marine fisheries from LSU, and is currently a Ph.D. candidate in Biological Oceanography at LSU.

Richard Shaw is the Director of the Coastal Fisheries Institute and a Professor in the Department of Oceanography and Coastal Sciences at LSU. He has worked with ichthyoplankton since 1973 and received his Ph.D. in biological oceanography from the University of Maine at Orono in 1981.

Talat Farooqi is a Research Associate at the Coastal Fisheries Institute. She has worked with ichthyoplankton from the Gulf of Mexico since 1985. She received her M. S. in marine biology from the Institute of Marine Biology, Karachi, Pakistan.

IMPORTANCE OF ZOOPLANKTON TO PLATFORM PRODUCTIVITY

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ABSTRACT

The source of productivity that sustains the high numbers of fishes associated with petroleum platforms remains a poorly understood question. Recent studies on the feeding ecology of blue runner *Caranx crysos* suggest that zooplankton form a substantial portion of the diet during early-mid summer. The dominant zooplankton in the diets of these highly abundant fishes are predominantly pelagic marine taxa. We suggest that the combination of artificial illumination and modification of the hydrodynamic flow field by the platform structure favor the accumulation of large numbers of oceanic zooplankton. The artificial illumination also allows nocturnal feeding by visual predators such as blue runner. This subsidy of zooplankton may provide an important link in the food web at offshore platforms.

INTRODUCTION

Approximately 5,000 offshore petroleum platforms exist in the Gulf of Mexico (Reggio 1996). In the northwest Gulf of Mexico, these structures provide the vast majority of hard substrata available to sessile organisms. Fouling genera established on the platform substructure thrive in nutrient-rich waters of the northern Gulf and form reef-like communities. This unique existence of hard substrata found in open ocean environments has been termed *vertical benthos*.

Increased concentrations of pelagic and demersal fish species are found in proximity to platforms. How these populations are sustained remains an important question in developing strategies for decommissioning platforms. Successful rigs-to-reefs programs in Louisiana and throughout the Gulf of Mexico rely on converting these decommissioned structures into productive artificial reef communities. A critical component of a sound rigs-to-reef management strategy is an understanding of the trophic ecology of rig communities.

Our study coincided with research conducted by the LSU Coastal Fisheries Institute on recruitment periodicity, growth and mortality of pre- and post-settlement juvenile fishes at offshore petroleum platforms. Fortnightly sampling trips were made for this MMS-funded project which utilized surface and subsurface (20m) plankton net tows, and light traps deployed beneath and downstream from the platforms.

In May 1996, a single blue runner *Caranx crysos* (Carangidae) was collected by hook and line at (GI94B) a mid-shelf platform. The stomach of this fish was full of hyperiid amphipods, small crustaceans that were highly concentrated in the plankton samples from that evening. The phenomenon of a medium sized (25 cm. SL) schooling, pelagic fish consuming relatively small (2-5 mm.) zooplankton suggested a trophic linkage between the platform and the surrounding fish community. This led to a LSU Sea-Grant Undergraduate Research Opportunities Program investigation of the relationship between secondary zooplankton productivity and the *C. crysos* populations at GI94B.

Little is known about the behavioral changes that pelagic zooplankton undergo when they encounter a platform or other structure. We set forth two hypotheses to explain mechanisms for zooplankton association with these structures: (1) hydrodynamic entrainment; and (2) phototaxis. Large amounts of flotsam were observed beneath the platform, suggesting the formation of eddies due to interactions between the platform and the currents. These eddies could also lead to hydrodynamic entrainment of plankton. Additionally, many of the zooplankton collected, including hyperiid amphipods, decapod/stomatopod larvae, and copepods, are attracted to light fields. At night, the platforms illuminate the surrounding waters, which may attract positively phototaxic zooplankton. The objectives of our study were to: (1) determine if hyperiid amphipods and other zooplankton were important in the diet of *C. crysos*; (2) compare species composition of prey items in fish guts with concentrations in the environment; and (3) determine if platforms serve to increase concentrations of prey items beneath the structure relative to downstream waters.

METHODS

Mobil's Grand Isle 94B platform (28.5267°N, 90.0983°W) served as the location of our study. Blue runner feeding data was collected during three sampling trips on 28-30 June, 28 July -1 August, and 12-15 August 1996. Hook and line collections using artificial lures were made opportunistically. Mass, length, sex and time of capture were recorded for each fish. The stomach contents were preserved in ethanol for subsequent examination and identification of contents. Nocturnal light traps and 60 cm. diameter plankton nets (335 μm) alternated in deployment as part of the MMS-funded ichthyoplankton research. We attempted to assess the potential for entrainment and phototaxis in evening zooplankton concentrations by comparing the catch per unit effort (CPUE) of animals in light traps beneath and downstream from the platform. The attractive qualities of the lighted platforms are tested by viewing the amphipod concentrations in light traps over time.

In the laboratory, stomach contents and plankton samples were divided into the following taxonomic groups: hyperiid amphipods, decapod/stomatopod larvae, copepods, chaetognaths, fish, fish eggs, other invertebrates, and other material. Displacement volumes for prey items were measured to compute gut fullness for each animal. Plankton densities, computed from plankton net tows, along with stomach content results were used to form electivity indicies. To determine whether blue runner were actively selecting for specific prey items, we employed Ivlev's electivity index:

$$E = \frac{r_i - p_i}{r_i + p_i}$$

where r_i represents the numerical proportion of prey item i found in the gut and p_i the relative abundance of the same prey item in the environment (Ivlev 1961).

RESULTS

A total of 40 blue runner (including the fish captured on 19 May) were collected from near surface waters. The fish ranged in size from 24.5 - 42.5 cm. SL, indicating all were at or approaching sexual maturity. Peak catches occurred at 1,200h, 2,000-2,100h, and 0,100h. Gut fullness data suggest blue runner feed during the night and around mid-day (Figure 1B.2)

Zooplankton comprised a large numerical fraction (80-100%) of stomach contents of blue runner in May (initial fish), June and July with a shift in diet towards fish during August (Figure 1B.3). See Benfield, *et al.* (1996) for a further description of gut content data.

Electivity results were estimated for fish taken during the 28-30 June trip, because that was when the majority of fish (63%) were collected. Electivity indicies require both gut and environmental abundance data. Plankton sampling was only conducted at night. Thus, only nocturnal electivities could be estimated. Selection for amphipods and decapods was positive while copepods display negative selection.

Hyperiid amphipod concentrations are significantly greater ($p<0.006$) beneath the platform compared to downcurrent (Figure 1B.4). Similar trends, although not significant, were suggested for decapod/stomatopod larvae, and copepods. Increases in the CPUE of amphipods over a three-hour period beneath the platform with concurrent decreases in the CPUE from off-platform traps were observed (Figure 1B.5).

DISCUSSION

Zooplankton comprised a large proportion of the diet of blue runner at GI94B during summer; however, they appear to be a seasonal forage supply. That hyperiid amphipods do not continue as a dominant category in the diet may be due to a general decline in the abundance of these zooplankton in the water column. Amphipod abundance from plankton sampling appeared to be at a maximum during May samples and decreased during the rest of the study (Benfield). The seasonal shift in dietary preference may also have contributed to the change in prey. The early-midsummer utilization of zooplankton may also have been due to the paucity of suitable sized fish prey until the summer.

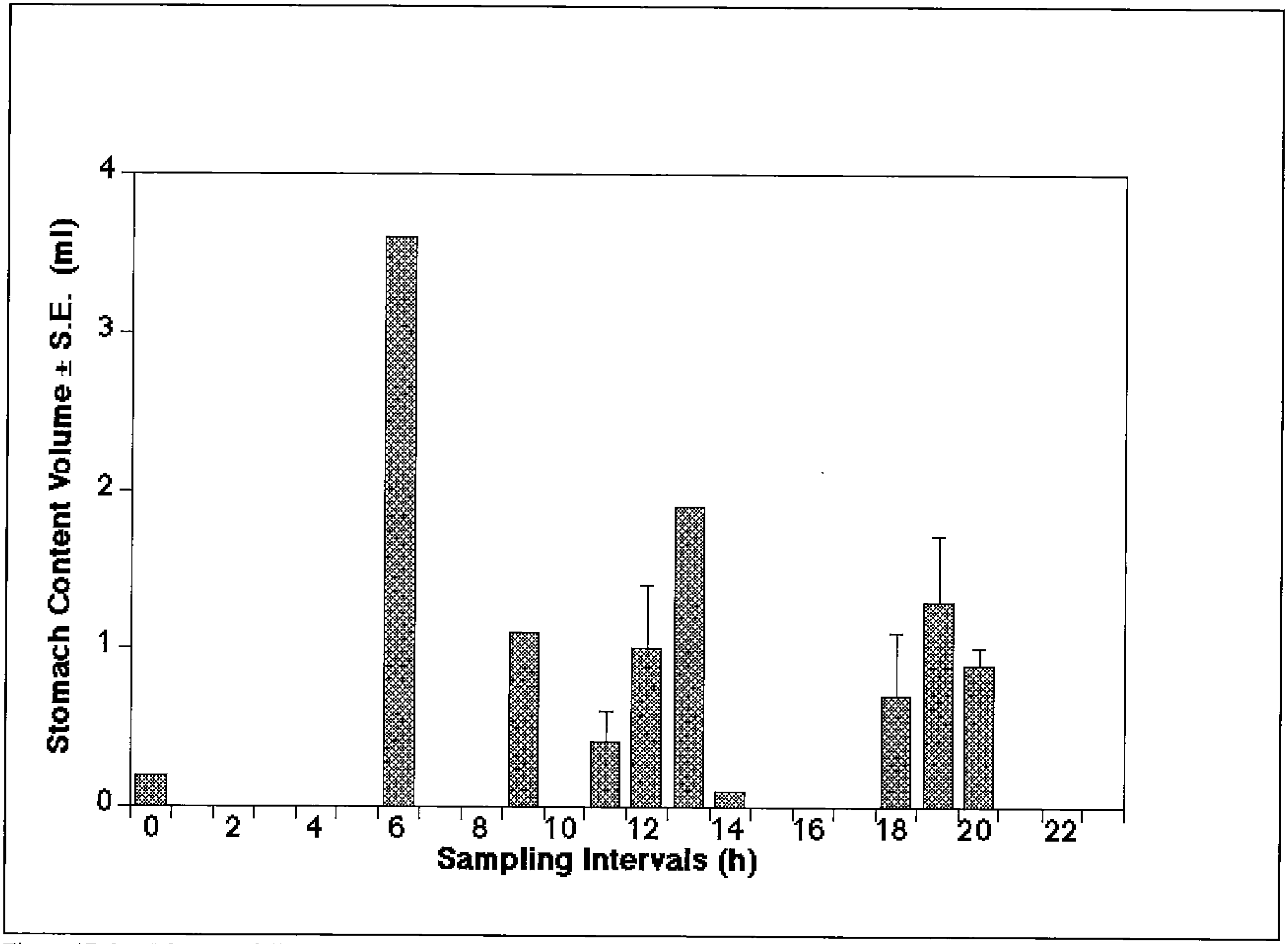

Figure 1B.2. Mean gut fullness ± standard error of blue runner collected at GI94B during June and July.

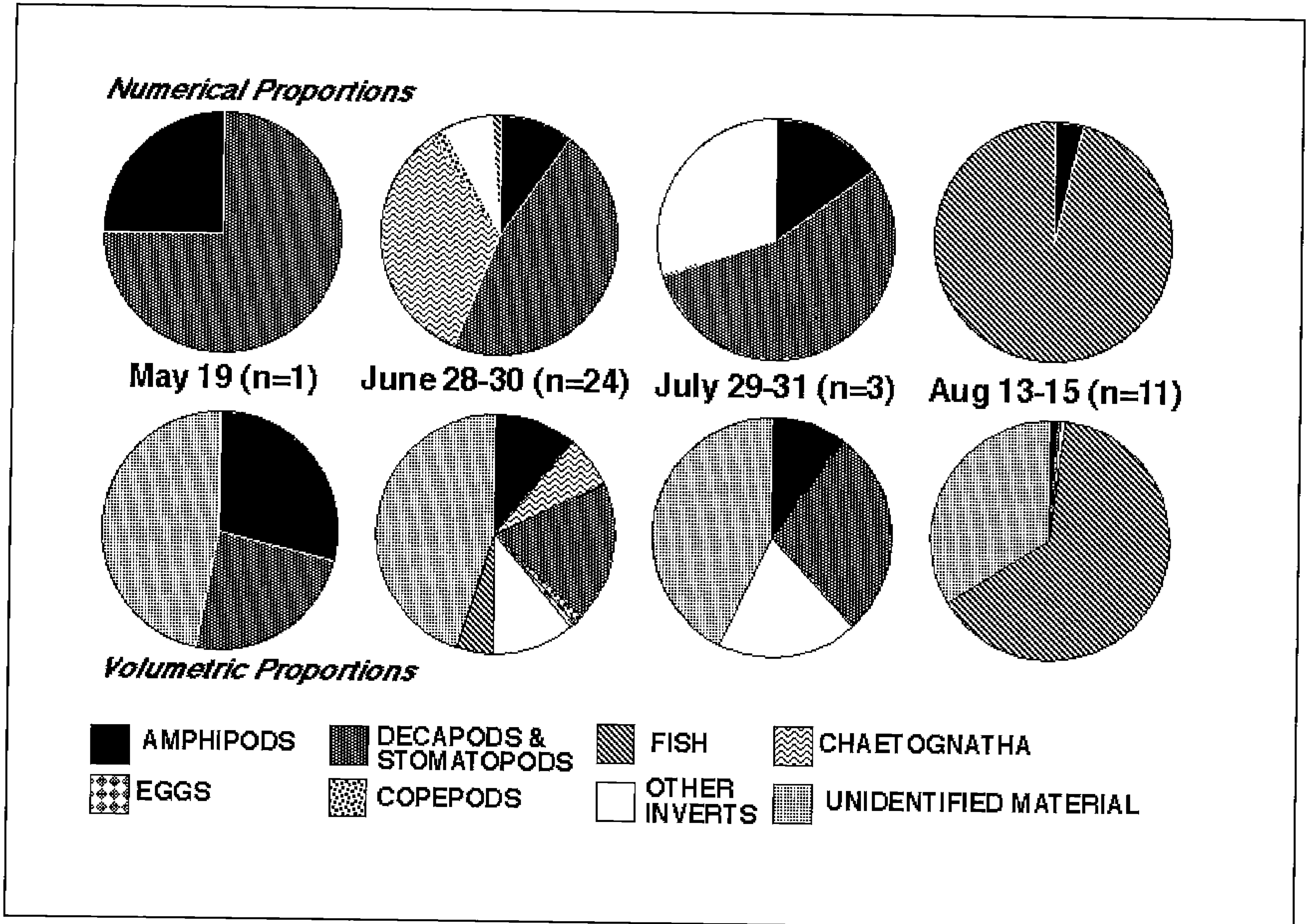

Figure 1B.3. Numerical (upper row) and volumetric contributions (lower row) of prey items in the diet of blue runner from four sampling trips to GI94B during 1996.

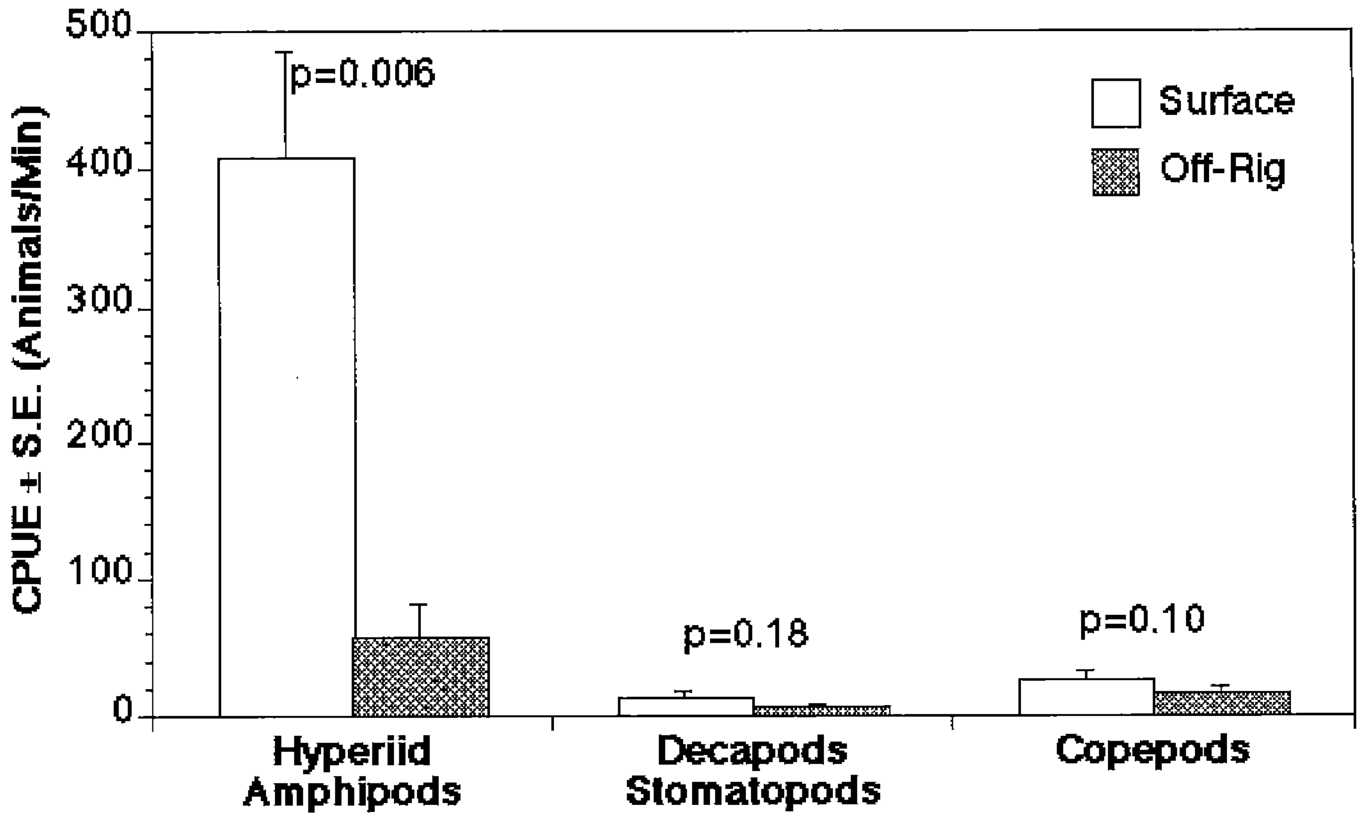

Figure 1B.4. Catch per unit effort (CPUE) ± standard error of hyperiid amphipods, decapod/stomatopod crustaceans and copepods in surface samples directly beneath GI94B and off-rig samples located downstream from the platform.

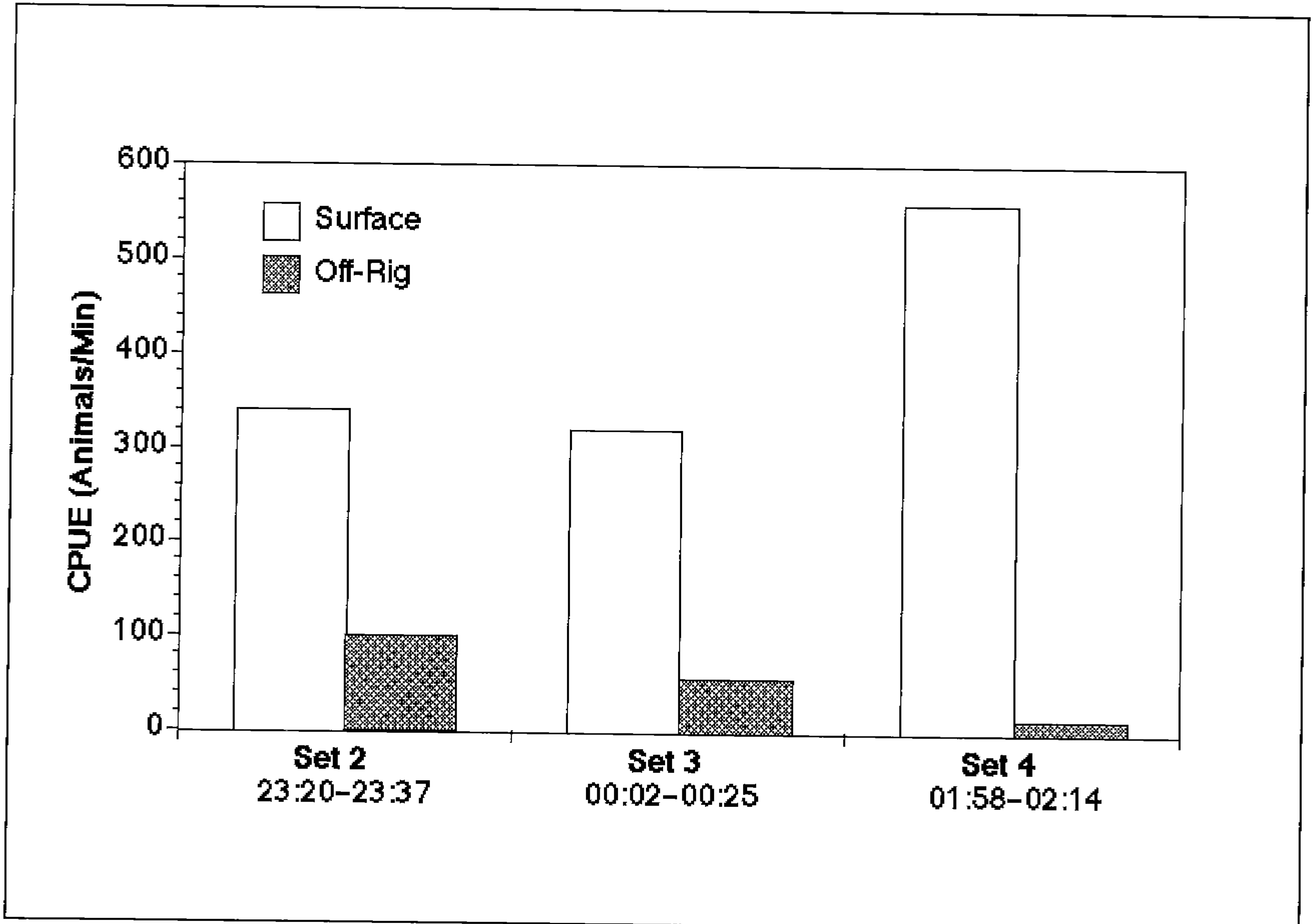

Figure 1B.5. Time series of hyperiid amphipod catch per unit effort (CPUE) beneath GI94B from 23:20 to 02:14 in surface and off-rig samples.

The unidentifiable material found in the stomachs of the fish may have been fish remains. Digestion rates increase in the warm waters of the Gulf, which could have made the material difficult to identify. The absence of scale or bone remnants suggests that the material was not of fish origin. Even if the material is from fish, on a volumetric basis, zooplankton comprised approximately half the gut contents. Zooplanktivory by blue runner has been reported by Randall (1967), who noted that the gut contents of two medium-sized fish (22 and 23 cm FL) consisted of 40 % "planktonic organisms."

A trophic linkage between the platform and pelagic species cannot be confirmed solely by the presence of zooplankton in the diet of blue runner. Most of the zooplankton in the diet were from holoplanktonic or meroplanktonic groups. Our primary taxonomic group of interest, hyperiid amphipods, however, is known for its association with structure, in the form of gelatinous zooplankton commonly used as hosts. The manner at which amphipods and other zooplankton may react to structure in the pelagic environment is unknown.

One explanation for these dense aggregations beneath the platform is the interaction of the structure with the prevailing currents. The complexity of the platform casing decreases current velocity and creates eddies, which accumulate flotsam. This hydrodynamic effect may contribute similar influences to plankton species. Our results indicate that hyperiid amphipods, and potentially other zooplankton, are found in greater numbers beneath the platform than are found in downstream sites.

Another testable hypothesis may explain increased concentrations of zooplankton around platforms. Manned platforms produce light that is bright enough to cast a clearly visible field into the surrounding water. The attraction of zooplankton and fish to light is well cited and is the principal reason behind our use of light traps. Zooplankton may actively swim to maintain position in the light field. As currents bring more plankton through the structure, concentrations should increase. Support for this theory comes from our time series analysis of light trap CPUE.

Regardless of the process by which planktonic taxa accumulate beneath the platform, the elevated concentrations of prey beneath GI94B at night provide blue runner with an enhanced prey density while the artificial light permits an extended foraging period.

While the attraction-production issue remains under investigation, our study identified a potential linkage between structure and enhanced secondary production. Through physical or attractive means the platforms appear to aggregate prey items that enhance productivity. Further investigations into this interaction should include quantitative sampling of zooplankton, during day and night, both beneath and upstream of the platforms. The influence of light on attraction could be tested by comparing plankton samples from both manned (lighted) and unmanned platforms. Finally, documenting the food habits of pelagic species will require year-round sampling with larger numbers of replicate specimens.

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EFFECT OF DEPTH ON THE DENSITY OF FISHES AT THREE PETROLEUM PLATFORMS

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INTRODUCTION

The largest artificial reef complex in the world, although unplanned, is composed of the 4000 petroleum platforms scattered across the outer continental shelf (OCS) of the northern Gulf of Mexico (GOM). Scientists have hypothesized that artificial reefs and platforms improve and/or diversify habitat, increase resources, modify the assemblages of organisms in the region or concentrate existing resources. The placement of these defacto reefs has undoubtedly impacted the regional marine community although little information is available. Only recently have assessment methods been developed to test these and other hypotheses concerning artificial reefs.

Since the first petroleum platform was placed off the Louisiana coast in 1948, they have been the preferred destination of commercial and recreational anglers. Past research has found that platforms were the destination of 70% of all recreational angling trips in the Exclusive Economic Zone (Reggio 1987). The high documented catch rates and the popularity with user groups in the region make platforms an important component in the regions fisheries. Despite the number of sites, the longevity of the structures and their importance to the regions fisheries little information exists on the assemblage of fishes associated with petroleum platforms. Research projects at petroleum platforms did not start until the late 1970's. They consisted of visual surveys conducted by SCUBA divers, remotely operated underwater vehicles (ROV) and stationary cameras; the majority of these projects were short term, often only "snapshots" of the fishes at each site (Sonnier *et al.* 1976; Gallaway *et al.* 1981; Continental Shelf Associates 1982; Gallaway and Lewbel 1982; Putt 1982). The results of this early research provided insights into the structures associated assemblages as abundance and species composition varied with platform, water depth and time of the year and results have been difficult to compare due to problems with limited visibility, gear bias, diver avoidance and a lack of standardized survey methodology.

In response to the difficulty in assessing the fisheries resources associated with petroleum platforms and the bias's inherent with visual surveys. Gerlotto *et al.* (1989) demonstrated that towed hydroacoustics could be used to measure fish density near petroleum platforms off Cameroon. We later utilized complimentary sampling methods of visual surveys and quantitative dual beam hydroacoustic surveys to document the assemblage of fishes associated with petroleum platforms in the northern Gulf of Mexico (Wilson and Stanley 1991; Stanley and Wilson 1995; 1996; 1997; *in press*). Despite the range of methodologies, investigators found that fish abundance and species composition change dramatically with proximity to platform, location, and time of year (Sonnier 1976; Continental Shelf Associates 1982; Gallaway and Lewbel 1982; Putt 1982; Stanley and Wilson 1996; 1997; *in press*).

The objectives of this research were to use dual beam hydroacoustics to measure the density of fishes associated with three petroleum platforms off the Louisiana coast. The goals of this research were to determine the effect of water depth on fish density at platforms in 22, 60 and 219 m of water and ultimately measure the fisheries value of platforms of different depths in the same geographical region.

METHODS

This research project was designed to sample platforms in three water depths (shallow-shelf (South Timbalier 54, ST54, water depth 22m), mid-shelf (Grand Isle 94. GI94, water depth 60m) and continental slope (Green Canyon 18, GC18, water depth 219m) across the Louisiana shelf. The platforms were selected to approximate a transect extending offshore from Fourchon LA, ST54 was 24 km southwest, GI94 was 54 km south and GC18 was 179 km southwest from the port.

Two arrays of stationary dual beam hydroacoustic equipment developed through our past research were used to determine the density of fishes associated with the study sites (Wilson and Stanley 1991; Stanley and Wilson 1995; 1996; 1997; *in press*). Arrays 1 and 2 were designed to measure *in situ* target strength distribution and density of fishes immediately adjacent to each side of the platform. Array 1 consisted of four upward oriented transducers (120 kHz) suspended approximately 25 m below the surface (at ST 54 they were placed on the bottom), one on each side of the platform. The upward facing transducers provided acoustic coverage from the surface to a depth of 10-15 m.

Array 2 consisted of four downward oriented transducers (120 kHz) placed approximately 3 m below the surface, one on each side of the platform. The downward facing transducers provided acoustic coverage from a depth of 10 m to 1 - 5 m from the substrate depending on the site. The use of four transducers (both upward and downward orientations) enables the calculation of density throughout the water column on all sides of the platform.

Acoustic sampling was conducted over consecutive 24 hour intervals for each sampling trip; two hours of hydroacoustic data were collected encompassing four periods (dawn, noon, dusk and midnight) over each 24 hour interval. Hydroacoustic data were collected sequentially from each of the transducers in five minute intervals for each trip. Acoustic data were collected using a Biosonics model ES2000 scientific echosounder/multiplexer-equalizer and see Stanley and Wilson (1995; 1996; 1997; *in press*) for details on acoustic parameters and a more detailed desrciption of methods.

Fish density data (number of fish·m^{-3}) from echo integration analysis contained a large number of zero values, similar to catch data from traditional fisheries sampling techniques (Pennington 1983; 1985; Shaw *et al.* 1985; Stanley and Wilson 1995; 1996; 1997; *in press*). Therefore, hydroacoustic density data were transformed by log(density + 1) to approximate the normal distribution. Separate randomized block ANOVAs using SAS (1986) GLM procedures were performed with vertical log(density + 1) density data for each site on depth, side and the interaction of side*depth. Tukey's studentized range tests (Ott 1982) were used to compare the means of significant variables for vertical and horizontal analyses. Tests were reported as significant at the alpha ≤ 0.01 level.

RESULTS

Fish density varied with platform side, depth and the interactions of depth*side at ST54 (Table 1B.1). Significantly higher densities were found on the north side of the platform than all others (Figure 1B.6). With respect to depth, densities were significantly higher in the upper 10 m of the water column than all other depth strata, although an increase in density from 20-22 m was also observed but it was not significant (Figure 1B.7). While the interaction of depth*side was significant At GI94 fish density varied with platform side and depth (Table 1B.2). Significantly higher densities

were found on the north and west sides of the platform than all others while lowest densities were found on the east side of the platform (Figure 1B.6). With respect to depth, densities varied significantly with depth and were significantly highest near the bottom, than immediately adjacent to the surface and mid depth (Figure 1B.7). The interaction of depth*side was significant the trend of highest abundances near the surface and the bottom was consistent on all sides of the platform but differences in densities between sides were observed (Table 1B.2).

Densities of fishes at the GC18 production platform were highly variable over the study period ranging from 0 to over 1.44 fish/m^3. Spatially fish density varied with platform side, depth and the interaction of depth*platform side (Table 1B.3). Significantly higher densities were found on the west side of the platform than all others, while densities were not significantly different on the north and south sides (Figure 1B.6). Densities on the east side were five to eight times less than those on

Table 1B.1. Randomized block design ANOVA (block on platform side) of log fish density data (log (number fish * m^{-3})) from South Timbalier 54 with platform side, depth and the interaction of depth and side.

Source	DF	SS	MS	F	Prob > F
Model	19	23.81616337	1.25348228	13.16	0.0001
Error	2365	225.25333370	0.09524454		
Corrected Total	2384	249.06949707			
	R-Square	C.V.	Root MSE		LDENSITY Mean
	0.095621	145.0434	0.3086171		0.2127757
Variables	DF	Type I SS	Mean Square	F Value	Pr > F
Side	3	13.09084337	4.36361446	45.81	0.0001
Depth	4	6.40854576	1.60213644	16.82	0.0001
Side * Depth	12	4.31677424	0.35973119	3.78	0.0001
Variables	DF	Type III SS	Mean Square	F Value	Pr > F
Side	3	12.08934034	4.02978011	42.31	0.0001
Depth	4	5.82590975	1.45647744	15.29	0.0001
Side * Depth	12	4.31677424	0.35973119	3.78	0.0001

Table 1B.2. Randomized block design ANOVA (block on platform side) of log fish density data (log (number fish * m^{-3})) from Grand Isle 94 with platform side, depth and the interaction of depth and side.

Source	DF	SS	MS	F	Prob > F
Model	47	157.11677757	3.34291016	22.42	0.0001
Error	8890	1325.7941409	0.14913320		
Corrected Total	8937	1482.9109184			
	R-Square	C.V.	Root MSE		LDENSITY Mean
	0.105952	127.0847	0.3861777		0.3038743
Variables	DF	Type I SS	Mean Square	F Value	Pr > F
Side	3	57.41183015	19.13727672	128.32	0.0001
Depth	11	81.51039732	7.41003612	49.69	0.0001
Side * Depth	33	18.19455010	0.55135000	3.70	0.0001
Variables	DF	Type III SS	Mean Square	F Value	Pr > F
Side	3	58.41688848	19.47229616	130.57	0.0001
Depth	11	81.30836301	7.39166936	49.56	0.0001
Side * Depth	33	18.19455010	0.55135000	3.70	0.0001

Table 1B.3. Randomized block design ANOVA (block on platform side) of log fish density data (log (number fish * m^{-3})) from Green Canyon 18 with platform side, depth and the interaction of depth and side.

Source	DF	SS	MS	F	Prob > F
Model	43	2.19861886	0.05113067	51.10	0.0001
Error	7738	7.74271777	0.00100061		
Corrected Total	7781	9.94133663			
	R-Square	C.V.	Root MSE		LDENSITY Mean
	0.221159	296.1676	0.0316324		0.0106806
Variables	DF	Type I SS	Mean Square	F Value	Pr > F
Side	3	0.24722057	0.08240686	82.36	0.0001
Depth	10	1.51026045	0.15102604	150.93	0.0001
Side * Depth	30	0.44113784	0.01470459	14.70	0.0001
Variables	DF	Type III SS	Mean Square	F Value	Pr > F
Side	3	0.22377102	0.07459034	74.54	0.0001
Depth	10	1.51920801	0.15192080	151.83	0.0001
Side * Depth	30	0.44113784	0.01470459	14.70	0.0001

other sides of the platform (Table 1B.3, Figure 1B.6). The most dramatic results of the research was the relationship between fish density and depth. A significant and spectacular drop in density with depth was observed at GC18 below 100 m (Table 1B.3, Figure 1B.8). Fish densities from 0 - 15 m were significantly higher than all other depth strata and were 4 to 68 times higher than all other depths (Figure 1B.8). Densities from 15 to 95 m were not significantly different but were 3 to 12 times higher than depths from 115 to 210 m (Figure 1B.8). From 115 to 210 m fish density was less than 0.002 fish/m^3, essentially zero, and lower than densities measured on the continental shelf of the open waters of the Gulf of Mexico (Figure 1B.8). The interaction of depth*side was significant the trend of highest abundances near the surface and decreasing with depth was consistent on all sides of the platform but differences in densities between sides were observed (Table 1B.3).

DISCUSSION

This study again demonstrates the utility of merging hydroacoustics and visual survey techniques to study the assemblage of fishes associated with petroleum platforms. The combination of these techniques allows for the measurement of the area of influence of these defacto artificial reefs, estimates of abundance, size distribution and species composition throughout the water column and over long time periods.

Our results emphasize the variability in the density of fishes associated with petroleum platforms especially with respect to depth and side. Similar results from this project and our earlier research

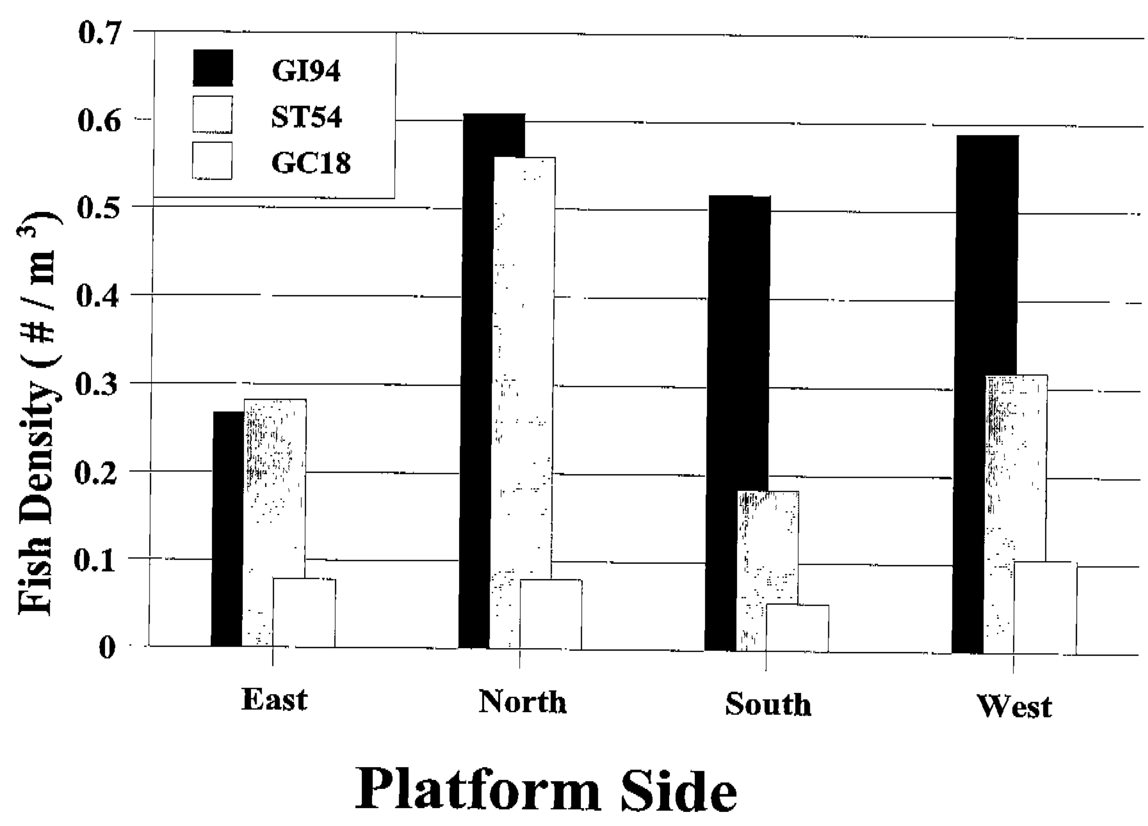

Figure 1B.6. Estimated fish density (number of fish / m^3) by platform side at petroleum platforms Grand Isle 94 (GI94), South Timbalier 54 (ST54) and Green Canyon 18 (GC18).

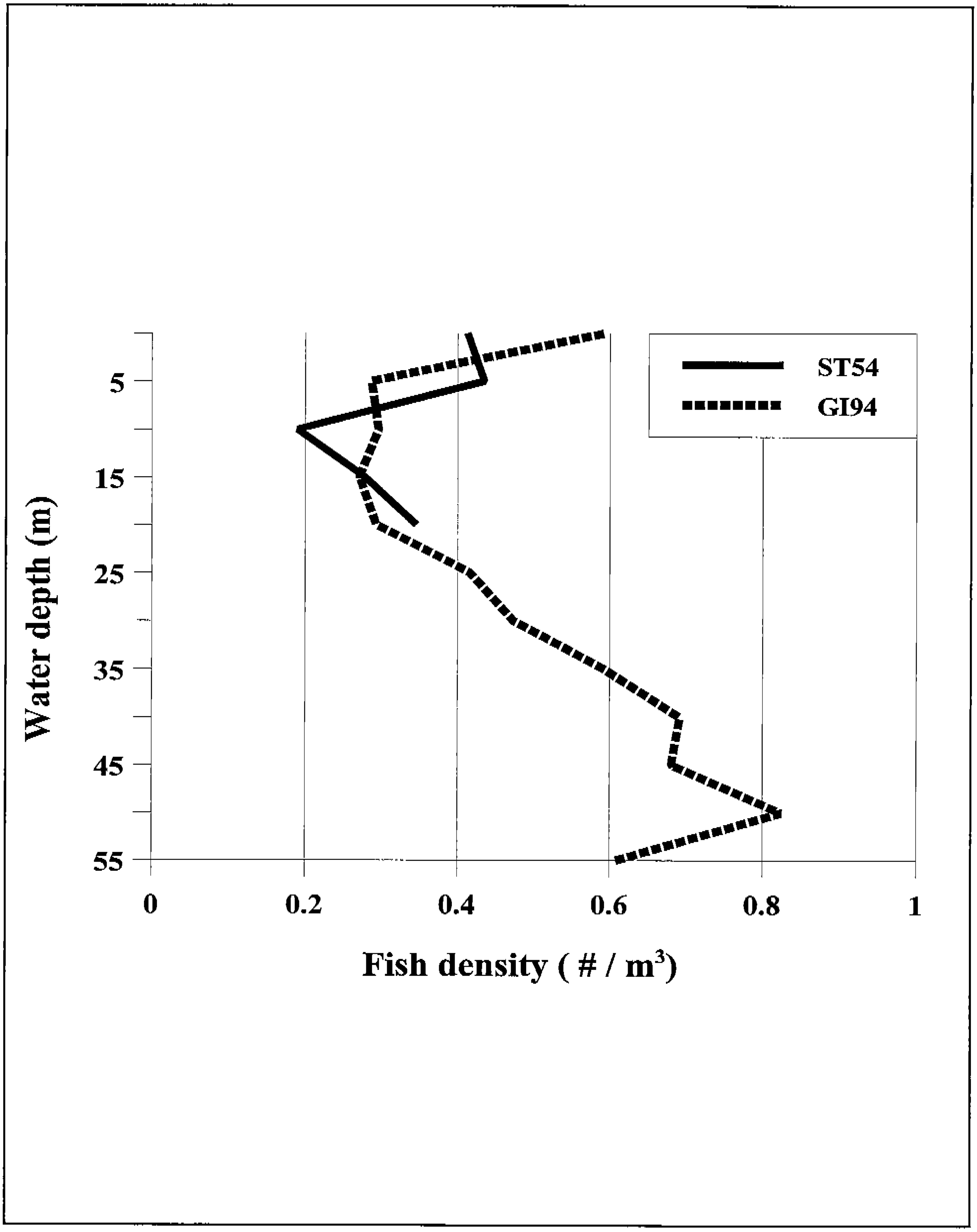

Figure 1B.7. Estimated fish density (number of fish / m^3) by depth at petroleum platforms Grand Isle 94 (GI94) and South Timbalier.

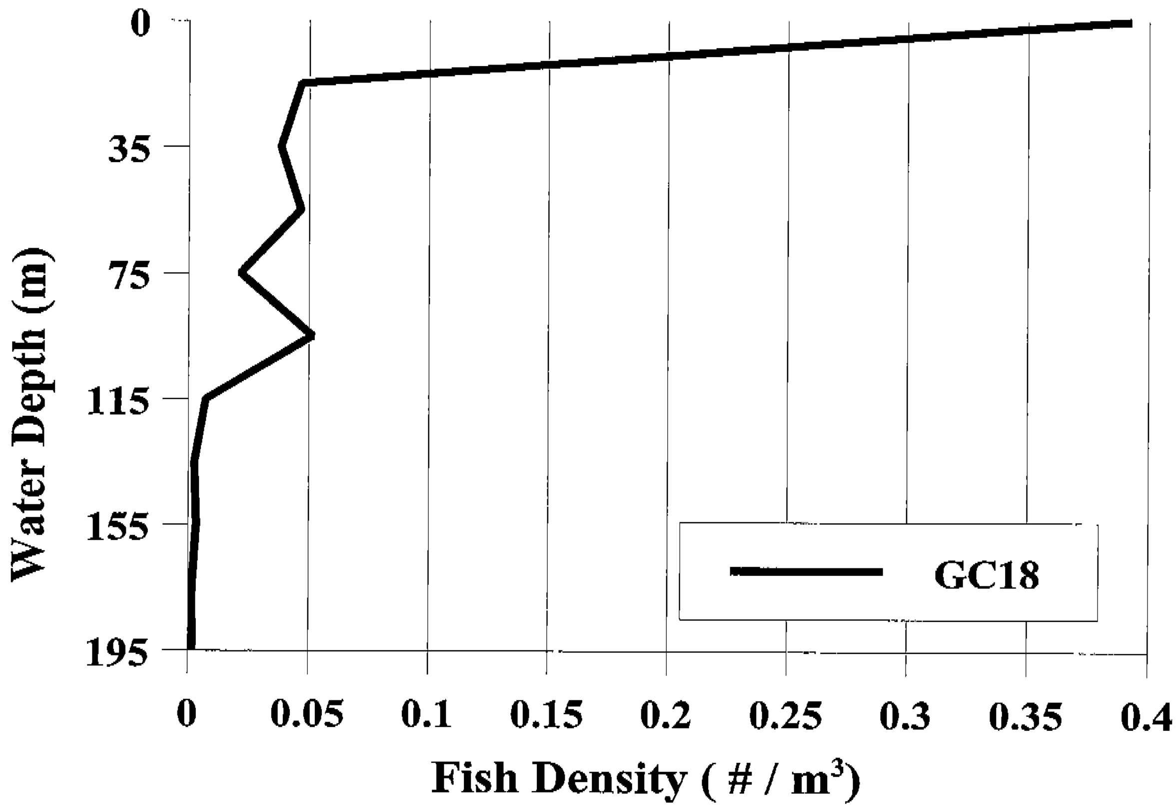

Figure 1B.8. Estimated fish density (number of fish / m^3) by depth at petroleum platform Green Canyon 18 (GC18).

were found with respect to the variability of fishes with respect to side of the platform and depth at the shallow site (Stanley and Wilson 1996, 1997). Before this research no project has examined the relationship between depth and density at deeper platforms. The observation of consistently higher densities on one or two sides of the platform is similar to our past research (Stanley and Wilson 1996, 1997). The highest densities typically found on the north side may be due to the increased structural complexity from the well bay found at the north end of these structures. Since fish abundance has been positively correlated with structural complexity at other artificial reefs this may explain the increased densities on the north side of the structures (Shulman 1984, Hixon and Beets 1989).

The primary questions to be addressed by the research was the effect of depth on the fish density. Similar results with respect to density and water depth were found for sites on the continental shelf, ST54 and GI94, as highest densities were found adjacent to the surface and the bottom. These results were similar to those of our earlier research (Stanley and Wilson 1995, 1996, 1997) and those of Chang (1985), Shinn and Wicklund (1989) and Rooker *et al.* (1997). The most dramatic results of the project was the change in density with depth at the site on the continental slope, GC18. A significant and striking decrease in fish density with depth was found and below 100 m as very low fish densities fish densities were detected. Previous research supports these findings as species richness in the Pacific was negatively correlated with depth, especially in tropical latitudes (Stevens 1996) and bottom trawl data from the shelf break in the Gulf of Mexico (water depth > 110 m) documented the presence of 69 species however, low abundances were found and few reef dependent species were captured (Chittenden and Moore 1977). The concentration of fishes at GC18 near the surface is reflected in the fact that 88% of the fishes were found in the upper 60m of the water column. While near surface fish densities at GC18 were significantly higher than those below 60 m the densities were only one half to two thirds compared to sites on the continental shelf. The decrease is likely due to the location of GC18 and its distance from the highly productive waters of the Mississippi River. Both ST54 and GI94 were regularly influenced by the highly productive waters from the Mississippi River as reflected in the lower surface salinities observed at these sites. The high salinities observed at GC18 with varied little from surface to the bottom, indicative of low productivity oceanic waters and the oligoltrophic conditions appear to be reflected in lower fish densities even near the surface.

Comparison of results from this research with other petroleum platform studies from the northern Gulf of Mexico revealed similarities and significant differences in density and abundance. Comparison of acoustically derived estimates of density from our past research showed similar density values with those from this project especially at ST54 and GI94. Mean densities from our earlier work (Stanley and Wilson 1995, 1996, 1997) at a site in 24 m of water were 0.244 (+/- 0.062, 95% confidence interval) fish·m^{-3}, while mean densities found during this project were 0.333 (+/- 0.034) fish·m^{-3} at ST54, 0.496 (+/- 0.017) fish·m^{-3} at GI94 and 0.029 (+/- 0.003) fish·m^{-3} at GC18. With the exception of GC 18 these values are consistent with those from Putt (1982) for a platform in approximately 22 m of water off the Texas coast and an order of magnitude higher than the results of Continental Shelf Associates (1982) from four platforms in June 1980. Both Putt (1982) and Continental Shelf Associates (1982) used visual surveys with Putt employing stationary cameras and

Continental Shelf Associates using a ROV for visual surveys. While the densities from previous studies are comparable to those estimated from our earlier and current research using hydroacoustics; the visual techniques utilized are of limited value in low visibility by the authors' admission their conclusions are limited to characterizations of fish populations under high visibility conditions. The densities found at platforms also are much higher than those from the open waters of the Gulf of Mexico. Morgan (1996) acoustically measured fish densities in the open waters of the northern Gulf of Mexico in 20 to 35 m of water on the continental shelf and found mean fish densities were approximately 0.001 fish·m^{-3}. Based on all the results to date it is apparent that large concentrations of fishes are found around these structures in the northern Gulf of Mexico but the debate continues as to the exact function of these structures on whether they increase productivity or attract existing organisms.

The 4000 petroleum platforms in the northern Gulf of Mexico, provide an estimated 12 km^2 of additional hard substrate (Stanley 1997) to a ecosystem that is dominated by a mud/sand substrate (Parker *et al.* 1983). The expansion of hard substrate habitat especially habitat in the upper water column has undoubtedly changed the dynamics of energy flow and influenced the utilization of marine resources in the region but has proved difficult to quantify the impact of these structures. In response to the use of platforms by fishers in the region Louisiana and Texas created artificial reef programs and the materials of choice are retired platform jackets (Wilson *et al.* 1986, Stephan *et al.* 1990). The standard deployment of these structures as reefs involves placing the jacket on its side. However, this deployment minimizes vertical relief and if a platform such as GC18 was deployed in this manner it would extend approximately 80 m off the bottom. Based on our results at the site very few fishes would utilize the structure in this orientation and its value as an artificial reef would be questionable. This project is the first demonstrating the importance of vertical relief in maximizing the effectiveness of platforms as artificial reefs especially with respect to deep water environments.

This research confirms the variability of fish assemblages associated with petroleum platforms and reinforces the need to sample on each site and throughout the water column to obtain an accurate estimate of fish abundance. This study continues to demonstrate the utility of merging hydroacoustics to study the assemblage of fishes associated with petroleum platforms.

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FISHERIES IMPACTS OF UNDERWATER EXPLOSIVES USED IN PLATFORM SALVAGE IN THE GULF OF MEXICO 1993-1998

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INTRODUCTION

There are approximately 4,000 oil and gas structures in the Gulf of Mexico. Federal regulations require removal of platforms within one year of lease termination. About 100 removals occur each year. Plastic explosives, primarily Comp-b and C-4, are used to sever structural members and well conductors in about two-thirds of these removals while mechanical techniques are used on the remaining third. Explosives are typically placed inside the hollow pilings and generally do not exceed 50 lb in weight (Gitschlag & Herczeg 1994). Offshore platforms serve as excellent artificial reef habitat that attract a vast array of marine life (Dugas & Fischer 1979; Hastings *et al.* 1976; Lewbel *et al.* 1987; Scarborough-Bull 1989; Sonnier *et al.* 1976; Stanley & Wilson 1990). The use of underwater explosives can severely impact fish and other marine life in close proximity to the structure during the removal process. This report discusses preliminary results of assessments of fishery impacts conducted at nine platform removals between August 1993 and July 1998.

METHODS

Prior to detonation of explosives, fish were captured, tagged and released alive at the study site. After detonation, fish killed by explosives either floated to the sea surface or sank to the sea floor. To estimate the number and species of fish fatally impacted by explosives we attempted to collect all the moribund fish which floated up to the sea surface. Field personnel operating from inflatable boats used dip nets to perform this task. Recovering dead fish from the sea floor was much more difficult and required SCUBA divers. Due to the large impact zone it was not feasible to attempt recovery of

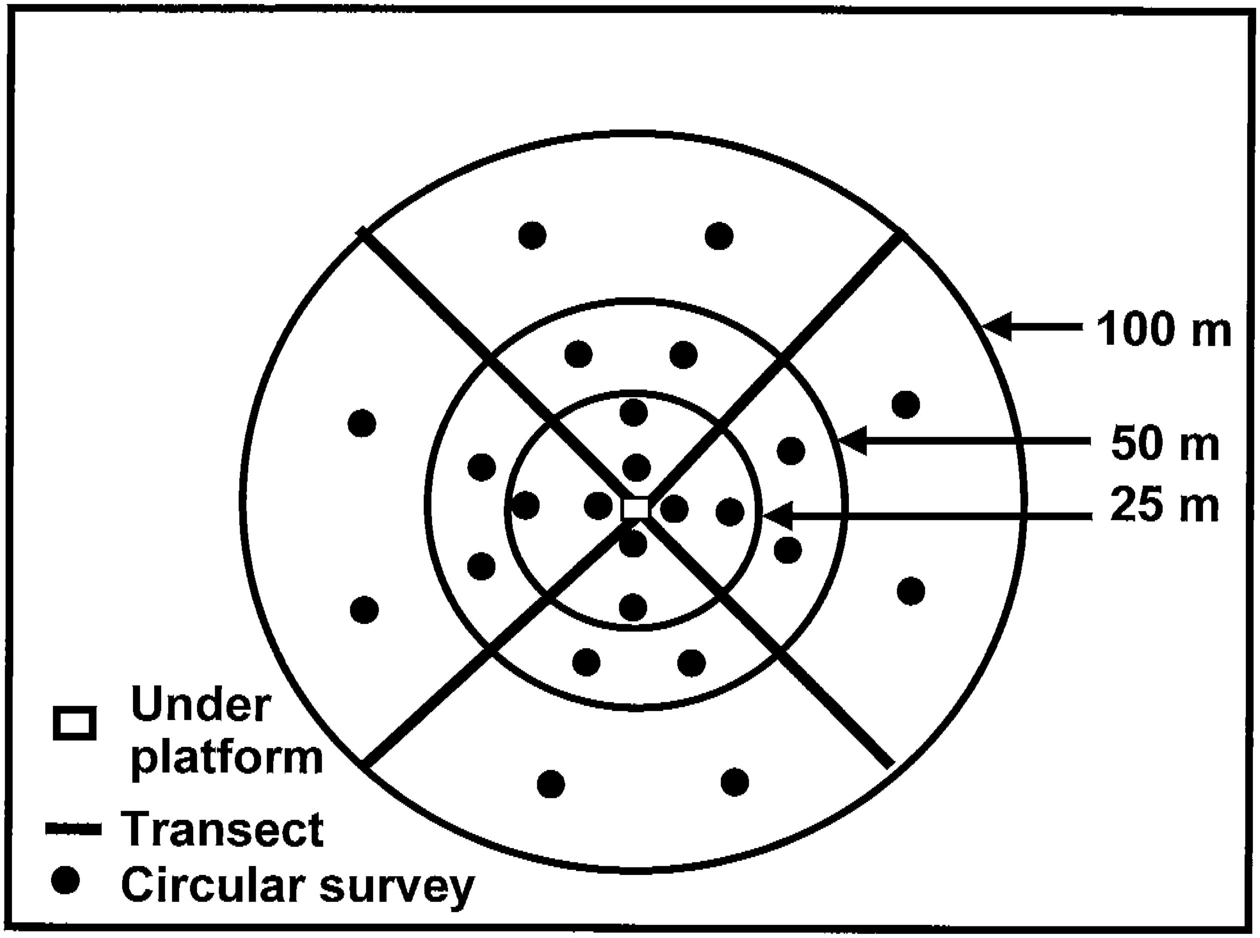

Figure 1B.9. Final sampling design.

all moribund "sinkers." A sample of these "sinkers" was collected using three techniques: line transect surveys, circular surveys, and sampling frames placed beneath the platform. To increase efficiency, procedural modifications were made early in the study and only final sampling protocols are described here (Figure 1B.9). Twenty-four circular surveys measuring 6.7 m (22 ft) in diameter and four 100 m (328 ft) transect lines were sampled. At one platform (WC172), 200 m (656 ft) transect lines were surveyed. Divers collected discrete samples of moribund fish in 25 m (82 ft) increments along the transect line. Sampling width was either 1 or 2 m (3 or 6 ft) on either side of the line depending on visibility. Sampling frames constructed of PVC pipe were placed beneath the platform. Although frame dimensions varied due to obstructions encountered on the sea floor, the total area sampled generally covered 20-30% of the footprint area beneath the platform. Extremely small fish such as blennies which live inside dead barnacles encrusting the structural members of the platform were not targeted for collection. Generally, fish smaller than 8 mm total length were not sampled. Due to time constraints and safety considerations all targeted samples were not always collected.

Fish mortality was estimated by multiplying fish density (number of fish in sample divided by area sampled) by total area for each region of interest (e.g. 0-25 m radius around the platform, 25-50 m, 50-75 m, etc. for transect line analysis). Similar procedures were applied to data collected from circular surveys and sampling frames. The total estimated mortality at a study site was calculated by adding the estimated fish mortalities at the surface, beneath the platform and in open water around the platform to a maximum distance of 100 m. The transect and circular survey techniques served as duplicate estimators for mortality in the open water area.

Population size was estimated for various species when pre-detonation fish tag and release efforts were successful and sufficient numbers of tagged fish were recovered dead after blasting. Estimates were calculated for individual species using direct proportions of tagged to untagged fish.

RESULTS

From 1993-1998 an assessment of fisheries impacts due to underwater explosives was conducted at 9 platform removals which occurred during the months of May, June, July, August and September. Study sites spanned the Louisiana coast from the western border to the Mississippi delta. Water depths ranged from 14-36 m (45-118 ft). All platforms had 4 pilings except for one 24 pile structure. The weight of explosives used per site was 160-640 lb. Structures varied in age from 12-39 years. Total mortality estimates were calculated for 8 of the 9 platform removals studied. At the deepest platform sea floor sampling by divers did not begin until 50 hours after the first of two detonation sequences because the platform owner would not allow sampling until the structure had been toppled in place and the salvage barge departed the site. Due to a combination of this and other factors including zero visibility on the sea floor, strong currents, rough seas, and extremely large amount of debris around the platform which resulted in entanglement of divers, insufficient data were collected from the sea floor to provide estimates of fish mortality although surface mortalities were collected using standard protocols.

Total estimated mortality ranged from less than 2,000 to 6,000 fish at individual platforms (Table 1B.4). These figures appear small when compared with estimates from other sources of fish mortality such as trawl bycatch. Very small fish less than about 8 cm are not routinely collected by divers. Blennies account for most of these mortalities. However, during removal of the platform in West Cameron Area Block 181, an abundance of small, dead fish other than blennies were encountered. These carcasses were collected from one of the sampling frames placed beneath the platform. A mortality estimate was calculated assuming uniform density of these fish in the footprint area of the structure. Results indicated an estimated 6,400 mortalities of small fish, primarily vermilion snapper (6100 mortalities), measuring less than 8 cm. Note that this figure does not include any estimate for the area outside of the platform footprint.

Fish species with the highest estimated mortality included Atlantic spadefish, red snapper, blue runner, and sheepshead. Estimated mortality at seven study sites ranged from 500-2,500 for spadefish, 0-1,300 for red snapper, 0-1,500 for blue runner, and 100-1,100 for sheepshead. Combining the results from these eight platforms yielded a total estimated kill of 10,170 spadefish, 4,387 red snapper, 4,200 blue runner, and 3,514 sheepshead. These four species accounted for approximately 89% of the combined estimated fish mortality at these eight study sites.

Table 1B.4. Estimated fish mortality.

Depth ft	Size	Age	LBS Expl	Depth (ft) BML	Est. Fish Kill
45	24 pile	39	640	20-30	1500-1900+
48	4 pile	23	300	20	2000-2300
48	4 pile	19	210	16-20	2600-2900
55	4 pile	12	350	15	2200-4700
58	4 pile	33	160	20	4700-6000+ (6400 <8cm)*
82	4 pile	16	380	20	4300-5000
92	4 pile	17	350	13-25	3000
105	4 pile	37	250	20	1600-1900

* Under platform

Prior to the detonation of explosives, a fish tag and release study was conducted. Although all captured species were tagged and released, red snapper was by far the most numerous. Typical recovery rates for tag-release studies of fish are about 5%. The percentage of tagged red snapper that were recovered after detonations was 19%, 20%, 41%, 48%, 60%, and 64% at our successful study sites (Table 1B.5). Too few red snapper were tagged at the other three sites to estimate population size. High recovery rates indicated a large impact of underwater explosives on red snapper at platform removals.

Data from the red snapper tag-release study conducted at WC 181 during summer 1997 were especially interesting. Field work was interrupted for a week due to bad weather. Three estimates of the pre-detonation population size of red snapper were calculated using data for fish tagged during the first cruise, the second cruise, and both cruises combined. Results were similar (1,142; 936; and 1,048, respectively) indicating consistency between the two cruises. It is interesting to note that post-detonation recovery rate of tags was about 5% higher for the second cruise than for the first cruise.A summary of all red snapper population and mortality, estimates to date is shown in Table 1B.6. Population estimates ranged from about 500-1,900 for those platforms where sufficient numbers of fish were tagged. The percent of the population which was killed by blasting activity was calculated by dividing estimated red snapper mortality by estimated population size. Results ranged from 57-90%. Actual mortality is probably higher due to artifacts inherent in tag-recapture studies.

Many factors affect fish mortality which occurs during the explosive removal of offshore structures. The list may include but is not limited to such things as water depth, water temperature, salinity, oxygen concentration, season, structure size and age, number of nearby structures, amount of explosives used, placement and configuration of explosives, and sediment characteristics.

Table 1B.5. Red snapper tag-recovery study.

Site	# tagged	# dead with tags	% recovery	Water depth (ft)
WD 30	0	0	0	45
WC 172	132	84	64	48
WC 173	172	32	19	48
SS 158	4	0	0	55
WC 181	298	60	20	58
SMI 23	44	18	41	82
ST 146	117	56	48	92
SS 209	58	35	60	105

Table 1B.6. Red snapper population and mortality estimates.

Site	% tag recov.	Pop. est.	Mortality est.	% mortality	Water depth (ft)
WD 30	-	-	-	-	45
WC 172	64	700	500	73	48
WC 173	19	1100	700	66	48
SS 158	0	-	300	-	55
WC 181	20	1000	900	90	58
SMI 23	41	1900	1200	61	82
ST 146	48	500	300	57	92
SS 209	60	600	400	71	105

Recent attention to the biological impacts of explosive platform salvage has resulted in discussion of potential methods for mitigation. None has received overwhelming support. Topics include attracting or repelling fish out of the impact zone, using bubble curtains or mats to dampen the effect of the blast, and developing special shaped charges that can dramatically reduce charge weight and subsequent blast over-pressure. Although additional research is required, recent developments in configured explosives may prove very beneficial to the fish populations and other marine life which occur at offshore oil and gas structures.

In conclusion, impacts of underwater explosives on fish appears small in terms of total numbers when compared to other sources of mortality such as trawl bycatch. Standard deviation of mortality estimates is a bit high probably due to small sample size as well as natural variability between fish populations present at platforms. Platforms in deeper water are generally believed to have larger red snapper populations than shallow water structures.

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PRELIMINARY SURVEYS OF SESSILE INVERTEBRATE COMMUNITY ON A PARTIALLY REMOVED PLATFORM REEF OFF SOUTH PADRE ISLAND, TEXAS

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ABSTRACT

In 1997, Seagull Energy, Inc. petroleum production platform NPI 72 A was donated to the Texas Parks and Wildlife Artificial Reef Program. In June 1997 a preliminary survey was conducted by TAMU-CC-CCS personnel to obtain baseline data of the fouling community associated with the platform prior to being partially removed. A post-cut survey (i.e. partial removal) was conducted during August 1998. Photographic analysis was used to determine vertical biological zonation, diversity, dominance, evenness and area coverage. Rugosity measurements were taken to indicate of fouling density. Data was compared to NPI 59 A, a standing petroleum platform, approximately 17 km north which is still in production and two bluewater production platforms EB 165 A and HI 389 A.

INTRODUCTION

Researchers have long discussed the importance of artificial hard substrates to attract targeted sport and commercial finfish species; hence the development of artificial reefs became an important aspect for the recruitment and sustainability of finfish populations. Fish species such as the gray triggerfish, *Balistes capriscus*, rock hind, *Epinephelus adscensionis,* and creole fish, *Paranthias furcifer* utilize cryptic macroinvertebrates as a food source (Beaver *et al.* 1997; Nelson and Bortone 1996). Common herbivores such as sergeant major, *Abudefduf saxitilis,* and several species of the genus *Pomatricentrus* also utilize cryptic species as incidental food sources (Edwards 1992), making cryptic invertebrate species an important nutrient resource.

Artificial reefs provide a "reef of opportunity" for organisms that settle on hard bottom substrates which are limited in the deeper waters of the northwestern Gulf of Mexico. Cyclic abiotic factors, such as seasonality, light intensity, temperature and water depth influence the settling process of larval and algal species. Many species settle within specific biological and photic zones within the water column, while others have adapted to survive in all zones. Most marine organisms disperse during a planktonic larval stage (Gallaway and Lewbel 1982; Beaver *et al.* 1997).

The development of a productive artificial reef is affected by the degree at which these organisms can settle and survive, and the fish community is affected by the fouling community (Rooker *et al.* 1997; Beaver *et al.* 1997). The purpose of this study was to provide information regarding the sessile invertebrates (i.e. fouling community) of a South Texas nearshore platform reef.

STUDY SITES

This study was performed on the coastal petroleum production platform, Seagull Energy Inc. North Padre Island (NPI) 72 A (26 52' 20.9" N x 096 46' 19.3" W), South Padre Island, Texas, which had recently been donated to Texas Parks and Wildlife Department Artificial Reef Program (TPWDARP) for partial removal. During June 1997 a pre-cut survey was conducted to gather baseline data and to characterize the fouling community and fish populations. North Padre Island 72 A was mechanically severed at a depth of 33.5 m (110 ft). Data collected during June 1997 (pre-cut) and August 1998 (post-cut) was compared to a standing platform, NPI 59A, located ≈ 18.5 km northeast of NPI 72 A. The data was also compared to existing and previous studies performed on standing platforms; High Island 389 A (27 54' 30"N x 093 35' 06"W) and East Breaks 165 A (27 49"N x 094 19' W) located in blue water biological zones of the continental shelf in the northwestern Gulf of Mexico.

North Padre Island 59 A is a petroleum production platform that is still in production. NPI 72 A and NPI 59 A platforms are three pile (i.e. leg) platforms situated in 72 m of water, located in the North Padre Island mineral lease block approximately 103.9 km and 89.2 km (respectively) east of Port Mansfield, Willacy County, Texas. Mobile Exploration and Production United States (MEPUS) High Island (HI) 389 A is located approximately 3.07 km east of the Flower Garden Banks National Marine Sanctuary (FGBNMS) east bank. British Petroleum Exploration (BPX), East Breaks (EB) 165 A is located ≈ 157.4 km southeast of Galveston Island.

METHOD AND MATERIALS

Fouling community sampling was conducted using a modified photographic transect technique (Ohlhorst *et al.* 1992). This technique produces a 35 mm color transparency of ≈ 0.50 m^2 of substrate using a Nikonos V camera, 28 mm lens, two SB102 strobes and a photo framer with a Aqua Lung D-Timer attached to record depth (Dokken *et al.* 1994). All photographs and samples were collected utilizing SCUBA technology.

Vertical transects extended from a depth of 33.52 m to a depth of 53.34 m. Photographs were taken at 1.52 m (5 ft) intervals on each of three piles and each transect contained 14 transparencies. Transparencies were projected at a 1:1 ratio onto a screen with 100 randomly located points and quantified using the planar point intercept method as per Ohlhorst *et al.* (1992). Organisms were identified to lowest possible taxon and quantified.

When necessary, the images were magnified to facilitate species identification. A total of 144 transparencies were analyzed, producing a total of 14,400 data points. A checklist was compiled, and relative frequency was determined by dividing the total number of points from a given species by the total number of points in the transect. Shannon Diversity Index (H') was utilized to assess species diversity for each zone and values were calculated from the formula:

$$H' = -\Sigma p_{ilog}\, p_i$$

where p_i equals the decimal fraction of total individuals of the i^{th} species. Simpsons Dominance (Dn) was calculated with the formula:

$$Dn = 1 - \Sigma pi^2$$

Where pi^2 equals the proportion of individuals found in the i^{th} species and n equals the number of individuals of a species.

Evenness (J') indices was calculated as:

$$J' = H' / \ln S$$

where S equals the total number of species.

A one-way analysis of variance (ANOVA) was used to determine significant differences in fouling community diversity within population zones of the transects ($\alpha = 0.05$). Tukey's HSD was employed to identify significantly different means.

Rugosity measurements were recorded for each 3.04 m (10 ft.) depth from 45.72 m (150 ft.) to the top of the remaining section of piles (35 m). Rugosity (amount of surface relief formed by the fouling community) is defined with the formula:

$$\frac{\Sigma\, 3\,(X+1) - 1}{3}$$

RESULTS

Thirty-seven fouling species were identified and enumerated on NPI 72A during the pre-cut survey (Riggs *et al.* 1998). A total of 36 species were identified and enumerated from NPI 72 A during the post-cut survey. Analysis of NPI 59 A identified a total of 36 species. Forty-eight species were identified from all platform reefs analyzed (Table 1B.7). Two deep zones were delineated during the pre-cut analysis at depths of 24.6 m and 42.8m (Table 1B.8). During the post-cut analysis, only a single zone was present beginning at the cut area (30 m) and ending with the deepest depth used for the analysis of 53.3 m ($p = .326$). Hydroids and sponges constituted the majority of organisms during the pre-cut survey, covering 25% and 40%, respectively (Figure 1B.10). Post-cut analysis has determined an unidentified Chlorophytic algal species, perhaps of the genera *Enteromorpha*,dominating the structure (44.4%), followed by sponge (21%). North Padre Island 59 A also displayed a high percent algal coverage (35%) and reduced sponge coverage (23%) (Figure 1B.10).

Table 1B.7. Fouling species identified from photographic transsects on NPI 72 A, NPI 59 A, EB 165 A, and HI 389 A.

Chlorophyta
- Ulvaceae
  - *Enteromorpha sp.*
- Cladophoraceae
  - *Cladophora sp.*
  - *Chaetomorpha sp.*

Hydroida
- Sertularidae
  - *Sertularia dalasi*
  - *Sertularia inflata*
  - *Sertularia turbinate*
- Plumularidae
  - *Aglaophenia cristifrons*
  - *Aglaophenia rigida*
- Campanularidae
  - *Obelia dichotomy*
  - *Obelia hyalina*

Thoracica
- Balanidae
  - *Balanus eburneus*
  - *Balanus sp.*
  - *Megabalanus antillensis*

Echinoidea
- Arbaciidae
  - Arbacia punctulat
- Diadematidae
  - *Diadema antillarum*

Octocoralia
- Alcyonacia
  - *Carijoa riisei*
  - *Telesto antillensis*

Rhodophyta
- Bangiaceae
  - *Bangia sp.*

Ascidiacea
- Unidentified sp.

Bryozoa
- Membraniporidae
  - *Membranipora sp.*
- Bicellariellidae
  - *Bugula turrita*
  - *Bugula neritina*
- Schizoporelidae
  - *Schizoporella sp.*

Bivalvia
- Isognomonidae
  - *Isognomon bicolor*
- Arcidae
  - *Arca zebra*
  - *Barbatia candida*
- Spondylidae
  - *Spondylus americanus*
- Pteriidae
  - *Pteria colymbus*

Decapoda
- Majidae
  - *Stenorhynchus seticornis*

Annelida
- Amphinomidae
  - *Hermodice carunculata*
- Serpulidae
  - *Spirobranchus giganteus*

Porifera
- Dysideidae
  - *Aplysilla sp.*
- Clathrinidae
  - *Clathrina coriacea*
- Stellettidae
  - *Stelletta sp.*
- Geodiidae
  - *Geodia gibberosa*
- Suberitidae
  - *Suberites sp.*
- Halichondridae
  - *Halichondria sp.*
- Desmacellidae
  - *Neofibularia nolitangere*
- Myxillidae
  - *Tedania ignis*
- Phorbasidae
  - *Phorbas amaranthus*
- Clathriidae
  - *Clathria schinata*
  - *Rhaphidolphus schoenus*
- Haliclonidae
  - *Haliclona molitba*
- Callyspongiidae
  - *Callyspongia sp.*
- Thorectidae
  - *Ircinia felix*

Scleractinia
- Rhizangiidae
  - *Astrangia solitaria*
- Oculindae
  - *Oculina diffuse*
- Dendrophylliidae
  - *Tubastrea coccinea*

Table 1B.8. Vertical zones delineated during analysis of NPI 72 A, NPI 59 A, EB 165 A, and HI 389 A.

	Vertical Zone (m)			
Platform Reef	Zone 1	Zone 2	Zone 3	Zone 4
NPI 72 A pre-cut	1.03 – 3.04	3.3 – 24.3	24.6 – 42.5	42.8 – 53.2
NPI 72 A post-cut	Cut off	Cut off	30 – 53.2	
NPI 59 A	1.0 – 2.8	3.0 – 21.5	21.5 - 41.6	41.8 – 53.2
EB 165 A	1.0 – 4.6	4.8 – 22.3	22.5 – 35.8	36.1 – 53.2
HI 389 A	1.0 – 4.8	5.0 – 27.6	27.8 – 53.2	

Shannon Diversity Index for the pre-cut study calculated mean values of 1.6 at 35 m to 1.4 at 53.3 m. Post-cut analysis displayed a Shannon Diversity Index mean of 1.68 at 35 m and 1.65 at 53.3 m. Mean values for Simpsons Dominance Index from the pre-cut survey ranged from 0.26 at 35m to 0.27 at 53.3 m. The post-cut survey analysis demonstrated a Simpson Dominance Index of 0.48 at 35 m to 0.19 at 53.3 m. Analysis of the pre-cut survey concluded a mean Sheldon Eveness value of 0.72 at 35 m and 0.67 at 53.3 m. While the post-cut mean ranged from 0.63 at 35 m to 0.69 at 53.3 m. Pre-cut rugosity measurements recorded from NPI 72 A ranged between 0.25 (33.5 m) to 0.09 (45.7 m), while post-cut measurements for the same depths ranged between 0.03 and 0.13, respectively (Figure 1B.11).

DISCUSSION

Post-cut analysis has demonstrated the loss of one deep water biological zone from the reef and a reduction of invertebrate fouling community area coverage within the top of the remaining platform piles. An algal species not observed during the initial pre-cut survey dominated the platform to a depth of 53 m in the post-cut survey. Species diversity and dominance slightly increased from the pre-cut values for the shallower depths, but the eveness values dropped considerably. Diversity and eveness values for the deeper area increased, although the dominance values decreased.

Previous(1994 and 1996) diversity data reported from EB 165 A for comparable depths reported a diversity value of 0.879 (Dokken *et al.* 1996), lower than diversity values for NPI 72 A pre-cut and post-cut values (1.95 and 1.68, respectively) and NPI 59 A (1.56). However the data is consistent with current data acquired from EB 165 A for this analysis (0.85).

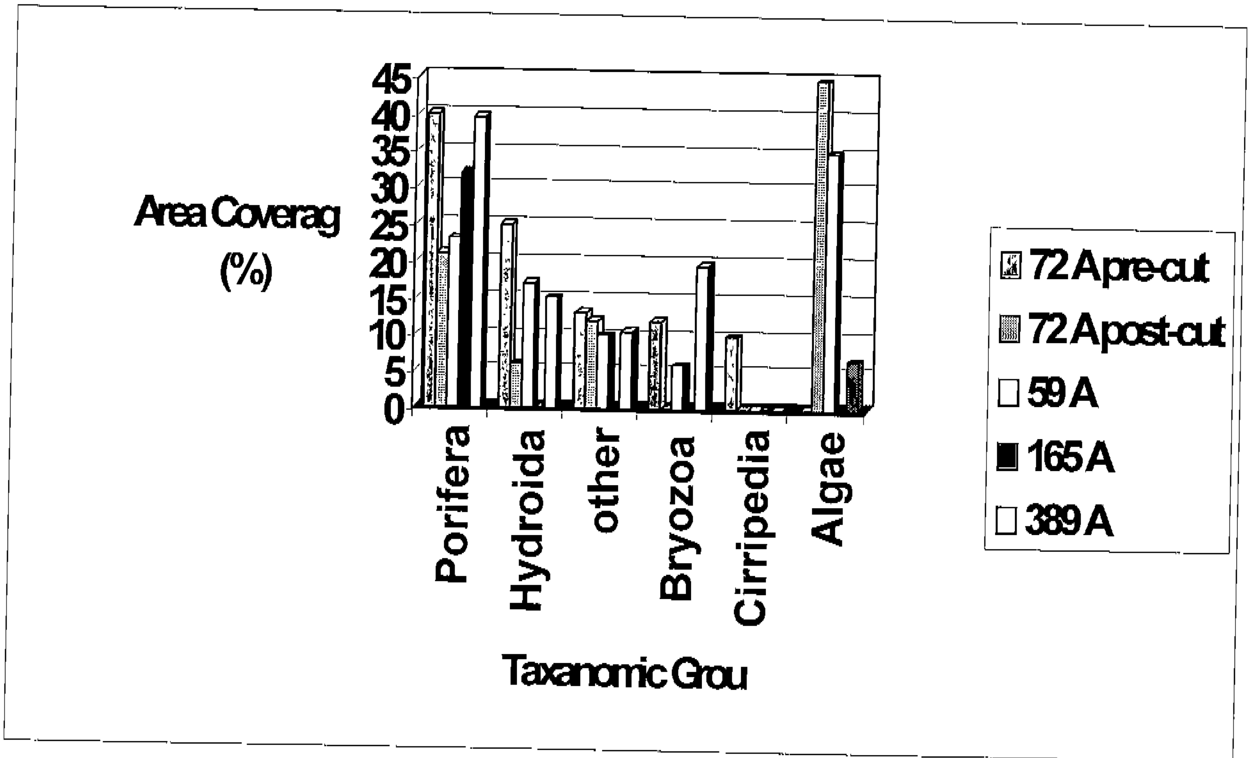

Figure 1B.10. Percent coverage of pre- and post-cut fouling constituents.

Adams (1995) identified 27 sponge species on HI 389 A with *Tedania ignis* and *Neofibularia nolitangere* being dominant species. During pre-cut analysis on NPI 72 A, *T. ignis* was the dominant sponge found and composed 40% of the area coverage for this group of invertebrates, and reduced to 35 % area coverage during the post-cut analysis. High Island 389 A also displayed lower dominance values than NPI 72 A and NPI 59 A.

Pre–cut rugosity analysis displayed relief patterns similar to those found on EB165 A reported by Dokken *et al.* (1996) and Dokken *et al.* (1994); as depth increased, rugosity decreased. Recent data obtained from EB 165 A did not exhibit any decrease or increase as depth increased and remained a constant 0.07 m for these depth ranges (Figure 1B.11). Rugosity of HI 389 A was considerably higher, ranging from 0.46 at 33 m to 0.33 at 47 m (Figure 1B.11). Rugosity analysis on NPI 59 A also displayed a slight decrease with depth (Figure 1B.11).

During the pre-cut survey of NPI 72 A, a nephloid layer was observed beginning at approximately 50.6 m, but was not observed at 60 m during the post-cut survey. The nephloid layer likely affected colonization patterns and biomass within the deepest zone observed during the pre-cut analysis.

Funded by the Texas Parks and Wildlife Department Artificial Reef Program (TPWDARP) in cooperation with Texas A&M University-Corpus Christi - Center for Coastal Studies (TAMUCC-CCS), this study will continue and be expanded to include other artificial reefs along the Texas coast.

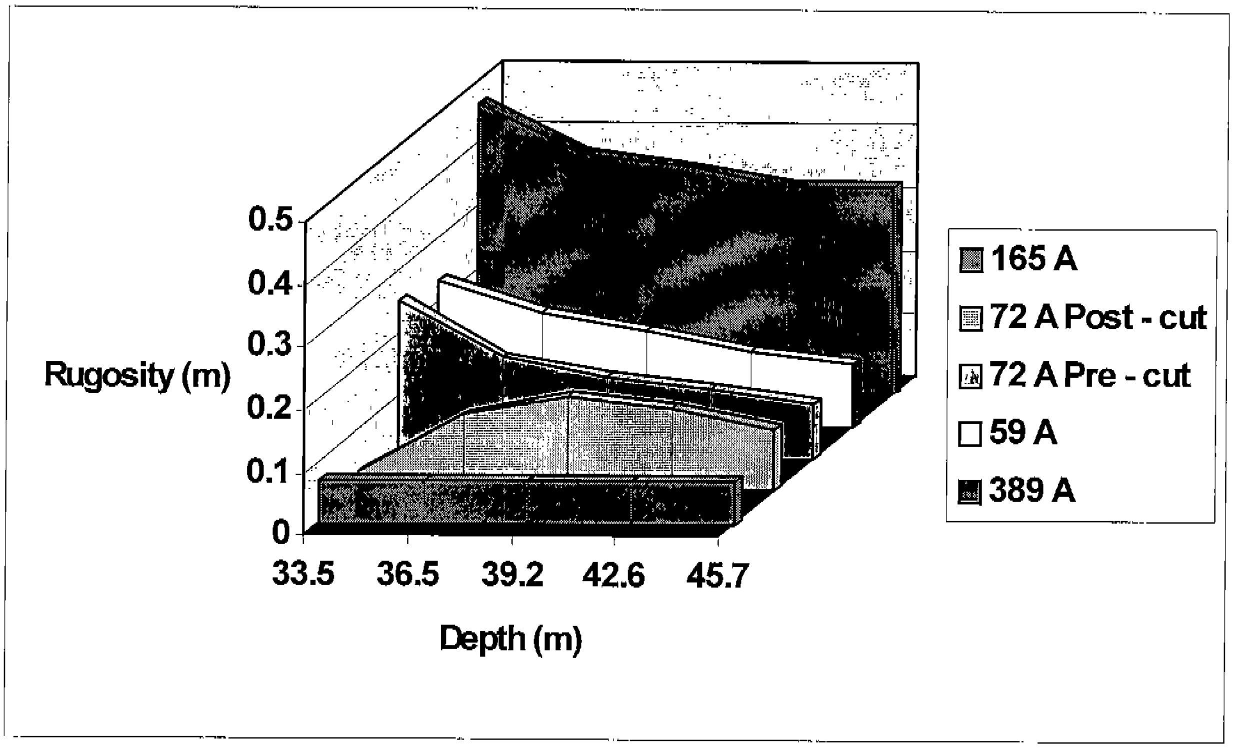

Figure 1B.11. Comparison of rugosity measurements from 33.5–45.7 meters at each site.

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PRELIMINARY OBSERVATIONS OF FISH ASSEMBLAGES ASSOCIATED WITH A PARTIALLY REMOVED PLATFORM OFF THE TEXAS COAST

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INTRODUCTION

Oil platforms are unique reef ecosystems extending throughout the water column providing a large volume and surface area, dynamic water flow characteristics and a strong profile (Ditton and Falk 1981; Dokken 1997; Stanley and Wilson 1990). Often, in the northern Gulf of Mexico, areas where oil platforms are located consist of a featureless seabed, and a reduced reef fish population (Meier 1989). Fish are attracted to oil platforms because these structures provide food, shelter from predators and ocean currents, and a visual reference which aids in navigation for migrating fishes (Bohnsack 1989; Duedall and Champ 1991; Meier 1989). Community characteristics of pelagic, demersal and benthic fishes are affected by the size and shape of the structure (Stanley and Wilson 1990).

According to Scarborough-Bull and Kendall (1992) there are over 5,000 oil platforms in the Gulf of Mexico and it has been estimated that they have increased the hard substrate in this area by as much as 28%. In recent years, 110 obsolete oil platforms in the Gulf of Mexico have been converted for use as artificial reefs (Reggio 1996).

Some scientists feel that a limiting factor to abundance for many fish species is the amount of hard-bottom habitat available, and that the presence of oil platform structures allows for the fish populations to grow, therefore increasing the fishery potential (Scarborough-Bull and Kendall 1992). It is likely that offshore oil platforms influence fish populations, however, due to inadequate information, there is some question as to the efficacy of artificial reefs and whether they simply aggregate fish populations or actually support increases of biomass (Polovina 1991; Scarborough-Bull and Kendall 1994; and Bortone *et al.* 1997). The purpose of this study is to advance understanding of the influence of platform reefs on finfish communities in the northwestern Gulf of Mexico.

STUDY SITE

The study was conducted on North Padre Island A72A (26° 52" 20.9'N x 96° 46" 19.2'W), a Seagull Energy Inc. petroleum production platform, located approximately 56.3 km northeast of Port Mansfield, Texas, in the Gulf of Mexico (Figure 1B.12). Water depth at the artificial reef site is 73 meters. The total volume of the reef site is 10,337 m^3 and the surface area is 16,576 m^2. North

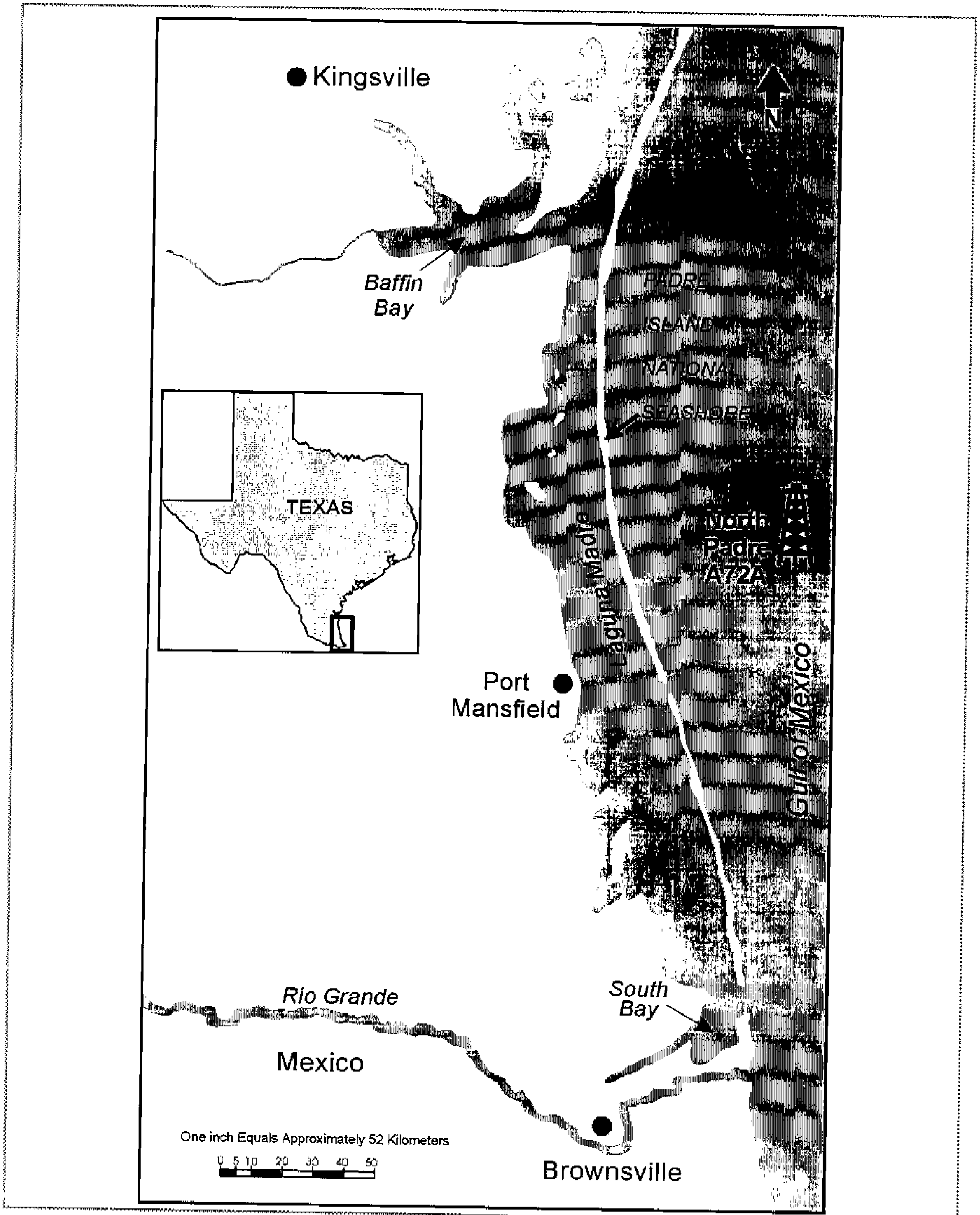

Figure 1B.12. Location of study site in relation to Padre Island National Seashore, Port Mansfield, and the Rio Grand.

Padre Island A59A (26° 61" 27.9'N x 96° 45" 17.6'W) was the platform used as a point of comparison. This platform is located 17.2 km north-northeast from North Padre Island A72A.

METHODS AND MATERIALS

The pre-cut survey of NPI A72A occurred on 10-11 June 1997 and the post-cut surveys of NPI A72A and NPI A59A (control) on 10-11 August 1998. NPI A72A was mechanically removed at 30m depth on 1 August 1998 and the top portion of the structure was laid horizontally on the ocean floor.

Pelagic fish populations were surveyed using a modified version of the stationary visual census method (Bohnsack and Bannerot 1986; Dokken *et al.* 1993). Two divers were positioned vertically in the water column on each side of the structure, with enough separation so the field of survey was non-overlapping. Surveying began with divers facing the platform. Each diver rotated slowly, 360°, identifying and counting all fish species observed within an imaginary cylinder with a 7m radius and depth. Each rotation was about one minute in duration. Only fish species observed within that time period were recorded. Three rotations were made at each position before moving to another location at that same depth or another depth. If schooling fish were present during a survey, they were counted first to avoid counting the same individual more than once. Surveys began at a depth of 36m and were taken at 6m intervals ending at a depth of 6m. At least 3 replicate surveys were performed at each depth.

For surveying cryptic reef fish species (those closely associated with the platform structure), a one-meter line with weights attached at each end marked the area of the structure to be surveyed. The placement of the line was random. Divers were positioned on opposite sides of the leg. All cryptic fish species within this one-meter transect around the circumference of the leg were identified and counted. Three surveys were performed at 6m intervals at each depth between 36m and the surface.

RESULTS

NPI A72A Pre-Cut Assemblages

A total of 24 pelagic and reef fish species representing 2 orders, 12 families, and 18 genera were observed (Table 1B.9). The dominant families (i.e. numbers of individuals) were Carangidae (jacks), 8,318 (98.9%), Lutjanidae (snappers), 452 (4.9%), Blenniidae (blennies), 151 (1.6%), and Pomacentridae (damselfishes), 91 (0.9%).

Of the pelagic species, the most abundant (i.e. number of individuals) species was the lookdown, *Selene vomer*, with 7,100 out of 8,323 individuals counted (=85.0%). Following the lookdown, the relative abundance of other pelagic species were the horse-eye jack, *Caranx latus*, 741 (8.9%), the blue runner, *Caranx crysos*, 395 (4.7%), and the greater amberjack, *Seriola dumerili*, 67 (0.7%).

The most abundant of the reef fish were the gray snapper, *Lutjanus griseus*, 435 (50.0%), tesselated blenny, *Hypsoblennius invemar*, 122 (14.0%), sergeant major, *Abudefduf saxatilis*, 91 (10.5%), and the spotfin hogfish, *Bodianus pulchellus*, 48 (5.6%).

Table 1B.9. Numbers of fish observed during surveys for the pre and post-cut of NPI A72A and NPI A59A (control).

Species	NPI A72A Pre-Cut	NPI A72A Post-Cut	NPIA59A Control
Family Carangidae			
Alectis ciliaris	0	52	50
Caranx crysos	395	235	960
Caranx hippos	14	16	13
Caranx latus	741	3005	64
Elagatis bipinnulata	0	74	0
Seriola dumerili	64	52	29
Seriola rivoliana	4	2	0
Selene vomer	7100	0	1356
Family Kyphosidae			
Kyphosus sectatrix	35	0	373
Family Rachycentridae			
Rachycentron canadum	5	1	1
Family Lutjanidae			
Lutjanus campechanus	17	0	0
Lutjanus griseus	435	234	367
Family Pomacentridae			
Abudefduf saxatilis	91	9	2
Chromis mutilineata	0	0	25
Stegastes fuscus	0	0	1
Stegastes partitus	0	0	7
Stegastes planifrons	0	0	2
Stegastes variabilis	0	0	6
Family Pomacanthidae			
Holacanthus bermudensis	0	0	1
Holacanthus ciliaris	0	0	1
Family Serranidae			
Epinephelus adscensionis	9	1	14
Epinephelus nigritus	1	0	0
Paranthias furcifer	43	94	56
Family Cirrhitidae			
Amblycirrhitus pinos	1	0	0
Family Chaetondontidae			
Chaetodon ocellatus	0	1	2
Family Scombridae			
Sarda sarda	0	800	221

Table 1B.9. (continued)

Species	NPI A72A Pre-Cut	NPI A72A Post-Cut	NPIA59A Control
Family Labridae			
Bodianus pulchellus	48	83	9
Bodianus rufus	1	3	5
Clepticus parrae	27	0	4
Family Blenniidae			
Hypsoblennius invemar	122	0	151
Ophioblennius atlanticus	2	1	2
Parablennius marmoreus	27	1	67
Scartella cristata	0	0	6
Family Ephippidae			
Chaetodipterus faber	3	117	373
Family Sphyraenidae			
Sphyraena barracuda	1	10	230
Family Balistidae			
Balistes capriscus	6	3	3
Family Tetraodontidae			
Canthigaster rostrata	0	0	2

NPI A72A Post-Cut Assemblages

A total of 21 pelagic and reef species representing 2 orders, 12 families, and 17 genera were observed (Table 1B.9). The dominant families (i.e. numbers of individuals) were Carangidae (jacks), 3,436 (71.5%), Scombridae (mackerel), 800 (17.0%), Lutjanidae (snappers), 243 (5.0%), and Ephippidae (spadefish), 117 (2.4%),

Of the pelagic species, the most abundant (i.e. number of individuals) species was the the horse-eye jacks, *Caranx latus*, 3,005 (79.6%), the Atlantic bonito, *Sarda sarda*, 800 (19.0%), the blue runner, *Carnax crysos*, 235 (6.0%), and the rainbow runner, *Elagatis bipinnulata*, 74 (1.7%). Of the reef fish, the gray snapper, *Lutjanus griseus*, 234 (43.0%), the Atlantic spadefish, *Chaetodipterus faber*, 117 (21.0%), the creole fish, *Paranthias furcifer*, 94 (17.0%), and the spotfin hogfish, *Bodianus pulchellus*, 83 (15.0%) were most abundant.

NPI A59A Control Assemblages

A total of 32 pelagic and reef species representing 2 orders, 14 families, and 25 genera were observed (Table 1B.9). The dominant families (i.e. numbers of individuals) were Carangidae (jacks), 2,472 (59.0%), Kyphosidae (chub), 373 (8.9%), Lutjanidae (snapper), 367 (8.7%), and Sphyraenidae (barracuda), 230 (5.4%).

Of the pelagic species, the most abundant (i.e. number of individuals) species was the lookdown, *Selene vomer*, 1,356 (50.0%), the blue runner, *Caranx crysos*, 690 (36.0%), the Atlantic bonito, *Sarda sarda*, 221 (8.2%), and the horse-eye jack, *Caranx latus*, 64 (2.4%). Of the reef fish species, the bermuda chub, *Kyphosus sectatrix*, 373 (25.0%), the gray snapper, *Lutjanus griseus*, 367 (24.5%), the great barracuda, *Sphyraena barracuda*, 230 (15.4%), and the tesselated blenny, *Hypsoblennius invemar*, 151 (10.0%).

DISCUSSION

North Padre Island A72A supported a diverse fish assemblage composed of both pelagic and reef species. Fish assemblages encountered on the pre- and post-cut survey of NPI A72A were similar to what has been found on other offshore oil platforms in the Gulf of Mexico (Hastings *et al.* 1976; Sonnier *et al.* 1976; Gallaway and Lewbel 1982; Scarborough-Bull 1987; Dokken *et al.* 1993; Bortone *et al.* 1997; and Rooker *et al.* 1997). Of the 28 fish species observed on the pre and post-cut surveys, ten species were seasonal transients, the carangids, rachycentrids, scombrids, and sphyraenids, while the others constituted resident species which consisted primarily of the lutjanids, ephippids, blenniids, and labrids.

Pre-Cut vs. Control

A total of seven pelagic species was found on the pre-cut survey representing 8,323 individuals, and eight pelagic species on the control with 2,694 individuals. Carangidae dominated pelagic surveys, 99.8% of the pre-cut survey with the lookdowns (*S. vomer*) and 99.5% without the lookdowns, and 91.8% of the control platform. The lookdowns on the pre-cut survey were present in high numbers, 7,100 out of 8,323 individuals counted. Substantial numbers of lookdowns were encountered on the control site survey (=50.0%) although not as extreme as on the pre-cut survey. As for the reef species, Lutjanidae dominated on the pre-cut survey (=51.9%) and Kyphosidae on the control survey (=25.0%).

Vertical stratification of pelagic fish on the pre-cut survey showed that at 12m depth the greatest species diversity, with six, occurred. The highest density occurred at 18m with 2,295 individuals (Table 1B.10 ; Figure 1B.13). At the control site, the greatest diversity of pelagic species was seen at 30m with the highest density at 36m with 1,220 individuals. On the control platform, 6m and 12m accounted for one species each, however, on the pre-cut survey these depths had a diverse number of species with five at 6m and six at 12m. As for the reef fish species, the vertical stratification on the pre-cut survey showed that 12m exhibited the greatest diversity with 10 species (also the same depth for the plagic species), with

the highest density at 36m with 253 individuals (Table 1B.10; Figure 1B.14). Reef fish species on the control platform exhibited the greatest diversity at 18m with 15 species and the highest density

Table 1B.10. Numbers of fish at each depth found on the pre- and post-cut survey of North Padre Island A72A and North Padre Island A59A (control).

	Total Numbers/Depth					
	6m	**12m**	**18m**	**24m**	**30m**	**36m**
PRE-CUT Pelagic:						
Caranx crysos	195	129	29	0	17	25
Caranx hippos	2	4	0	0	2	6
Caranx latus	150	440	0	150	0	1
Rachycentron canadum	0	3	1	1	0	0
Selene vomer	394	474	2235	1572	1157	1268
Seriola dumerili	3	4	28	12	11	6
Seriola rivoliana	0	0	2	2	0	0
Reef:						
Abudefduf saxatilis	14	9	2	66	0	0
Amblycirrhitus pinos	0	0	0	0	0	1
Balistes capriscus	0	0	3	3	0	0
Bodianus pulchellus	1	6	10	13	5	13
Bodianus rufus	0	1	0	0	0	0
Chaetodipterus faber	1	0	0	1	0	1
Clepticus parrae	0	20	0	0	0	0
Epinephelus adscensionis	0	0	1	8	0	0
Epinephelus nigritus	0	0	0	0	0	1
Hypsoblennius invemar	77	38	0	0	4	3
Kyphosus sectatrix	17	12	4	0	2	0
Lutjanus campechanus	0	1	12	1	0	3
Lutjanus griseus	0	24	3	12	94	224
Ophioblennius atlanticus	0	0	1	0	0	1
Parablennius marmoreus	7	11	2	1	2	0
Paranthias furcifer	0	0	0	25	12	6
Sphyraena barracuda	0	1	0	0	0	0
POST-CUT Pelagic:						
Alectis ciliaris	0	0	10	15	8	19
Caranx crysos	32	0	53	104	25	21
Caranx hippos	0	4	0	12	0	0
Caranx latus	90	258	1263	379	756	259
Elagatis bipinnulata	7	0	43	0	16	8
Rachycentron canadum	0	0	0	1	0	0
Sarda sarda	90	0	394	314	0	2
Seriola dumerili	0	0	8	26	1	17
Seriola rivoliana	0	0	0	2	0	0
Reef:						
Abudefduf saxatilis	0	0	0	0	0	9
Balistes capriscus	0	0	0	1	0	2
Bodianus pulchellus	0	0	0	2	2	79
Bodianus rufus	0	0	0	0	0	75

Table 1B.10. (continued)

	Total Numbers/Depth					
	6m	12m	18m	24m	30m	36m
Chaetodipterus faber	0	27	63	26	0	1
Chaetodon ocellatus	0	0	0	0	0	1
Epinephelus adscensionis	0	0	0	0	0	1
Lutjanus griseus	0	0	11	112	2	118
Ophioblennius atlanticus	0	0	0	0	0	1
Parablennius marmoreus	0	0	0	0	0	1
Paranthias furcifer	0	0	0	73	0	21
Sphyraena barracuda	3	5	0	2	0	0
CONTROL Pelagic:						
Alectis ciliaris	0	0	41	0	4	5
Caranx crysos	0	8	214	141	357	240
Caranx hippos	0	0	0	13	0	0
Caranx latus	0	0	62	0	2	0
Rachycentron canadum	0	0	0	0	1	0
Sarda sarda	76	0	0	0	145	0
Selene vomer	0	0	100	0	308	948
Seriola dumerili	0	0	1	1	0	27
Reef:						
Abudefduf saxatilis	14	2	5	0	0	0
Balistes capriscus	1	0	0	0	2	0
Bodianus pulchellus	0	0	2	0	5	1
Bodianus rufus	2	0	3	0	0	0
Canthigaster rostrata	0	1	1	0	0	0
Chaetodipterus faber	0	22	115	0	1	0
Chaetodon ocellatus	0	0	2	0	0	0
Chromis multilineata	12	13	0	0	0	0
Clepticus parrae	0	1	0	0	1	3
Epinephelus adscensionis	1	6	2	0	2	2
Holacanthus bermudensis	0	0	0	0	0	1
Holacanthus ciliaris	0	0	0	0	1	0
Hypsoblennius invemar	69	57	22	2	0	1
Kyphosus sectatrix	79	230	13	0	51	0
Lutjanus griseus	101	26	51	24	149	16
Ophioblennius atlanticus	1	0	0	1	0	0
Parablennius marmoreus	16	13	28	7	1	2
Paranthias furcifer	7	14	27	0	7	3
Scartella cristata	0	0	0	6	0	0
Sphyraena barracuda	172	35	15	7	0	1
Stegastes fuscus	0	1	0	0	0	0
Stegastes partitus	0	0	3	0	2	2
Stegastes planifrons	0	2	0	0	0	0
Stegastes variabilis	3	3	1	0	0	0

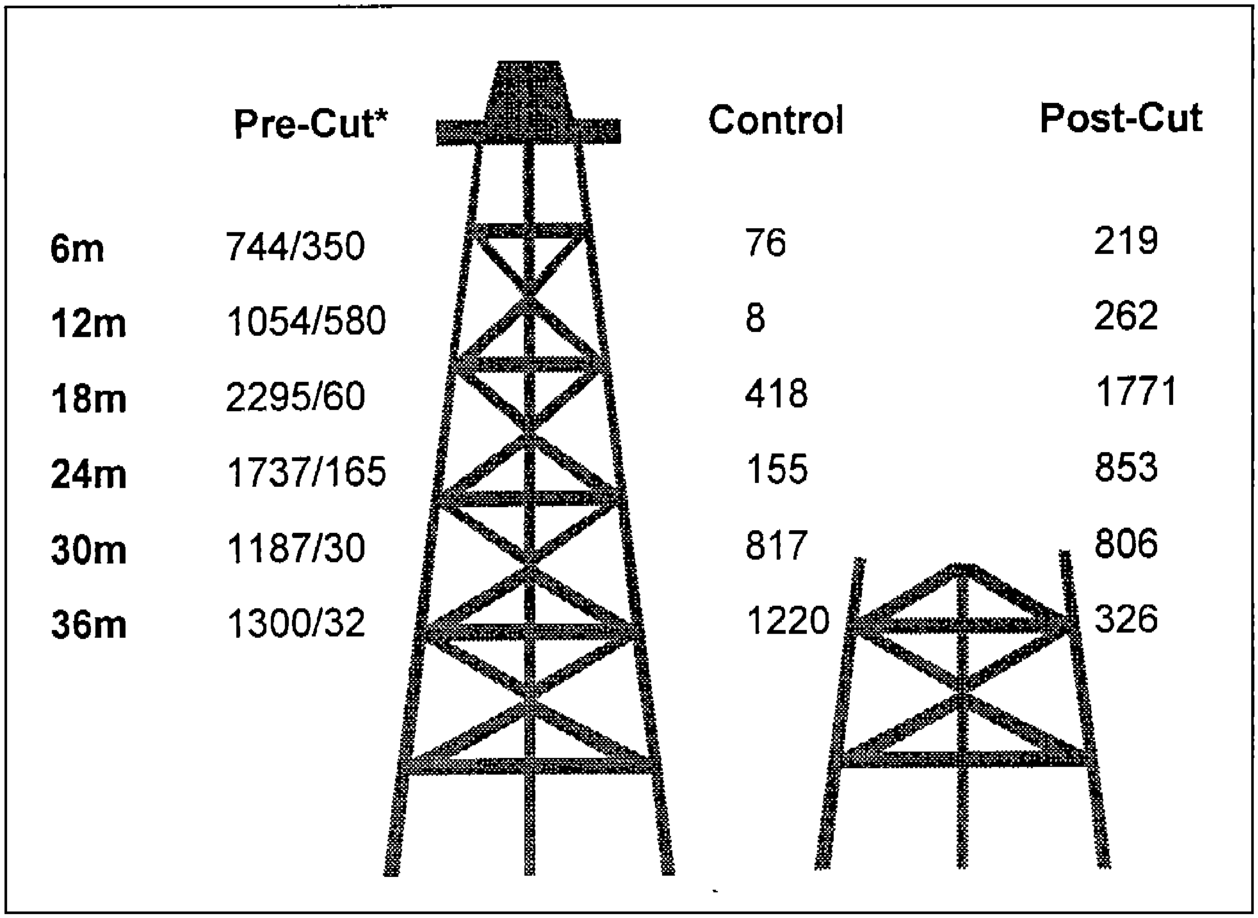

Figure 1B.13. Vertical stratification (total numbers at each depth) of pelagic fish species (*Pre-Cut: with lookdowns/without lookdowns).

at 6m with 479 individuals. The control platform had the greatest numbers of species and individuals above 18m. The control platform had greater diversity with 24 species, whereas, the pre-cut platform had 17 species.

Post-Cut vs. Control

A total of nine pelagic species were observed on the post-cut survey representing 4,237 individuals, and eight pelagic species on the control with 2,694 individuals. Carangidae dominated pelagic surveys, 79.6% of the post-cut survey and 91.8% of the control platform. As for the reef species, a total of 12 species and 564 individuals was found on the post-cut platform with Lutjanidae representing the dominant family (=43.0%), and 24 species representing 1,491 individuals with Kyphosidae dominating on the control survey (=25.0%).

Vertical stratification of pelagic fish on the post-cut survey showed that 24m exhibited the greatest diversity with eight species and the highest density at 18m with 1,771 individuals (Table 1B.10; Figure 1B.12). As for the control platform, the greatest diversity was at 30m with the highest density

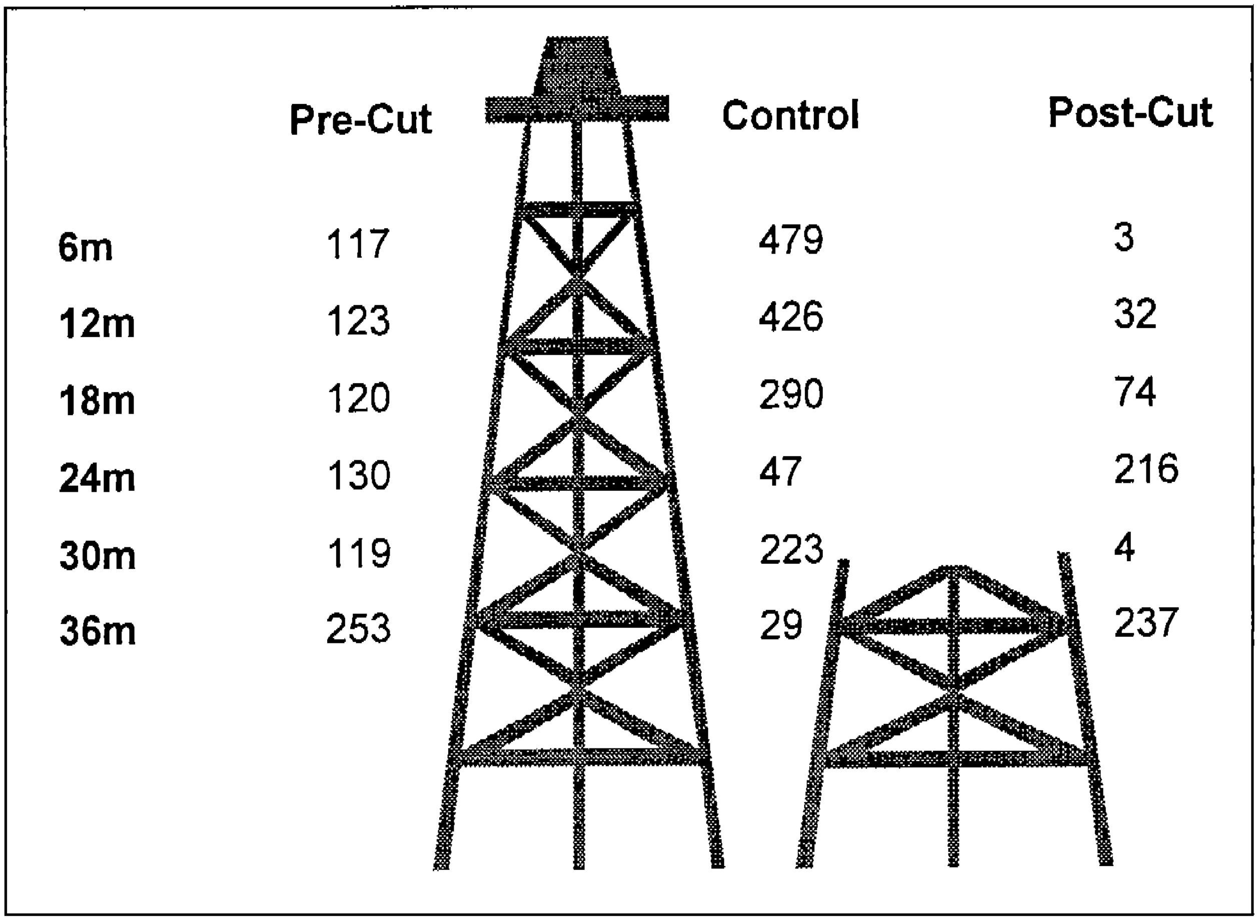

Figure 1B.14. Vertical stratification (total numbers at each depth) of reef fish species.

at 36m with 1,220 individuals. The highest numbers of pelagic fish were observed swimming above the structure between 18m-24m.

As for the reef fish species, the vertical stratification on the post-cut survey showed that 36m exhibited the greatest diversity with 11 species and the highest density at 36m with 237 individuals (Table 1B.10; Figure 1B.13). Reef fish species on the control platform exhibited the greatest diversity at 18m with 15 species and the highest density at 6m with 479 individuals. The control platform had a more diverse reef fish community with 24 species, whereas, the post-cut platform had 12 species. The reduction of reef fish species seen on the post-cut survey can be attributed to the lack of structure above 30m. There appears to have been a downward shift in reef fish with the removal of the structure. The majority of reef species were seen at 24m with 216 individuals and 36m with 237 individuals with 30m (4 individuals) appearing to be a transition zone.

Pre-Cut vs. Post-Cut

The number of pelagic species remained similar, although there were no lookdowns (*S. vomer*) encountered on the post-cut structure. Being that pelagic fishes are transient species, their diversities and densities will likely change throughout the year. Horse-eye jacks (*C. latus*) were found in high numbers on both the pre-cut survey (=8.9%) and post-cut survey (=70.9%).

With the removal of the structure above 30m, changes occurred in the reef fish community between the pre-cut survey and post-cut survey (Figure 1B.13). Densities and diversities were reduced on the post-cut survey. Very few reef species were seen above 18m, the majority of these were the great barracuda (*S. barracuda*) and the Atlantic spadefish (*C. faber*). A downward shift in depth was observed, the majority occuring at 24m with six species and 216 individuals and at 36m with 11 species and 237 individuals. The greatest difference could be seen with the spotfin hogfish (*B. pulchellus*) with only 13 individuals enumerated on the pre-cut survey and 79 on the post-cut survey. Gray snapper (*L. griseus*) was found at the greatest densities at 36m on the pre-cut survey; however, no gray snapper were found at 36m on the post-cut, although 112 individuals were counted at 24m. Reef fish were observed swimming above the structure at 24m just as the pelagic fishes were observed.

CONCLUSION

The NPI A72A platform, before and after partial mechanical removal, supported a diverse population of both pelagic and reef fish species. Changes in zonation occurred. Results from this study may provide a useful basis from which to evaluate other oil platform and artificial reef research. Long-term monitoring of the NPI A72A artificial reef and NPI A59A (control) over a range of variables is necessary in order to conclusively describe the dynamics of this reef ecosystem. This is a work in progress and more surveys are planned for NPI A72A and NPI A59A (control).

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SESSION 1C

ATMOSPHERIC SCIENCES SESSION

Co-Chairs: Dr. Alexis Lugo-Fernández and Ms. Terry Scholten

Date: December 8, 1998

Presentation	Author/Affiliation
Comparison of 1-Hour and 8-Hour Ozone Impact Calculations for Gulf of Mexico OCS Activities	Mr. Dirk C. Herkhof Mr. Charles F. Marshall U.S. Department of the Interior Minerals Management Service Herndon, VA
Intercomparison of Air Pollutant Dispersion Models	Dr. Mark E. Fernau Mr. Joseph C. Chang Mr. Joseph S. Scire Mr. David G. Strimaitis Earth Tech, Inc. Concord, MA
Project Status Report: Emissions Inventories of OCS Production and Development Activities in the Gulf of Mexico	Mr. Lyle R. Chinkin Sonoma Technology, Inc.
Dispersion Meteorology Over The Breton National Wildlife Area (BNWA)	Dr. S.A. Hsu Louisiana State University
The Breton Air Quality Study/Breton Aerometric Monitoring Program	Dr. Stephen D. Ziman Chevron Research and Technology Company Richmond, California
Boundary Layer Study in the Western and Central Gulf of Mexico	Dr. Paul T. Roberts Mr. Timothy S. Dye Sonoma Technology, Inc. Dr. Steven R. Hanna Consulting Meteorologist

COMPARISON OF 1-HOUR AND 8-HOUR OZONE IMPACT CALCULATIONS FOR GULF OF MEXICO OCS ACTIVITIES

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EXECUTIVE SUMMARY

Modeling output from the Gulf of Mexico Air Quality Study (GMAQS) was used to evaluate OCS impacts relative to the new 8-hour average ozone standard. Model results were available for the 17-20 August and the 6-11 September 1993 ozone episodes using year 1993 emissions data. In the Southeast Texas model domain, the highest OCS contribution to the daily maximum 8-hour average ozone value at those locations on shore where the predicted values exceeded 85 ppb was less than 1% of the total concentration in the August episode, and about 6% of the total concentration in the September episode. Impacts over the offshore waters in the Gulf of Mexico were slightly larger. In the Louisiana model domain, the highest OCS contribution to the daily maximum 8-hour average ozone value at those locations on shore where the predicted values exceeded 85 ppb was about 5% of the total concentration in both the August and September episodes.

This study showed that the effects of OCS emissions relative to the new 8-hour standard are larger than those relative to the former 1-hour standard. The area of impact on any particular day tended to be rather limited. An analysis of the wind field indicated that recirculation and offshore pooling of ozone tended to play a major role in generating OCS impacts onshore. It was concluded that there is clearly a need to conduct additional work to evaluate OCS impacts relative to the new 8-hour standard.

INTRODUCTION

On 18 July 1997 the Environmental Protection Agency (EPA) promulgated a new ambient air quality standard for ozone (*Federal Register* 1997). The existing ambient standard was 0.12 parts per million (ppm) for the maximum 1-hour average. The standard allows less than one day per year, based on three years of continuous data, when the maximum 1-hour ozone concentration may exceed 0.12 ppm. The revised primary standard is based on an 8-hour average ozone value of 0.08 ppm. The annual fourth-highest daily 8-hour average ozone concentration averaged over three years cannot exceed 0.08 ppm. In the year 2000, the States are required to determine which areas do not meet the new 8-hour standard based on three years of data (1997-1999). Current monitoring data indicate that a number of areas that presently meet the 1-hour standard will not meet the new 8-hour standard.

The Minerals Management Service (MMS) conducted a study, the Gulf of Mexico Air Quality Study—GMAQS), to determine the impacts of OCS emissions in the Gulf of Mexico on adjacent onshore areas in Texas and Louisiana relative to the 1-hour ozone standard (MMS 1995). It was determined from this study that the effect of OCS emissions on ozone was small. With the upcoming implementation of the 8-hour ozone standard, it will be important to know what the OCS impacts are likely to be, relative to this new standard. The objective of this paper is not to present with any certainty the expected magnitude of these impacts. Rather, it is to provide a qualitative measure of how the OCS impacts may be affected by the longer averaging time and lower threshold associated with the new standard. It also describes the atmospheric processes that may be important in characterizing the 8-hour average impacts.

SUMMARY OF OCS CONTRIBUTIONS TO 1-HOUR AVERAGE OZONE CONCENTRATIONS

The GMAQS applied the UAM-V model for two multi-day ozone episodes, 17-20 August and 6-11 September 1993. OCS impacts were determined by running two emission scenarios, one that included all onshore emissions and another that had OCS-petroleum-related emissions subtracted out. The overall model domain extended from South Texas to the Florida Panhandle and utilized 72 by 62 grid cells with 16 km grid spacing. A more refined sub-domain was used for Southeast Texas that consisted of 62 by 55 grid points with 4 km grid spacing. The maximum daily 1-hour average ozone concentration was determined for each grid cell. The OCS contributions were determined for each grid point by subtracting one model run from the other. Table 1C.1 presents the GMAQS for two subareas, Southeast Texas and Louisiana (with the latter also including the Mississippi coastal area).

Southeast Texas

In the 17-20 August episode, the highest simulated 1-hour average ozone concentrations occurred over the Houston metropolitan area to the northwest of Galveston Bay. The highest calculated daily maximum ozone values were well above 125 ppb on all episode days and reached 223 ppb on 19 August. The highest OCS contribution to the daily maximum value was 7.5 ppb at a location about

Table 1C.1. Maximum Predicted OCS Contributions to the Daily Maximum 1-Hour Average Ozone Concentration, 1993 Emissions.

	Highest OCS Contribution, ppb, at Locations Where O_3 Concentrations Exceed 125 ppb	
	Over Water	**Over Land**
Southeast Texas		
August Episode	NA[1]	0.4 (<1%)
September Episode	6.6 (4%)	3.2 (2%)
Louisiana		
August Episode	NA[1]	0.5 (<1%)
September Episode	2.9 (2%)	2.1 (1.5%)

[1] NA indicated not applicable. No value exceeds 125 ppb.

100 km from shore and where the total ozone concentration was about 50 ppb. At those grid points where the daily maximum 1-hour ozone value exceeded 125 ppb, the highest OCS contribution was only 0.4 ppb, which is less than 0.5% of the total concentration at that point. This occurred over land; there were no points over water where the ozone concentration exceeded 125 ppb.

In the 6-11 September episode, the highest 1-hour average ozone concentrations occurred over Galveston Bay and adjacent coastal areas. High ozone concentrations were found near the coast and extending some distance offshore. The highest simulated daily maximum 1-hour ozone values exceeded 125 ppb on all episode day, except one, and reached 234 ppb on 9 September. The highest OCS contribution to the daily maximum value was 15 ppb at a location well offshore and where the total concentration was about 80 ppb. At those grid points where the daily maximum value exceeded 125 ppb, the highest OCS contribution was 6.6 ppb, which is about 4% of the total concentration. If one considers grid points on land only, the highest OCS contribution was 3.2 ppb, or about 2% of the total concentration.

Louisiana

In the 17-20 August episode, the highest simulated 1-hour average ozone concentrations occurred over the Baton Rouge area. The highest daily maximum 1-hour ozone values exceeded 125 ppb on the last 2 days of the episode and reached 140 ppb on 20 August. The highest OCS contribution to the daily maximum 1-hour ozone concentration was 30 ppb at a location about 80 km offshore central Louisiana. The total ozone concentration at that point was about 70 ppb. At those points where the total concentration exceeded 125 ppb, the highest OCS contribution was 0.5 ppb, which was less than 0.5% of the total concentration. This occurred in the Baton Rouge area.

In the 6-11 September episode, the highest simulated ozone concentrations generally occurred over southwestern Louisiana area. The highest daily maximum 1-hour ozone values exceeded 125 ppb on only 1 day, 10 September, with a highest value of 181 ppb. The highest OCS contribution to the daily maximum 1-hour ozone concentration was 22 ppb at a location well offshore southwestern Louisiana. At those grid points where the daily maximum value exceeded 125 ppb, the highest OCS contribution was 2.9 ppb, which is about 2% of the total concentration. This value also occurred just offshore southwestern Louisiana. If one considers grid points on land only, the highest OCS contribution was 2.1 ppb, or about 1.5% of the total concentration.

SUMMARY OF OCS CONTRIBUTIONS TO THE 8-HOUR AVERAGE OZONE CONCENTRATIONS

Running 8-hour average ozone concentrations were calculated from the model output for the two episodes for each grid point in the Southeast Texas and Louisiana model subdomains. The daily maximum 8-hour average ozone concentration was determined for each grid point. The OCS contributions to the daily maximum value were calculated by subtracting the model output without OCS petroleum-related emissions from the model output with the OCS petroleum-related emissions. Highest OCS contributions were determined for each day for those grid points where the daily maximum ozone concentration exceeded 85 ppb. This provides a measure of the relative importance

Table 1C.2. Maximum Predicted OCS Contributions to the Daily Maximum 8-Hour Average Ozone Concentration, 1993 Emissions.

	Highest OCS Contribution, ppb, at Locations Where O_3 Concentrations Exceed 85 ppb	
	Over Water	Over Land
Southeast Texas		
August Episode	NA[1]	0.6 (<1%)
September Episode	11 (12%)	5.5 (6%)
Louisiana		
August Episode	15 (18%)	4.4 (5%)
September Episode	18 (20%)	4.7 (5%)

[1] NA indicated not applicable. No value exceeds 85 ppb.

of OCS emissions in any potential exceedances of the 8-hour ozone standard. Table 1C.2 summarizes the highest OCS contributions for the two episodes.

Southeast Texas

In the 17-20 August 1993 episode, the highest 8-hour average ozone concentrations occurred over the Houston metropolitan area to the northwest of Galveston Bay. The highest simulated daily maximum ozone values exceeded 85 ppb on all four episode days and reached a highest value of 111 ppb on 19 August. The highest OCS contribution to the daily maximum value was 7.3 ppb at a location about 50 km from shore and where the total ozone concentration was less than 50 ppb. At those grid points where the daily maximum ozone value exceeded 85 ppb, the highest OCS contribution was only 0.6 ppb, which is less than 1% of the total concentration. This occurrence was over land; there were no points over water where the ozone concentration exceeded 85 ppb.

In the 6-11 September 1993, episode, the highest 8-hour average ozone concentrations occurred over Galveston Bay and adjacent coastal areas. High ozone concentrations were found near the coast and extending some distance offshore. The highest daily maximum ozone values were well over 85 ppb on all episode days and reached 203 ppb on 9 September. The highest OCS contribution to the daily maximum value on 11 September was 16 ppb at a location about 50 km from shore and where the total concentration was a little less than 80 ppb. At those grid points where the daily maximum value exceeded 85 ppb, the highest OCS contribution was 11 ppb, which is about 12 percent of the total concentration. If one considers grid points on land only, the highest OCS contribution was 5.5 ppb. The total concentration at that location was 86 ppb, so the OCS contribution is about 6 percent of the total concentration. Figure 1C.1 illustrates the location and magnitude of the OCS contributions along with the geographic extent of the area where the total concentrations exceeded 85 ppb.

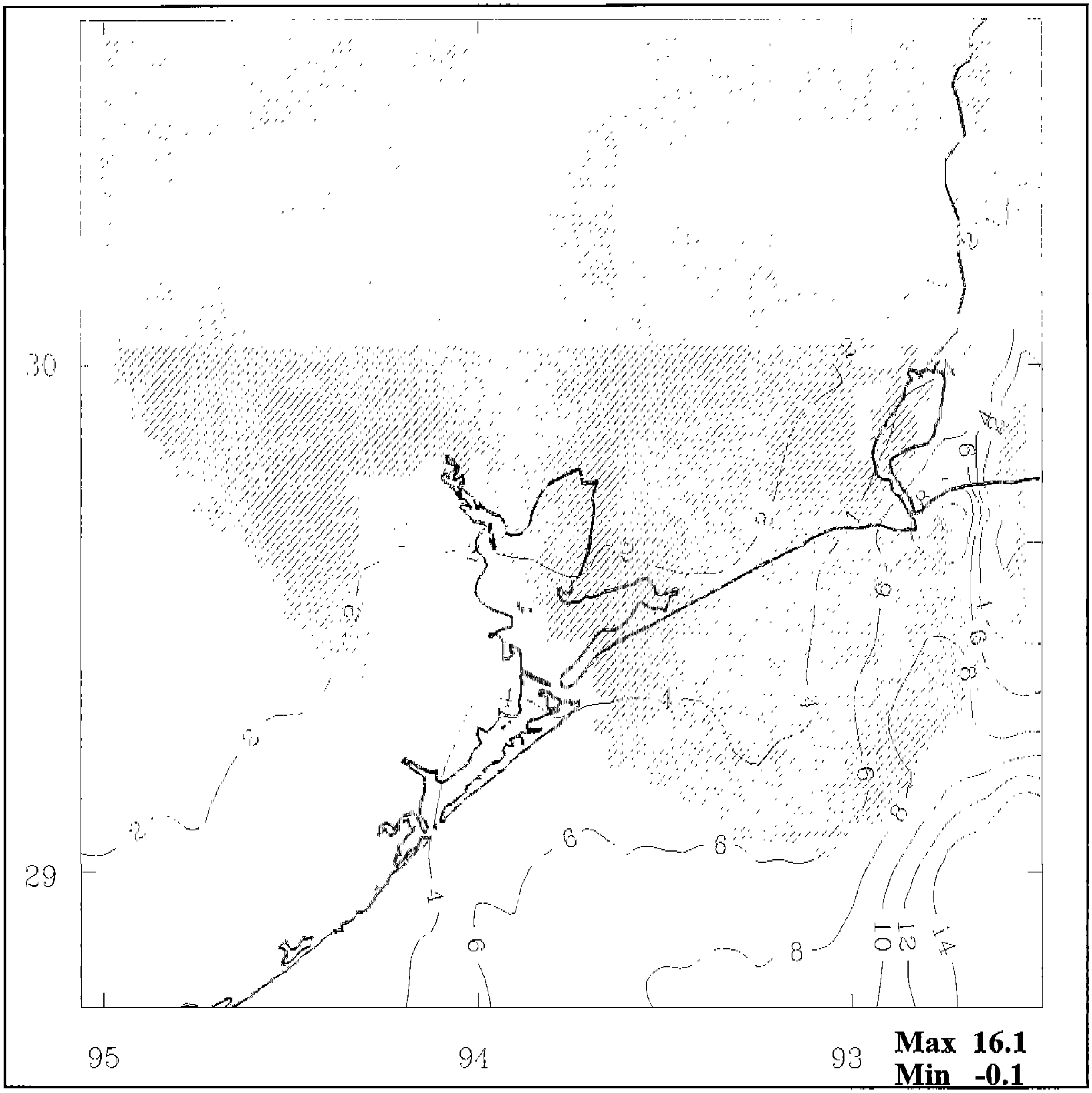

Figure 1C.1. Texas, 11 September—OCS Contribution.

Louisiana

In the 17-20 August episode, the highest ozone concentrations occurred over the Baton Rouge area. The highest daily maximum 8-hour ozone values exceeded 85 ppb on all episode days and reached 119 ppb on 19 August. The highest OCS contribution to the daily maximum 8-hour ozone concentration was 28 ppb at a location about 70 km offshore central Louisiana. The total ozone concentration at that point was about 70 ppb. At those grid points where the daily maximum value exceeded 85 ppb, the highest OCS contribution was 15 ppb, which was about 18 percent of the total concentration. This value occurred offshore east of the tip of the Mississippi Delta. If one considers grid points on land only, the highest OCS contribution was 4.4 ppb. The total concentration at that location was 85.4 ppb, so the OCS contribution was about 5% of the total concentration. This contribution occurred on 19 August in the Mississippi Delta.

In the 6-11 September episode, the highest ozone concentrations generally occurred over southwestern Louisiana area. The highest daily maximum 8-hour ozone values exceeded 85 ppb on all except the first two days of the episode; the highest value was 155 ppb on 10 September. The highest OCS contribution to the daily maximum 8-hour ozone concentration was 22 ppb at a location well offshore southwestern Louisiana. The total ozone concentration at that point was about 80 ppb. At those grid points where the daily maximum value exceeded 85 ppb, the highest OCS contribution was 18 ppb, which was about 20% of the total concentration. This value also occurred well offshore southern Louisiana. If one considers grid points on land only, the highest OCS contribution was 4.7 ppb. The total concentration at that location was 92 ppb, so the OCS contribution was about 5% of the total concentration. This contribution occurred on 11 September, just inland of the south-central Louisiana coastline.

COMPARISON BETWEEN 1-HOUR AND 8-HOUR IMPACTS

Table 1C.3 compares the impacts based on the old 1-hour standard with those relative to the new 8-hour standard. It shows that for the August episode in Southeast Texas, there were negligible impacts relative to both the 1-hour and the 8-hour ozone standard. In the September episode, however, the highest OCS contribution relative to the 8-hour standard was 5.5 ppb, while it was 3.2 ppb relative to the 1-hour standard. For Louisiana, discernable differences are seen for both episodes. In the August episode, the highest OCS contribution relative to the 8-hour standard was 4.4 ppb, while it was only 0.5 ppb relative to the 1-hour standard. In the September episode, the highest 8-hour OCS contribution was 4.7 ppb, compared with a maximum 1-hour OCS contribution of 2.1 ppb.

SPATIAL AND TEMPORAL CHARACTERISTICS OF OCS CONTRIBUTIONS

The new 8-hour ozone standard is more stringent than the old 1-hour standard. It is, therefore, not surprising that the modeling simulations show that the size of the area where the 8-hour, 85-ppb threshold is exceeded is significantly larger than that of the area where the 1-hour, 125-ppb threshold is exceeded. This is true especially for Louisiana. Furthermore, there are more areas near the shoreline where the model simulates ozone concentrations that are greater than 85 ppb, as compared to the case where we consider 125 ppb as the threshold. Nevertheless, there is little overlap between areas that have high OCS contributions and areas where the total concentration from all sources exceed the 85-ppb threshold (See Fig. 1). Total concentrations are small in areas offshore, where OCS contributions are greatest. In areas where total concentrations are largest, the OCS contributions are small. There are relatively small areas where total concentrations exceed 85 ppb and where, at the same time, there is some OCS contribution. As shown above, the highest calculated OCS contribution for any onshore location where the 8-hour ozone level exceeds 85 ppb is 5.5 ppb, or 6 percent of the total concentration. This occurred in the Southeast Texas subdomain on 11 September.

Table 1C.3. Comparison of 8-Hour and 1-Hour OCS Contributions to Daily Maximum Ozone Concentrations.

	Highest OCS Contribution to Daily Maximum Ozone	
	Over Water	Over Land
Southeast Texas		
August Episode		
8-Hr O_3 > 85 ppb	NA[1]	0.6 (<1%)
1-Hr O_3 > 125 ppb	NA[1]	0.4 (<1%)
September Episode		
8-Hr O_3 > 85 ppb	11 (12%)	5.5 (6%)
1-Hr O_3 > 125 ppb	6.6 (4%)	3.2 (2%)
Louisiana		
August Episode		
8-Hr O_3 > 85 ppb	15 (18%)	4.4 (5%)
1-Hr O_3 > 125 ppb	NA[1]	0.5 (<1%)
September Episode		
8-Hr O_3 > 85 ppb	18 (20%)	4.7 (5%)
1-Hr O_3 > 125 ppb	2.9 (2%)	2.1 (1.5%)

[1] NA indicated not applicable. No value exceeds the applicable threshold level.

To illustrate temporal characteristics, Figure 1C.2 shows a time series plot of the 1-hour average ozone concentrations for same the grid cell. It shows that the peak 1-hour average concentration is only about 90 ppb, well below the 1-hour standard of 125 ppb.

The OCS contribution to the peak value is only 2.0 ppb. After the peak is reached for the day, the concentrations without OCS contribution drop off at a faster rate than those with OCS sources included. The OCS contribution continues to rise through the afternoon hours and reaches a peak of 13.5 ppb at 1800 local time (LT).

Figure 1C.3 shows the time series of the 8-hour running average concentration for 11 September at the grid cell 54, 27 in the Texas subdomain (near Sabine Pass). The time shown in the figure is the starting time of the running average. For example, the concentration for 1200 LT is the average of the hours from 1200 through 1900 LT. The plot shows that, for the model run with the OCS emissions, the peak 8-hour ozone concentration is just slightly above 85 ppb, while for the simulation without OCS emissions, the peak is only about 80 ppb. When the OCS emissions are included, there is about a 2-hour delay in the time that the peak is reached. The OCS contributions keep increasing slowly with time, even as total concentrations decline and reach a peak of 11.4 ppb at 1500 LT.

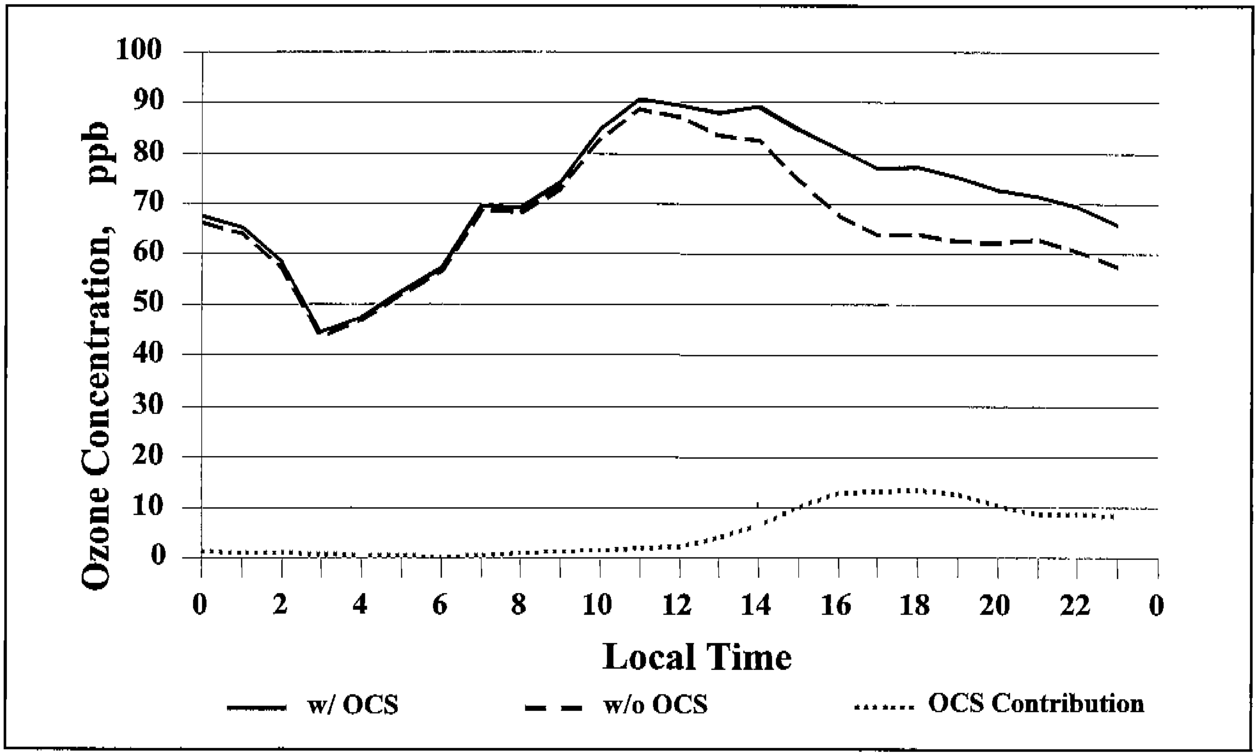

Figure 1C.2. 1-Hour Average Ozone, 11 September 1993—Grid Cell 52,27.

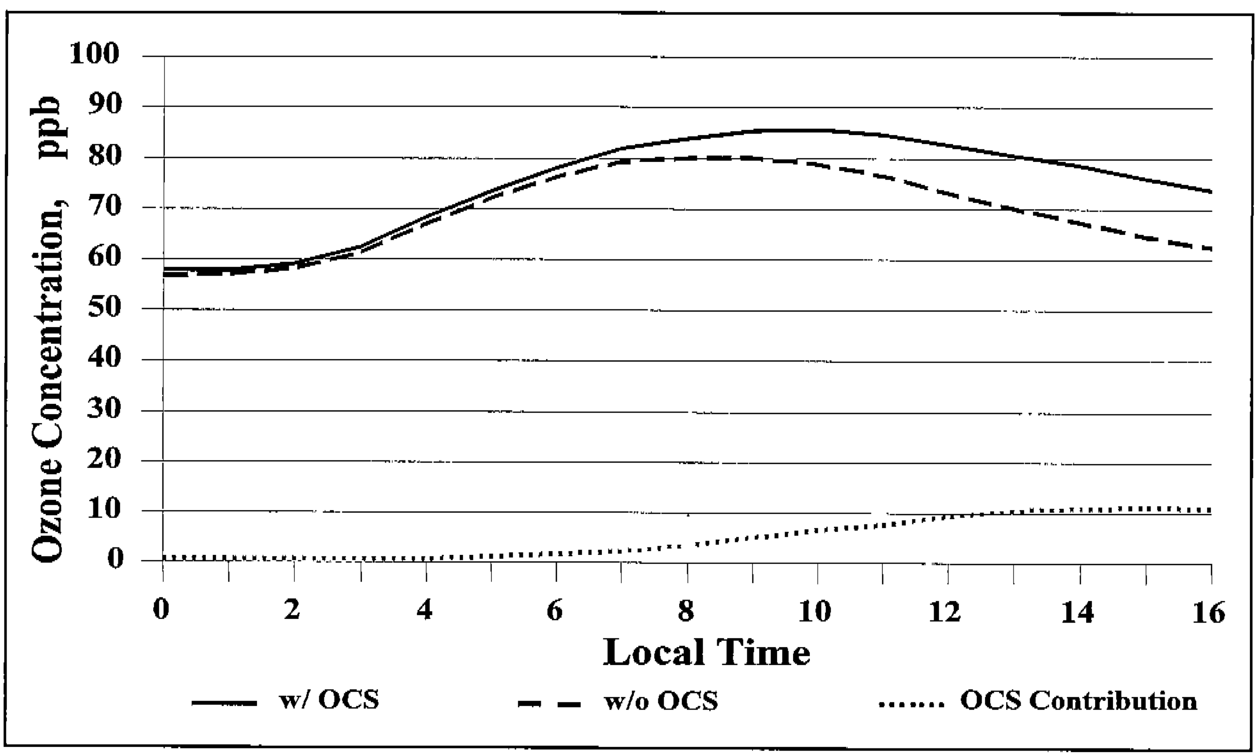

Figure 1C.3. 8-Hour Average Ozone, 11 September 1993—Grid Cell 52,27.

MECHANISMS AFFECTING OCS CONTRIBUTIONS

The dominating influence in onshore OCS contributions to ozone levels in the study region is that of recirculation and offshore pooling of ozone and ozone precursors. During ozone episodes in the Gulf coast region, prevailing winds are very light, and the atmosphere is stable. Local wind circulations induced by differential heating over land and water are dominant. These features are most pronounced over coastal Texas, and a little less so over Louisiana. The land breeze establishes itself after midnight. It starts weakening after sunrise, and winds become light and variable by late morning or noon. The sea breeze starts shortly after noon and gains strength throughout the afternoon; it normally lasts through the evening.

Ozone precursors from onshore sources are carried offshore in the morning land breeze. These emissions start to interact as solar radiation increases through the day and generate ozone. Additional ozone may be formed by interaction with OCS sources. The ozone is then recirculated onshore with the afternoon land breeze. However, when the sea breeze is strong, as in the August episode for Southeast Texas, the pollutant mass is centered some distance inland, and OCS contribution is minimal.

The September episode for Southeast Texas was different. A series of weak cold fronts from the north kept the daily sea breeze from penetrating very far inland. Ozone levels built up near shore and some distance offshore, allowing an opportunity for already polluted air masses to spend time over the Gulf entraining OCS emissions. When the air mass was finally circulated back to shore on the last days of the episode, the model simulated OCS contributions when ozone levels exceeded 85 ppb.

Examining again the peak OCS contribution at grid point 54, 27 on 11 September, the observed surface wind data at a nearby monitoring station revealed that winds were offshore from about midnight till about 1100 LT, at which time the winds shifted to southeasterly and then southerly directions, which then lasted through midnight. A trajectory analysis (not shown) indicated that precursor emissions from the OCS had been picked up off Southwestern Louisiana on that same day as well as on the previous day. This particular OCS area has a fairly high density of emissions.

Time series plots (not shown) for points some distance from shore off Southeast Texas showed a steady buildup of ozone from the background concentrations of 40 ppb to a level of about 85 ppb over several days. Most of this buildup was from onshore ozone precursors. OCS contributions were about 10 to 15 ppb. It should be noted that OCS contributions by themselves are never enough to cause the concentration to exceed the 85 ppb threshold. It takes a combination of onshore and OCS emissions to have concentrations exceed the new standard. When the pollution mass that had been pooling offshore eventually reached shore with the sea breeze, it caused the 85-ppb threshold to be exceeded, with part of the concentration being attributed to OCS emissions.

The same mechanism of recirculation and pooling was evident in Louisiana. However, the flow had more of an east-west component, and trajectories followed a less direct path. Onshore impacts from OCS emissions were attributed to OCS emissions picked up the day before rather than the same day.

DISCUSSION OF CAVEATS

A number of different factors make it possible for us to interpret the results only qualitatively. First, the emissions used in the UAM-V modeling are for the year 1993. Emissions for the year 2000 baseline will be different. Furthermore, one would need to consider projected emissions beyond the year 2000 if the modeling results are to be applied to any future control strategies to be developed in the year 2003. Second, the episodes that were used in the analysis were selected based on the old 1-hour ozone standards. If one were to base ozone modeling on the 8-hour standard, the suite of episodes available for analysis would likely be different.

Third, there are uncertainties in the calculated OCS impacts. These impacts were determined by taking the difference between two sets of model runs, both of which are subject to errors. These errors may be magnified by subtracting one data set from another. Since the calculated OCS impacts are small relative to the total contribution from all sources, the magnitude of these impacts is subject to uncertainties. Finally, one must not place too much confidence in the location of predicted impacts. Variations in the wind field used can significantly influence the location of predicted maxima.

CONCLUSION

This study showed that the effects of OCS emissions relative to the new 8-hour standard are larger than those relative to the former 1-hour standard. The largest OCS contributions tended to be at those locations where the predicted concentrations were just above 85 ppb. The area of impact on any particular day tends to be rather small. An analysis of the wind field indicated that recirculation and offshore pooling tended to play a major role in generating any OCS impacts onshore.

There is clearly a need to conduct additional work to evaluate OCS impacts on the new 8-hour standard. This would involve (1) updating the emission inventory for the OCS in the Gulf of Mexico, (2) determining appropriate episodes for modeling ozone relative to the 8-hour standard, (3) conducting modeling analyses to quantify OCS impacts, and (4) developing criteria for determining significance of OCS impacts (perhaps the most challenging task).

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INTERCOMPARISON OF AIR POLLUTANT DISPERSION MODELS

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The Minerals Management Service (MMS) uses different types of air dispersion models to perform tasks such as environmental impact studies and regulatory analyses to regulate the activities of offshore operators. The MMS would like to expand the current suite of air quality models used to ensure that MMS' model selections are scientifically credible and can withstand possible critiques, a critical review of the following four types of air quality models is necessary:

- Regional-scale dispersion models for applications where phenomena such as advection, deposition, and potential chemical transformations of pollutants are important on a spatial scale up to 1,000 km. Eulerian photochemical grid models might be best for this purpose.

- Lagrangian trajectory (puff) models for instantaneous and short-duration emissions, or for releases when spatially-varying meteorological fields are important.

- Toxic release models for analysis of consequences of accidental releases of hazardous pollutants.

- Steady-state Gaussian models for general review of offshore operator's plan when the source-receptor distance is less than 50 km or so.

Based on MMS' needs, we considered the following six major model evaluation categories, where some of the categories were further divided into a number of subcategories or attributes:

- Science and Credibility
  A1. Technical and general descriptions
  A2. Grid options for Eulerian and trajectory models
  A3. Quality of physical processes simulated
  A4. Sparse data treatment
  A5. Overwater dispersion
  A6. Model evaluation history

- Ease of Use (From User's Perspective)
  B1. User's guide
  B2. Model Options
  B3. Data preparation time

B4. Ease of data acquisition
B5. Model interfaces to preprocessors / GUI
B6. Run-time diagnostics
B7. Post-run diagnostics

- Computational Requirements
  C1. Multiple sources
  C2. UNIX / PC portability
  C3. Run time
  C4. Code flexibility and readability

- Cost

- Availability / Restrictions / Terms

- Language for Model and GUI

Only Categories A, B, and C were used to rank the models, where a score from 1 to 3 was assigned to each attribute. 3=good, very flexible or state-of-the-art; 2=fair, less flexible, or somewhat out of date; and 1=poor or not flexible. Categories D, E, and F are for information only. To account for varying degree of importance, we further assigned a weight to the score for each attribute. The attributes for Categories A and B have a weight of 2; the attributes for Category C have a weight of 1. We then designed a normalized model score (0 to 100%) based on the summation of weighted scores over all applicable attributes divided by the summation of weighted highest possible scores over all applicable attributes. This normalized score was then used to produce the final model ranking.

The current review is not intended to be comprehensive. Instead, four to seven "representative" models in each model category (except for steady-state Gaussian models, see below) were chosen for review, and the top two to three in each category are then recommended. The omission of a model does not mean in any way that the model is inferior or less desirable. For steady-state Gaussian models, we limited our review to the technical components in the Offshore and Coastal Dispersion (OCD) model, which has been a regulatory model used by the MMS.

The evaluation mainly consisted of reviews of the user's guide, technical documentation, peer-reviewed journal articles, conference proceedings, web pages, and the source code for each model. Model developers and users were interviewed if necessary. This study is not a formal performance evaluation, where the model results are compared against field data.

The following list gives the models that were chosen for evaluation along with the scores that they received in the review:

- Regional-scale dispersion models:
  CALGRID 74.4% ←
  CAMx 74.4% ←

SAQM	60.0%
UAM-IV	57.8%
UAM-V	83.3% ←

- Lagrangian trajectory models:

CALPUFF	93.3% ←
HYSPLIT_4	88.3% ←
INPUFF	63.5%
MESOPUFF II	77.8%
SLAM	77.6%

- Toxic release models:

AFTOX	66.7%
ARCHIE	79.4%
CANARY	84.1% ←
DEGADIS	81.8%
HGSYSTEM	87.9% ←
SLAB	86.7% ←
TSCREEN	68.9%
BREEZE HAZ SUITE (GUI only)	93.3% ←
SLAB View (GUI only)	84.6% ←
SLAB for Windows (GUI only)	74.4%

The models marked by arrows are our recommendations based on the above evaluation criteria and methodology. These models were recommended mainly because of their high technical qualities, relevance to MMS' special needs (e.g., overwater dispersion, multiple sources, and environmental impact studies), and proven track records. The two graphical user interface (GUI) programs, BREEZE HAZ SUITE and SLAB View, were recommended because of their state-of-the-art design, ease of use, and value-added features such as source term calculations and graphical functions.

In the report, we made various recommendations for the Offshore and Coastal Dispersion (OCD) model in technical areas such as the overwater mixing height, parameterizations of the marine boundary layer, the use of overland meteorological data, the vertical dispersion coefficient, the thermal internal boundary layer, multiple land and water transitions, and impacts on offshore areas due to coastal sources. Recommendations were also given in operational areas such as the shoreline database and the documentation. We caution that while it is relatively easy to upgrade the OCD code to incorporate new theories and algorithms because of OCD's modular design, any changes must be subject to careful evaluation. Some of the important issues to consider include (1) whether the new algorithms are physically meaningful; (2) how the new algorithms affect predicted concentrations; (3) potential cancellation of errors; (4) whether the new algorithms are robust enough so that they will always succeed when running with, for example, one year of data; and (5) whether the new algorithms require data that are always readily available.

Dr. Mark E. Fernau (presenter) has worked in the Atmospheric Sciences Group at Earth Tech for five years as a Senior Scientist; before that, he worked in the Environmental Policy Group at Argonne National Laboratory. He has over 15 years of experience in the application of grid-based photochemical models and trajectory-based long range pollutant transport models to address scientific and policy issues. He has exercised the CALGRID, UAM-IV, UAM-V, SAQM, CAMx, ROM and RADM models on various regional, Northeast, California, Canadian and Midwestern domains, and has extensive experience in all aspects of running these models. Dr. Fernau received his B.S. from Cornell University and M.S. and Ph.D. degrees from the University of Michigan, all in atmospheric science.

Mr. Joseph Chang has over 10 years' of experience in the development of numerical models, data analysis, model evaluation and the atmospheric boundary layer. He is the Manager for Model Development and Analysis at Earth Tech, Inc. He is a specialist in toxic release modeling. He received his B.S. at the National Taiwan University and his M.S. degree at the Massachusetts Institute of Technology and is a Certified Consulting Meteorologist.

Mr. Joseph Scire is a Vice President and the Manager of Earth Tech's Atmospheric Sciences Group. He has played a major role in the development of several widely used models including BLP, MESOPUFF II, and CALPUFF, and parts of the ISC model. He has B.S. and M.S. degrees from the Massachusetts Institute of Technology.

Mr. David Strimaitis is a Principal Scientist at Earth Tech, Inc. with over 18 years' experience in developing and evaluating air quality models. He has participated in the development and evaluation of many of EPA's regulatory models, as well as CALPUFF. He received his B.S. from Trinity College and his M.S. from the Massachusetts Institute of Technology.

PROJECT STATUS REPORT: EMISSIONS INVENTORIES OF OCS PRODUCTION AND DEVELOPMENT ACTIVITIES IN THE GULF OF MEXICO

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INTRODUCTION

The purpose of this work effort, "Emission Inventories of Outer Continental Shelf (OCS) Production and Development Activities in the Gulf of Mexico" (MMS Contract No. J-30856) is to provide technical support for the development and maintenance of MMS's current and past-year (1977 and 1988) emission inventories for the OCS. The project team is developing and revising the softwaretools that will be used to collect and manage the emission inventories, including a PC-based database management system (DBMS), and the survey software originally developed by the MMS (AEIS) to query offshore operators regarding platform activity. Beginning in 1999, the project team will work cooperatively with the MMS to survey the offshore platform operators and compile emissions activity data. These data will then be used to prepare spatially distributed OCS emission inventories of primary air pollutants (carbon monoxide, NO_x, SO_x, total suspended particulates, PM_{10}, $PM_{2.5}$, total hydrocarbons, and volatile organic hydrocarbons). Area and mobile sources will be spatially resolved to the grid cell level, and point sources will be assigned specific coordinates.

A portion of the slide show that accompanied this presentation appears at the end of the article.

PROJECT BACKGROUND

The determination of the BNWA's PSD status depends upon regional air quality modeling. In turn, modeling results depend upon the qualities of the model algorithms, meteorological input data, and emissions input data. To improve the quality of the inputs, the MMS issued a Notice to Lessees (NTL No. 96-04, dated 15 August 1996) that required Outer Continental Shelf (OCS) leaseholders within 100 km of BNWA to collect and submit meteorological, air quality, and emissions data. In response, the Offshore Operators Committee (OOC) recently initiated the Breton Aerometric Monitoring Program (BAMP) to collect air quality, meteorological, and emissions information. The current project will provide the MMS with a new OCS gridded emission inventory for the BAMP monitoring period, backcast inventories for the PSD baseline years (1977 and 1988), and software tools that will facilitate maintenance of these inventories.

WORK PLAN

The critical tasks for this project fall under two related categories, software development and inventory development. Software development tasks include work on the AEIS software and DBMS. Inventory development includes data gathering, QA/QC checks, and emissions modeling for current and past years.

Software Development Tasks

Recently approved as a project add-on, the initial software development task is a revision to MMS's AEIS software program. AEIS is a PC-based, interactive software program designed to query offshore platform operators and record their responses as emissions activity data. Operators will submit these data to the MMS for later use during Inventory Development. The purpose of revisions to AEIS is to minimize the likelihood of user-input errors. Revisions will include automated quality assurance and quality control (QA/QC) features that will assist users to enter correct and complete data. Initially, the project team will work together with MMS's Information Technology (IT) staff and, if possible, with software users to finalize the scope of the software revisions. Following implementation of the revisions, the project team will turn the AEIS product back to MMS IT staff and software users to aid with product testing. The project team intends to conduct a pre-test of AEIS with four to six operators, and a full test for one to two months prior to the start of BAMP.

Under this contract, the project team is also developing a database management system (DBMS), a tool that will facilitate maintenance, review, and updates to the repository of OCS emissions data. Functions of the DBMS will include:

- Automated QA/QC functions
- Emissions calculations
- Updateable default parameters and emission factors
- Summary statistic calculations
- Selection queries
- Geographic data display (via an ArcView interface)
- Report generation
- The DBMS will be the primary tool used to accomplish inventory development tasks, such as QA/QC, emissions calculations, and data archival.

Inventory Development Tasks

Inventory development efforts for historical years 1977 and 1988, will address the source categories listed in Table 1C.4. The historical inventories will be prepared for the entire Gulf of Mexico. An

Table 1C.4. OCS emission inventory source categories.

Source Category	Source Description
Platform Sources	Platform Equipment -engines and turbines -storage tanks -flares -glycol regenerators -vents -amine units -fugitive emissions -petroleum loading/unloading
Platform-Associated Sources	Crew/Supply Boats Oil Barges Shuttle Tankers Tugboats Research Vessels Crew Helicopters Construction Barges
Pipeline Sources	Pipeline Construction Equipment -pipeline barges -tugboats
Exploration & Drilling	Drilling Equipment -Engines and Turbines -Mud Degassing

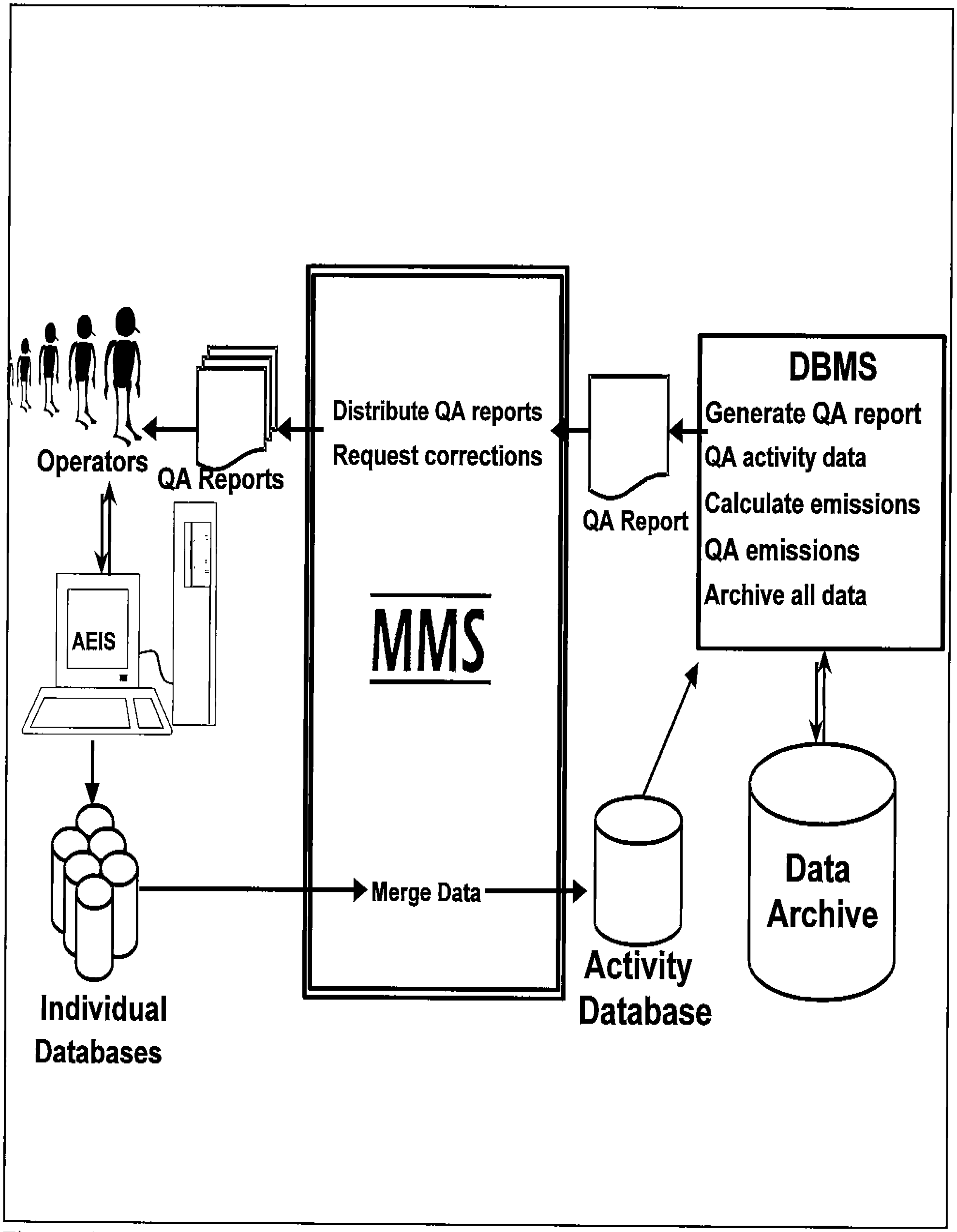


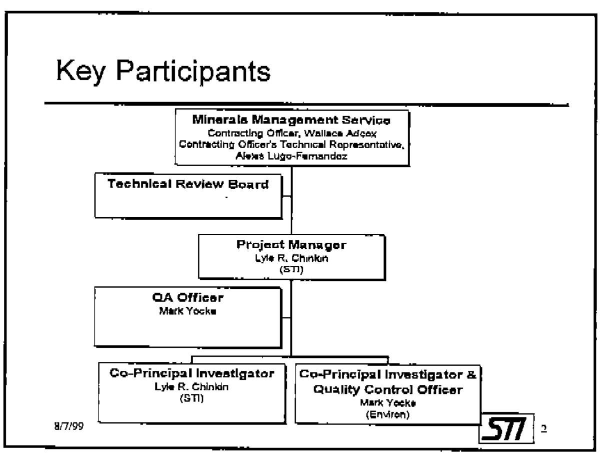
Figure 1C.4. Flow of information during development of the current-year inventory.

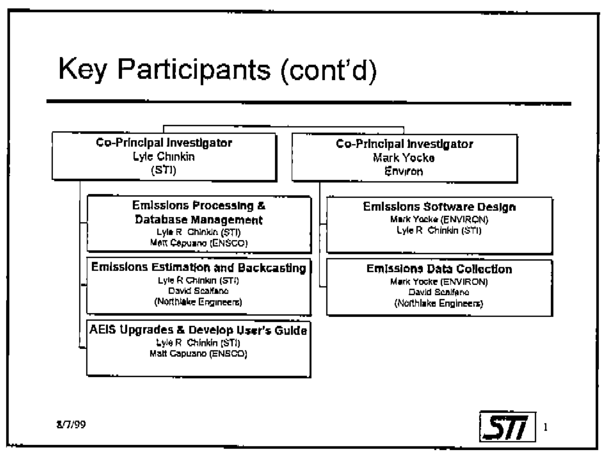
analysis of the current-year inventory will serve as a starting point for the backcasting process. The project team will adjust the current-year inventory according to historical events, such as commissioning or decommissioning dates, growth or decline in production rates, the addition of emissions controls, and the introduction of new technologies. When past-year data are unavailable for historically active emissions sources, the current-year inventory may be extrapolated to estimate past-year emissions for these sources. Data uncovered to date include records of platform installations/ decommissions, platform equipment lists, pipeline installations, and drilling activities.

The current-year inventory will be concurrent with the BAMP study period. The inventory will be based on MMS's AEIS survey of those facilities within 100 kilometers of BNWA (per NTL 96-04). Thus, it will include those sources listed as "Platform Sources" in Table 1C.4. If irreducible errors are discovered during QA/QC, the project team will bring the suspected errors to the attention of the MMS. The MMS will verify the suspected errors and forward corrections to the project team. Figure 1C.4 illustrates the anticipated flow of information between offshore operators, MMS, and the project team during the compilation of the current-year inventory. The project team anticipates receipt of AEIS survey data at monthly intervals over the course of 14 months, beginning in the spring of 1999. Upon a successful QA/QC evaluation, the project team will estimate emissions and archive the activity and emissions data for each source.

PROJECT STATUS

This project is somewhat delayed due to changes in schedule and scope precipitated by delays in the BAMP study schedule. The project team is cautiously moving forward with most tasks, including scoping the design of the DBMS and AEIS revisions, technical research into QA/QC protocols, and historical data collection. It is anticipated that current-year data collection will begin in the spring of 1999. The key deliverables (final electronic inventory files and software products, including source codes) will be handed over to MMS 18 months after the start of the BAMP study.





Project Overview

Objective: Provide technical support for development of current and past-year gridded OCS emission inventories.

- Generate spatially resolved emission inventories.
- Develop software that facilitates ongoing management and updates to the emission inventories.

Breton National Wilderness

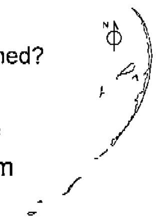
Class I air quality designation
- SO_2 & NO_2 increments consumed?

Many stakeholders

Air quality models questionable

325 OCS facilities within 100 km
- Initiated BAMP

This project: Emissions data for BAMP and baseline periods



Work Plan

Software development
- Revise the AEIS data collection software.
- Develop database management system (DBMS).

Emission inventory development
- Generate a current-year OCS inventory
  - Use AEIS and DBMS to:
    - -Gather, ingest, and QA survey data.
    - -Estimate and QA emissions.
    - -Archive all data.
    - -Return QA reports to MMS and platform operators.

Work Plan

Emission inventory development (cont'd)
- Historical inventories (1977, 1988)
  - Acquire historical activity data.
  - Combine current inventory and historical data in order to backcast past-year inventories.
  - Archive data.

Software Development

AEIS Revision
- Objective: Reduce the likelihood of user-input errors during the AEIS survey.
  - Introduce preliminary QA checks
  - Improve the user interface

DBMS Development
- Objectives: Facilitate updates, reviews, and maintenance of OCS inventories.
  - Editable tables of emission factors
  - Data review & display functionalities

Software Development

Steps
1. Thoroughly scope out the functionalities and graphical user interface (GUI)
2. Perform supporting engineering & technical research
3. Software implementation
4. Software testing

Database Management Issues 1 of 2

Relational database standards
Graphical User Interface (GUI)
On-the-fly QA/QC checks
Data entry
Easy access & display of data
Automated reporting
Queries

Database Management Issues 2 of 2

Updatable automated estimation methods
Statistical tools to aid QA/QC
Updatable default values
Future modifications
Data security
User's Guides

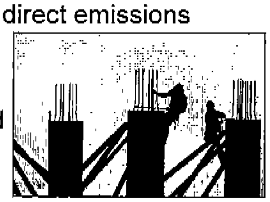
OCS Emissions Estimates

Emissions Estimation
- Direct Measurement
- E.F. × A
- Spatial & Temporal Distribution

Source Categories
- Transportation & Shipping
- Fugitives
- Storage Tanks & Loading
- OCS Facility Processes & etc.

OCS Emissions: Unique Issues

Daily variation in production quantities
Temporary activities (e.g., drill rigs, etc.)
Difficult to access direct emissions measurements
High labor costs
Electricity demand



Construction

Inventory QA/QC Procedures

Human-eye checks
- Data formatting & units
- Graphical data displays (automated)
- Statistical analyses (automated)
- Site visits

QA/QC provides a realistic perspective on the inventory.

OCS Inventory Uncertainties

Currently unquantified
Uncertainty analysis tools
- Database management utilities
- AEIS error checks & utilities
- Statistical uncertainty analysis
- Examine unusual facilities (e.g., site visits)

Historical Data & Backcasting

Examine each category for historical data
- Regulatory changes
- Technological changes

Update with surrogate activity data
- Production volumes
- Employment figures

8/7/99 STI 19

Project Status

Tasks Underway
- AEIS Revision
- Historical Data Collection
- QA Supporting Research

Note, some tasks are slowed or delayed due to changes in the BAMP schedule and related changes to project scope.

8/7/99 STI 20

Where do we go from here?

Complete software development by Spring 1999.

Collect current-year inventory data from Spring 1999 until Spring 2000.

Allow 6 months to complete data processing, QA, and backcasting.

Deliver draft inventory files and software (incl. source code) by Dec. 31, 2000.

8/7/99 STI 24

Mr. Lyle R. Chinkin, Vice President of Emissions Assessment with Sonoma Technology, Inc., is responsible for the strategic planning of emissions studies and preparation of emission inventories. During his 20-year career in the air pollution field, he has focused on issues related to emission inventories and air quality. Mr. Chinkin's contributions to the field include recommended guidance to improve the California Air Resources Board's (ARB) emission inventory methods and an EPA guidance document regarding the preparation of gridded emission inventories for air quality modeling. Mr. Chinkin possess B.S. and M.S. degrees in atmospheric sciences from the University of California – Davis.

DISPERSION METEOROLOGY OVER THE BRETON NATIONAL WILDLIFE AREA (BNWA)

Dr. S.A. Hsu
Louisiana State University

INTRODUCTION

In June 1997, surface meteorological measurements at our Breton Island air quality station were enhanced by the addition of water temperature and a pier-mounted UVW wind system. Wind turbulence data was collected at 30-minute intervals through July 1998; approximately 5 weeks of data was lost following passage of Hurricane Danny in July 1997. This brief report will summarize several preliminary findings related to stability and dispersion characteristics over the Breton area (including nearby NOAA buoys and C-MAN stations) and present a method for estimating mixed height from remotely-sensed (satellite) data.

METHODS AND RESULTS

Atmospheric stability may be characterized by Z/L formulation such that

$$\frac{Z}{L} = \kappa C_T C_d^{-\frac{3}{2}} R_b \tag{1}$$

where $\kappa = 0.4$, $C_T \approx 1.1 \times 10^{-3}$, R_b is the bulk Richardson number (Hsu 1992), and C_d is based on the wind-wave interaction method (see, e.g., Hsu 1995) for the buoy data. However, since no wave measurements were made at Breton or C-MAN station GDIL1, a second C_d formulation provided by Hsu (1995), which is dependent only on wind speed, was employed for the land-based stations.

Hourly values of Z/L were calculated for NOAA buoys 42007 and 42040 and C-MAN GDIL1 as well as at Breton. Stability was classified as unstable for $Z/L < -0.03$, neutral for $|Z/L| \leq 0.03$, and stable for $Z/L > 0.03$. Figure 1C.5 shows the frequency of occurrence for each category. Breton Island stability characteristics most closely resemble those at buoy 42007, particularly for unstable; therefore this station's long-term record may be used to simulate conditions over the BNWA. Note that the larger percentage of stable conditions at Breton may be due to chilling of the shallow waters in the Sound.

High concentrations of pollutants may be anticipated if a release occurred during very stable conditions offshore. Stable mixed height may be approximated by (Panofsky and Dutton 1984)

$$h_{stable} = 0.4\sqrt{\frac{u_* L}{f}} \tag{2}$$

where $f = 2\Omega \sin \varphi$. From Hsu (1998), when $T_{air} > T_{sea}$ (stable),

$$L = -\frac{u_*^3 C_p \rho T_{air}}{\kappa g H_s} \tag{3}$$

where H_s (sensible heat flux) = $\rho C_p C_T (T_{sea} - T_{air}) U_{10}$. Substituting back into Eq. (2) and reducing

$$h_{stable} = 0.4\, C_d\, U_{10}^2 \sqrt{\frac{T_{air}}{f \kappa g\, C_T \left(T_{air} - T_{sea}\right) U_{10}}} \tag{4}$$

Employing the WAMDI (1988) formulation for C_d, Figure 1C.6 shows that an estimated mixed height of only 104 m was found under an episode of stable conditions at buoy 42007.

Turbulence intensity data observed under near-neutral conditions ($|Z/L| < 0.4$) at Breton Island was compared to relationships found for the North Sea (Geernaert *et al.* 1987) and North Atlantic (Smith 1980). Data observed under light wind conditions ($U_{10} < 5$ m/s) were excluded to better represent stability class D (neutral) conditions (see, e.g., Zannetti 1990). In Figure 1C.7, good agreement is found for downwind (σu) and vertical (σw) intensities; however larger crosswind (σv) intensities are seen in this data set. Further defining these relationships is essential for proper σy and σz calculations in dispersion modeling efforts over the BNWA.

New satellite systems scheduled to come online will provide accurate measurements of surface and cloud-top temperatures as well as heights of cloud tops. Figure 1C.8 demonstrates a method for determining the mixed height from this remotely-sensed data. The computed LCL, or mixed height, from a radiosonde profile recorded at Breton Island on 4 August 1998 (Figure 1C.9), is shown to be in excellent agreement with that obtained from the satellite data.

CONCLUSIONS

Unstable conditions were observed at Breton Island during over 60% of the period from May 1997 through July 1998. Stability and disperison characteristics at Breton and NOAA buoy 42007 appear well-related; hence the long-term buoy record may be used to represent conditions in the BNWA as a first approximation. When stable conditions exist, mixed heights can drop to 100 m or less. Good correlation of downwind and vertical turbulence intensities is found between Breton Island data and that from the literature; however, larger crosswind intensities were observed. A method for estimating the mixed height from remotely-sensed data is demonstrated with excellent results.

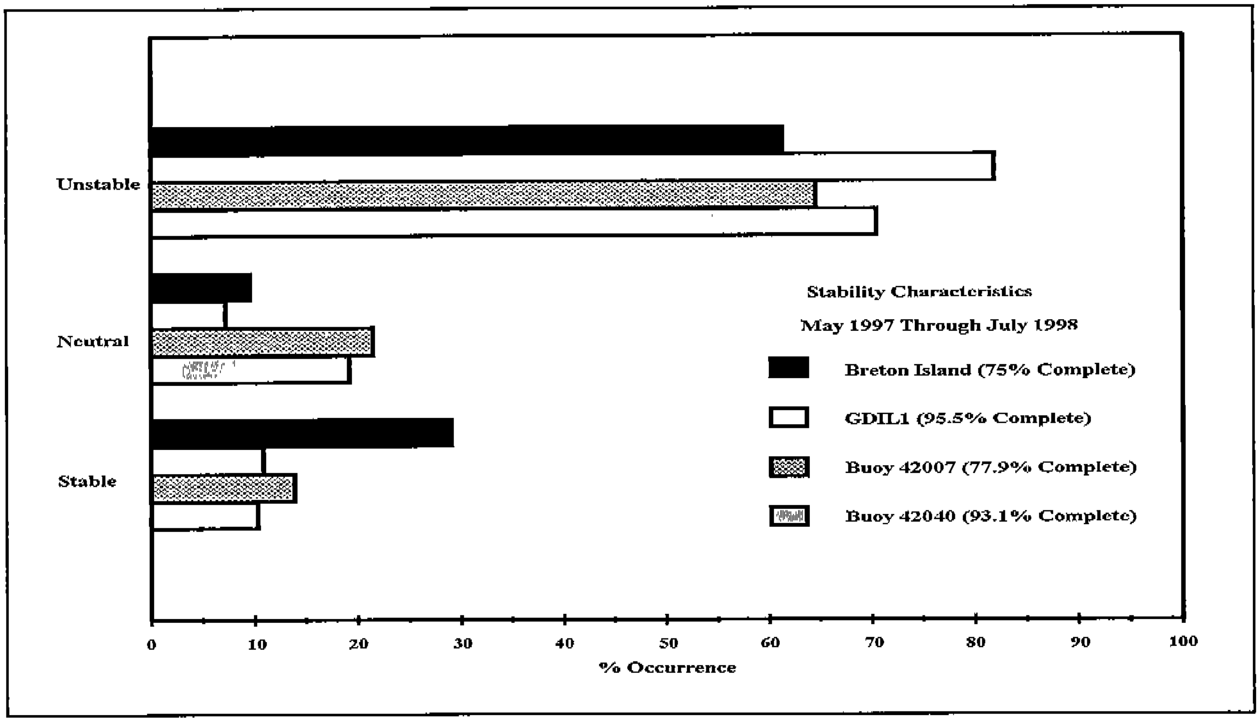


Figure 1C.5. Frequency of occurrence of stability classes for three NOAA stations and Breton Island during the period of May 1997 through July 1998.

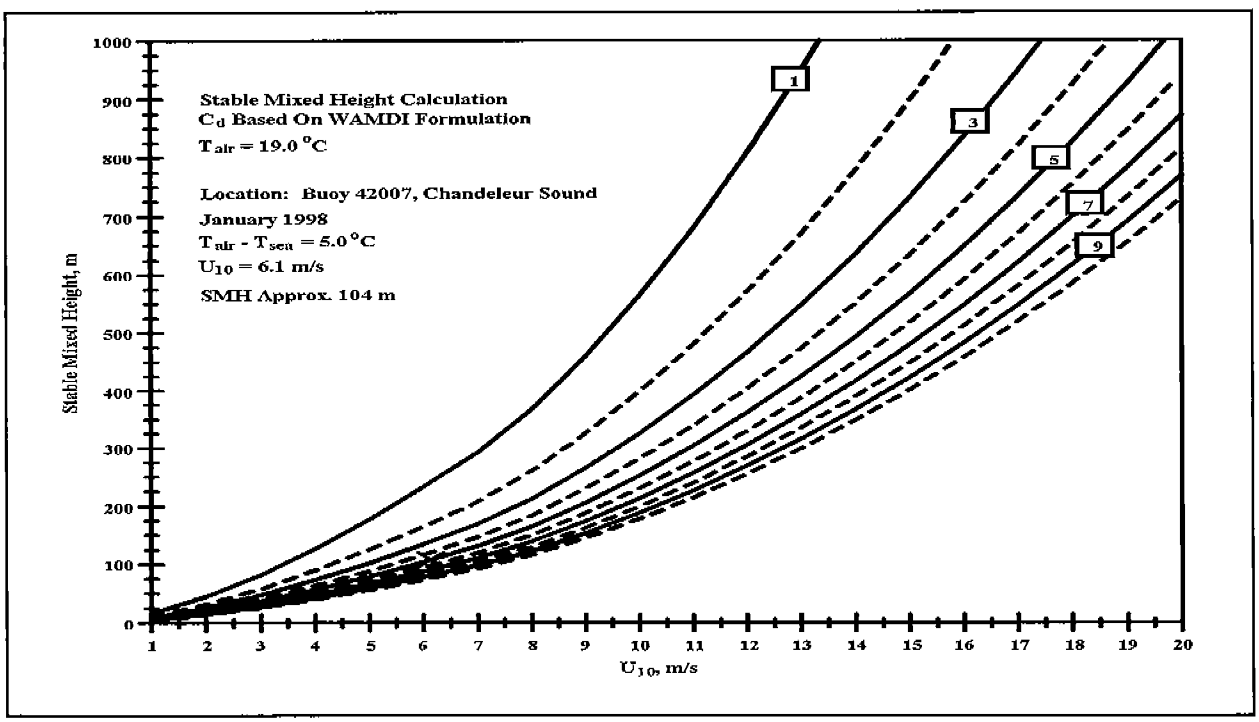


Figure 1C.6. Stable mixed layer height nomogram for air temperature of 19°C. Lines indicate temperature difference (T_{air} - T_{sea}).

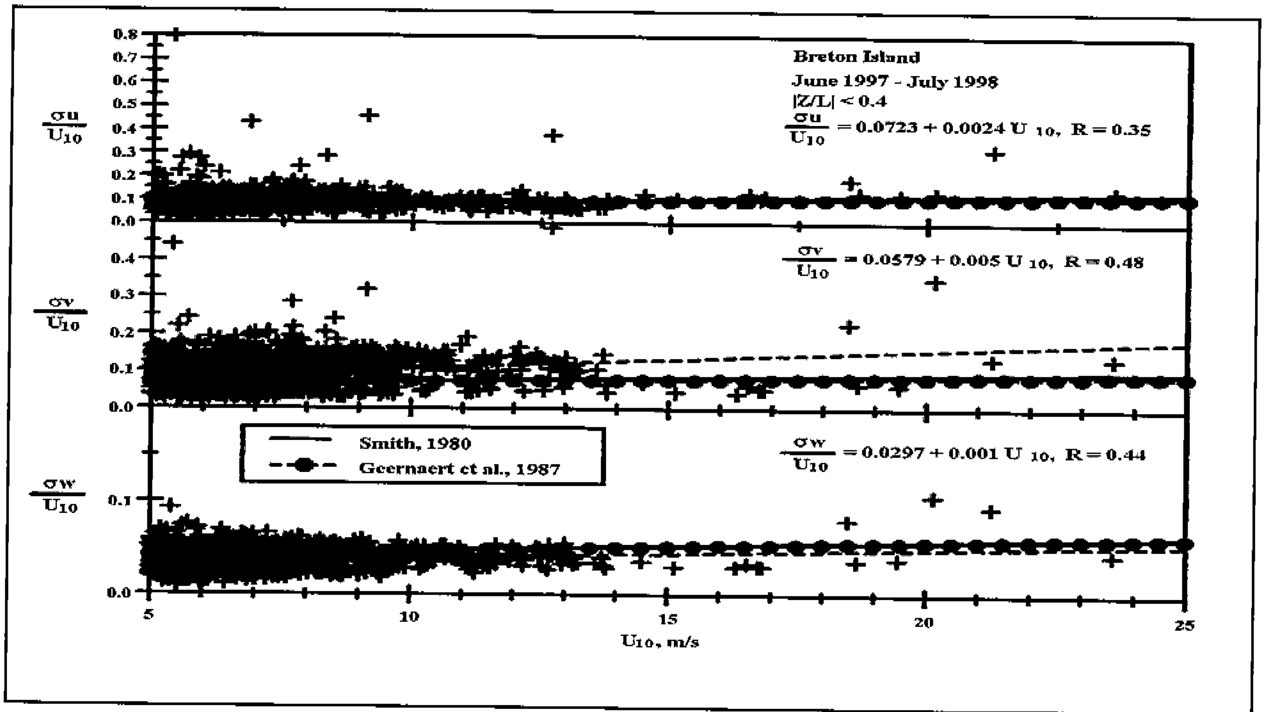


Figure 1C.7. Observed turbulence intensities at Breton Island compared to relationships found for the North Sea and North Atlantic.

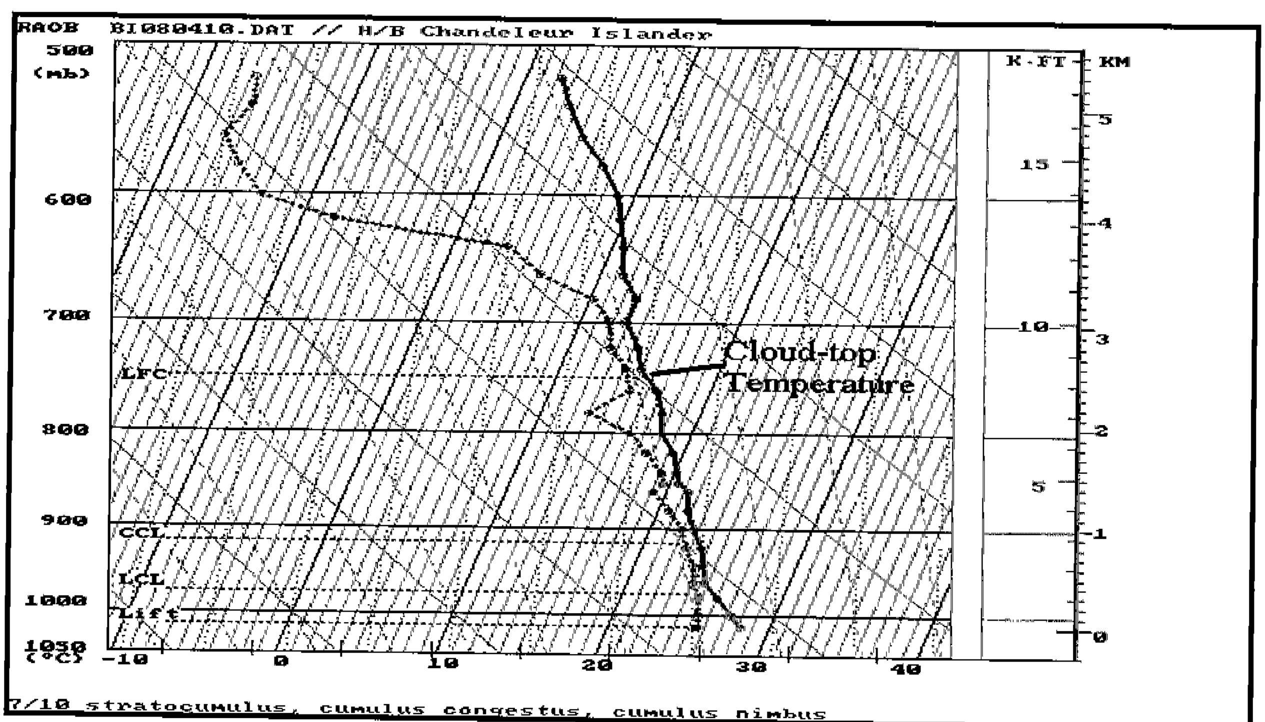


Figure 1C.8. A demonstration of LCL (mixed) height from cloud-top temperature using data obtained over Breton Island on 4 August 1998 at approximately 1500 GMT (1000 LT).

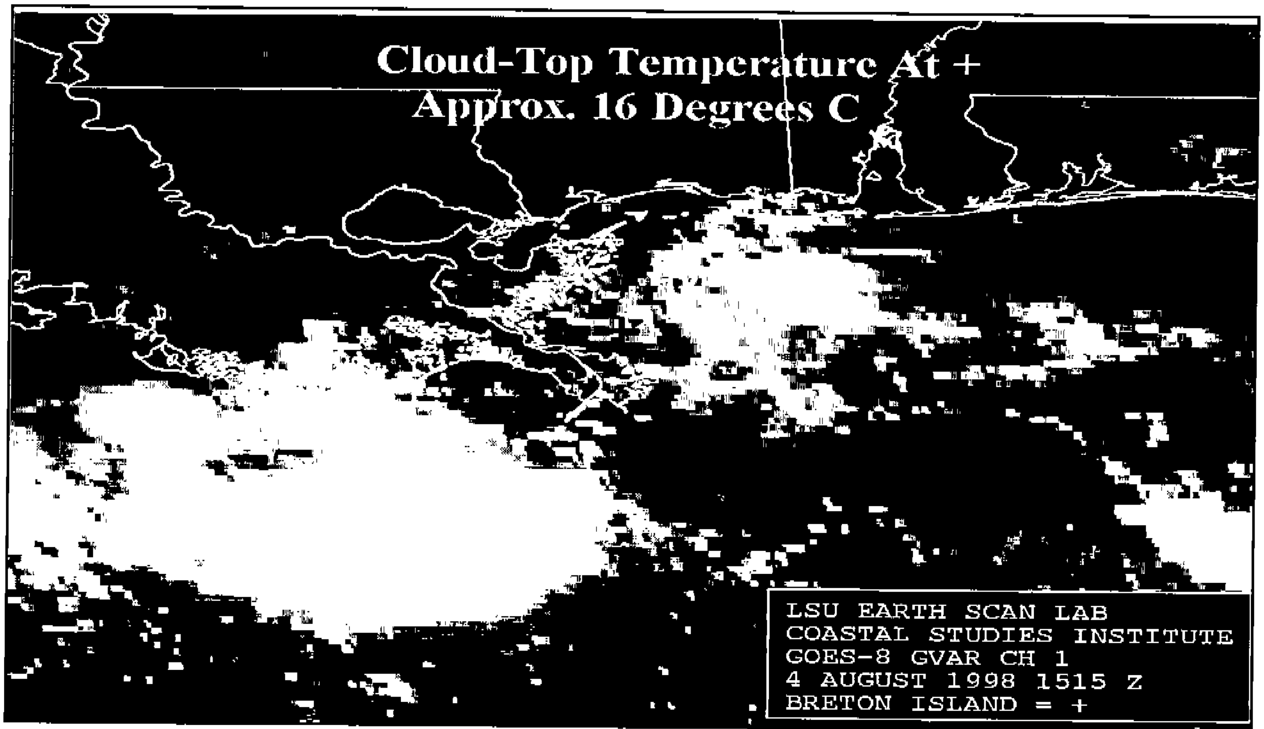


Figure 1C.9. Cloud-top temperature at approximately 16 degrees C.

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THE BRETON AIR QUALITY STUDY/BRETON AEROMETRIC MONITORING PROGRAM

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INTRODUCTION

This paper describes both the history and process by which a program has been developed to collect a meteorological and air quality data base within 100 kilometers of the Breton National Wildlife Area offshore of Louisiana and Mississippi. The proposed network and rationale are described. Uses for the data include: a) limited evaluation of different air quality model formulations; b) assessment of impacts on the Breton National Wildlife Area for Prevention of Significant Deterioration Class I increment consumption for the short-term SO_2 increments; c) data analysis leading to a better understanding of the high SO_2 impacts at the BNWA and, d) and use in Environmental Assessments and Environmental Impact Statements.

BACKGROUND

In early 1994, U.S. Fish and Wildlife Service (FWS) determined that there was significant possibility of an exceedance of the Prevention of Significant Deterioration Class I SO_2 three-hour and 24-hour increments at the Breton National Wildlife Refuge (BNWA) due to large short term releases of SO_2 from a facility near Breton Island in 1993. FWS, the Federal Land Manager for the area, expressed this concern to the Minerals Management Service (MMS), which has responsibility for regulating air quality in the Outer Continental Shelf.[1] To address this issue, FWS concluded that a study was

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[1]Meeting between MMS and Offshore Operators Committee, 12 December 1993.

needed to carry out a cumulative air quality assessment of impacts from surrounding offshore and onshore sources within a 100 kilometer radius of the BNWA. MMS undertook the study, and a Technical Review Group under MMS leadership was established.[2] The group included representatives from National Park Service/Fish and Wildlife Service, EPA and the Offshore Operators Committee. That group drafted a statement of work for the Breton Air Quality Study. The intent of the study was to design an air quality/meteorology/emissions inventory data collection program suitable to evaluate a set of air quality models for their predictive ability; and to use one or more of the models to determine increment consumption at the BNWA.

In 1996, the program was split into two parts, with concurrence of all parties. The data collection effort would be funded by the Offshore Operators Committee and was renamed the Breton Aerometric Monitoring Program (BAMP). The modeling would still be done by MMS. The Technical Review Group for the BAMP was expanded to include representatives from the state environmental agencies for Louisiana, Mississippi and Alabama, as well as representatives from onshore industries in those states. In early 1997, MMS issued a Notice to Lessees (NTL)[3] that formalized the mandate for data collection offshore under the requirements of the OCS Lands Act.

BRETON AEROMETRIC MONITORING PROGRAM

In early 1997 the revised and expanded Technical Review Group issued a Request for Proposals for the BAMP,[4] and awarded a contract to develop a phased approach to do the work. The first phase had three components, which are described below. The second phase would be implementation of the actual data collection program over a one-year time frame. Phase 1 has been completed. Decisions on the scope of phase 2 have not been finalized. However, due to questions of funding, an alternative scope for a network limited to the OCS has also been developed.

PHASE I EFFORTS

This phase had three components. The first component of this effort had three major tasks. The first task was review of the pertinent air quality and meteorological models that might be considered for assessment of increment consumption. The second task was the development of a conceptual model of the meteorological and air quality processes that are associated with high SO_2 concentrations at the BNWA. This task was dependent on climatological analysis of the periods associated with the high SO_2 concentrations. One of the problems confronting the analysts was the lack of sufficient aerometric data in the offshore area. Only a single year of surface meteorology and ambient air

[2]Letter of 18 November 1994 from Acting Regional Director, MMS, Gulf of Mexico OCS Region to prospective members of the Technical Review Group.

[3]Notice to Lessees and Operators of Federal Oil, Gas and Sulphur Leases in the Outer Continental Shelf, Gulf of Mexico OCS Region 97-02, Meteorological Data Collection (Breton National Wildlife Refuge/Wilderness Area, 23 January 1997.

[4]Request for Proposal for Breton Air Monitoring Program, Offshore Operators Committee, 26 March 1997.

quality measurements were available at Breton Island. The final task was a set of recommendations for monitoring that would meet the needs for both modeling and analysis. One major outcome of this last task was the realization that a rigorous evaluation of the air quality modeling system was practically unattainable because of cost considerations. Evaluation of plume dynamics would require a very dense network of surface monitors, as well as monitoring aloft. Much of this network would have to be over water. Therefore, a decision was made to emphasize a network that, from a meteorology perspective, would improve the modeling system's handling of transport. Most of the recommendations support acquisition of continuous surface and aloft meteorological data.[5]

The second component was the assessment of the emissions inventory that would be needed to provide input into any air quality modeling simulations. This task identified various portions of the inventory, significant gaps in the inventory, especially with respect to mobile sources onshore and offshore, and area sources. Based on the initial assessment and in conjunction with the initial driving force for the study, emphasis was placed on improvements in the SO_2 inventory.[6]

The third component synthesized the information in the first two tasks, incorporated additional data analysis, and provided a set of options for the proposed BAMP network.[7] The second option, which will be described below, met most of the overall goals of the Technical Review Group. However, the Technical Review Group also sought an independent review of this option. That review concurred with and enhanced the conceptual model upon which the option was developed.[8] This option emphasizes a program that is intended to improve our understanding of the flow dynamics and air quality associated with high SO_2 concentrations at Breton Island. The bases for the proposed network are derived from the above components:

- Surface wind speeds are relatively high and are from northwest to northeast
- Higher-than-normal temperature variations occur and lower-than-normal mixing heights and neutral to stable dispersion conditions occur.
- These conditions are associated with two meteorological regimes, a Continental High and Frontal Overrunning, that are dominant in winter, when most of the high SO_2 concentrations occurred.
- Those meteorological regimes may result in a regional plume capable of reaching the BNWA over an extended period of time.

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[5]Tesche, T.W. and McNally, Dennis. Recommendations for Air Quality Dispersion Models and Related Aerometric Data Sets in Support of the Breton Air Monitoring Program. Task 1 Final Report, Alpine Geophysics, AG-90/TS107, 28 February 1998.

[6]Lee, Edward, Final Draft Report. Task 2-Emissions Inventory Identification and Assessment for Offshore Operators Committee, Walk-Haydel, WH 37598-001-2001, 6 March 1998.

[7]Preliminary Draft Report, Task 3: Design of the Breton Aerometric Monitoring Program, Walk-Haydel, Dames and Moore Project No. 35610-007-140, 14 April 1998.

[8]Lehrman, Don and Blanchard, Charles. Memorandum: Independent BAMP Review and Assessment, T&B Systems, 7 October 1998.

- Greater than 90% of the total SO_2 emissions for the 100 km region are located onshore in the northeast to northwest quadrant.

BAMP PREFERRED OPTION

Table 1C.5 describes the second option and the rational for the location, the equipment, and data to be collected, along with a justification for the data collected.

The preferred option contains four sites for collection of continuous aloft meteorological data, including temperature, wind speed and wind direction at different heights. This information is necessary to describe the flow from onshore areas towards the BNWA and also to provide information on how transported emissions can be mixed down to the surface under the high SO2 regimes which occur during the winter. Three of the sites, those at Breton Island, southwest of Pascagoula in the OCS, and northwest of Breton Island would capture the dominant winter time flow, which is of most interest, as well as flow for other seasons. The latter site would also give information the land-water interface. The last site, at South West Pass, is important in that cold water from the Mississippi forms a cold water pool at the mouth of the Mississippi surrounded by the warmer Gulf water. Air above this cold water pool cools and sinks with resultant mixing. This mixing provides one way for emissions over the warmer Gulf waters to be brought to the surface and potentially impact the BNWA under certain flow regimes, and needs to be documented. This phenomenon occurs during high SO2 concentrations.[9] All this information would be used either for input or evaluation of whatever meteorological model is used in subsequent modeling.

The surface sites would provide, for the most part, surface wind speed, direction, temperature, relative humidity an and ambient SO_2 measurements. Those surface sites—mainly buoys—located in water would also provide sea surface temperature. These too, are necessary for whatever meteorological model would be used in subsequent modeling, either for input or for model evaluation. Similarly, the ambient measurements would be used for model evaluation.

All of the data would also be available for a more refined set of analyses that should lead to significant improvement in the conceptual model for describing the high SO_2 episodes.

A more complete description of the network design is Task 3 report, Design of the Breton Aerometric Monitoring Program.

BRETON NTL ALTERNATIVE NETWORK

As noted above, it appears that there are insufficient funds to implement the BAMP Preferred Option. Because the Breton NTL required development of a meteorological network to assess the impacts of OCS sources on the BNWA, an alternative network design was devised with input from

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[9]Roberts, Nash C, Jr., Memorandum: Local Influences of the Winter Cold Water Pool at the Mouth of the Mississippi River, 15 April 1998.

Table 1C.5. BAMP preferred option.

LOCATION	LOCATION JUSTIFICATION	EQUIPMENT	MONITORED PARAMETERS	EQUIPMENT JUSTIFICATION
Breton Island	Within BNWA; Critical for dispersion modeling input	- 30- meter tower - Radar profiler - RASS - Air Quality analyzers	- WS, WD, temp, turbulence data at 2 levels - Multi-level wind data - Multi-level temperature data - SO_2, NO_2	- Lower level met data to provide complete profile in the BNWA - Wind data for model input - Upper air temperature and mixing layer data - Air quality impact assessment within the BNWA
NW of Breton Island	Change from land to water-based influence	- 10-meter met station - Radar profiler - RASS	- WS, WD, Temp at 10-meters - Multi-level wind data - Multi-level temperature data	- Lower level met data - Wind data for model input - Upper air temperature and mixing layer data
East of Main Pass in OCS	Surface met data gap over water	- Buoy	- WS; WD; water, ambient air, and dew-pt temps; pressure; visibility; and wave ht. data	- Over water surface met data for model input
SW Pass in OCS	Key area for Mississippi River and Gulf water mixing	- Existing C-Man station - Radar profiler	- WS; WD; water, ambient air, and dew-pt temps; pressure; visibility; and wave ht. data - Multi-level wind data	- Existing over water data - Wind data for model input
Boothville, LA	Assess impacts from offshore emission sources to the S and SW	- Air quality analyzer - 10-meter met station	- SO_2 - WS, WD, Temp at 10-meters	- SO_2 impact assessment - Real-time corre-sponding met data for air quality measure- ments
Cat Island, MS (or closer to the northern end of the BNWA)	Assess impacts from onshore emission sources to the N and offshore sources to the SE and S	- Air quality analyzer - 10-meter met station	- SO_2 - WS, WD, Temp at 10-meters	- SO_2 impact assessment - Real-time corre-sponding met data for air quality measurements

Table 1C.5. (continued)

Dauphin Island, AL	Assess impacts from onshore emission sources to the N and offshore sources to the S and SW	- Air quality analyzer - Existing C-Man Station	- SO_2 - WS; WD; water, ambient air, and dew-pt temps; pressure; visibility; and wave ht. data	- SO_2 impact assessment - Real-time corre-sponding met data for air quality measure- ments
East of Chandeleur Islands in the OCS	Surface met and water data supplement	- Buoy	- WS; WD; water, ambient air, and dew-pt temps; pressure; visibility; and wave ht. data	- Data for model input
South of Mobile and East of Breton Island in the OCS	Surface met and water data supplement	- Buoy	- WS; WD; water, ambient air, and dew-pt temps; pressure; visibility; and wave ht. data	- Data for model input
South of Pascagoula, MS in the OCS	Northern end of the study area in an over water environment	- Radar profiler	- Multi-level wind data	- Over water wind profile data for model input

MMS regional meteorologists. This network is limited in scope and does not emphasize the transport from the onshore areas that represent the majority of SO_2 emissions within the 100-kilometer radius of the BNWA. The network builds upon the information that was gained in the BAMP Phase I effort, and is shown in Table 1C.6.

The equipment and equipment justification are not given on this table, but are the same as in Table 1C.5 for the corresponding equipment/justification. The locations for sites are similar or the same in most cases, but there is increased emphasis on delineating flow patterns associated with OCS sources (sites at the mouth of the Mississippi and the eastern portion of the Central Planning Area), rather than onshore sources. In addition, the air quality monitoring network would collect both hourly SO_2 and NOx ambient concentration data. This additional air quality information would be useful for preparation of Environmental Impact Statement for new lease sales in the Central Planning Area, as well as for the air quality portions of Environmental Assessments for OCS sources. While the data collected under this alternative can be used for modeling, it is not sufficient for a rigorous evaluation of any of the modeling systems identified in the BAMP Phase I work.

SUMMARY

The BAMP study was undertaken to provide information upon which to design an aerometric data collection network for the Breton National Wildlife Area (BNWA). The objective was to secure data to enhance the understanding of the causes of high SO2 concentrations at the BNWA, and toprovide data for air quality model evaluation. The resultant proposed network is intended to better define

Table 1C.6. Breton NTL alternative.

LOCATION	MONITORED PARAMETERS	JUSTIFICATION
Breton Island, LA	- Surface met - Doppler SODAR - RASS- NO_x/SO_x	- Characterize conditions over the islands
Mouth of Mississippi River	- Surface met - Doppler SODAR - RASS- NO_x/SO_x	- Most likely to experience stable atmosphere. Wind shift across Delta.
Dauphin Island, AL	- Existing surface meteorology- NO_x/SO_x	
Eastern portion of Central Planning Area	- Surface met	- Strong sea surface temp. gradients in winter. Wind shift across Delta
Eastern portion of Central Planning Area	- Surface met- Radar profiler- RASS	- Upwind location thru which pollutants have transported. Strong sea surface temp gradient in winter
Southeast of mouth of Mississippi River	- C-Man Buoy including surface met and sea surface temperature	- Strong sea surface temp. gradient in winter. Wind shift across Delta

transport of emissions from onshore sources to the BNWA, as the highest SO2 concentrations occur during the winter time when flow is from the northwest to northeast. While the proposed network can be used for modeling, it will not be sufficient for a rigorous evaluation of different models.

A second network, more limited in scope, is also described. This alternative network would satisfy the data collection requirements in the Breton Notice to Lessees, and focus on offshore sources.

BOUNDARY LAYER STUDY IN THE WESTERN AND CENTRAL GULF OF MEXICO

Dr. Paul T. Roberts
Mr. Timothy S. Dye
Sonoma Technology, Inc.

Dr. Steven R. Hanna
Consulting Meteorologist

This four-year project is just beginning. This paper summarizes the plan for the project; updates on the project will occur at future ITM meetings.

PROJECT OBJECTIVES

The purpose of this study is to provide the MMS with a description and analysis of the atmospheric boundary layer and how its structure influences the dispersion and transport of pollutants in the western and central Gulf of Mexico. MMS will use the results of this study to support techniques for evaluating the effects of oil and gas exploration, development, and production activities in the Outer Continental Shelf (OCS) on air quality over coastal areas. Specific activities will include the following:

Initiate the study and perform detailed planning for the study.

- Collect data into a common database.
- Perform characterization and analysis of the atmospheric boundary-layer structure.
- Prepare synthesis reports and a database.

To complete this study we will conduct a number of technical tasks including:

- Produce a data inventory for synthesizing the characteristics of the Atmospheric Boundary Layer (ABL) and its dispersion properties in the western and central Gulf of Mexico, based on 1998 to 2001 observations and modeling results.
- Evaluate annual, seasonal, and diurnal variations in the ABL's structure.
- Describe the processes governing variations in the ABL's structure.
- Evaluate transport and mixing characteristics that govern pollutant dispersion over diurnal and multi-day scales.
- Provide conceptual model summary of processes that influence the ABL's structure and variability and pollutant transport and dispersion.

KEY TECHNICAL ISSUES

- A complete and quality-assured data set. If the data set is incomplete, or if individual values are in error, then the analysis results obtained using the data set might be in error, or more uncertain than otherwise.
- Data that is quality assured at Level 1 (consistent with physical constraints and other measurements at the same site by the same monitor).
- Data that is quality assured at Level 2 (consistent with measurements collected at other sites, and with other methods).
- Data representativeness (of the ABL, of the region where the data were collected, of the important ABL processes).
- Control of data management activities.
- Database accessibility (ease of access to quality-controlled data, to statistical summaries of the data, and to derived ABL parameters).
- How to use data to characterize ABL.
- Understanding of ABL processes, especially over water and coastal areas.
- Understanding of transport and dispersion processes, including the uses and limitations of models

There has always been great uncertainty concerning the vertical and horizontal variability of the atmospheric boundary layer in the Gulf of Mexico. For example, the depth of the boundary layer and its vertical stability and wind and turbulence structure can vary greatly in OCS zones due to horizontal variations in sea surface temperature and the overlying air mass. We are fortunate that the MMS now has available the following new boundary layer observations in the Gulf of Mexico – two meteorological stations collecting observations of the atmospheric boundary layer for three years (1998-2001) by using 915 MHz radar profilers, 2 KHz Radio Acoustic Sounding Systems (RASS), and surface meteorology units. The profilers will measure winds and virtual temperatures between the surface and heights of a few kilometers, and the surface stations will measure sea surface temperature as well as wind speed, wind direction, air temperature, and mixing ratio.

The two most important meteorological parameters for use in transport and dispersion models are wind velocity and vertical stability. These parameters are needed over the full depth of the overwater boundary layer (i.e., up to heights of 1 or 2 kilometers), to better account for variations in transport speed, transport direction, turbulent dispersion, and stability over the depth of the pollutant plume. Over travel times of several hours to a few days, or travel distances of several kilometers to a few hundred kilometers, such pollutant plumes can disperse upwards to the top of the boundary layer, can shear off in several directions, and can be subjected to layering during the transition and nighttime hours. The previous practice of using estimates of stability based on the difference between sea surface and air temperature, and single wind speed observations was often unsatisfactory.

The new data will be analyzed to investigate the following technical issues:

- The overwater surface energy balance will be studied using the near-surface observations for both steady-state horizontally-homogeneous conditions and for conditions variable in time and space. A climatology of latent heat versus sensible heat fluxes will be developed for both situations, and parameterizations should be developed for use in situations when only degraded data are available.

- Given the surface energy balance components, the vertical profiles of wind and temperature will be studied to develop climatologies and parameterizations. In particular, it is desirable to be able to estimate the full vertical profiles of wind and temperature based only on near-surface measurements of air-water temperature differences and wind speeds.
- The extensive vertical temperature profiles could be studied to estimate the mixing depths and prepare empirical formulas to parameterize these observations.
- The frequency of occurrence of very stable conditions near the surface and in layers aloft could be investigated due to the importance of these layers for defining worst-case conditions for the dispersion of air pollutants.
- The horizontal spatial variability of wind speed and direction could be studied to identify the fraction of time that wind directions and speeds persist over several hours in the Gulf of Mexico, thus causing direct straight-line transport of pollutants toward receptors on the shoreline.
- Vertical profiles of wind and temperature in the near-surface layer (i.e., heights below about 50 m) could be plotted and analyzed to derive surface roughness length relations and to estimate the scaling velocity (u*) and scaling temperature (T*). These scaling parameters are directly related to surface momentum and heat fluxes. Since turbulent velocities (important to dispersion) are directly proportional to u*, it should be possible to derive improved parameterizations for the dispersion coefficients σ_y and σ_z. Perhaps the single most important technical issue for understanding over-water air quality dispersion is the ability to properly assess the mixing depth.

Using the data collected by the radar wind profilers, hourly mixing depth estimates can be estimated from a combination of the refractive index structure parameter (C_n^2), RASS virtual temperature profiles, and surface measurements. Radar profiler mixing depth estimates have been demonstrated to relate well to other fundamental mixing depth estimation techniques using rawinsonde temperature profiles and aircraft data.

Estimating hourly mixing depths from profiler/RASS data is relatively straightforward. Using a technique developed by STI, we will estimate mixing depths from the profiler's reflectivity measurements and RASS's virtual temperature profiles. The refractive index structure parameter (C_n^2) is computed from the profiler's reflectivity measurements. Maximum values of C_n^2 have been theoretically and observationally linked to the top of the mixed layer. RASS virtual temperature profiles coupled with surface virtual temperature measurements can estimate the height of the mixed layer by using stability analysis.

Conceptual Model Development

We will develop a conceptual model of ABL characteristics and variability (as part of Task 3) and of pollutant transport and dispersion (as part of Task 4) in the offshore and coastal environment of the western and central Gulf of Mexico. The conceptual model will describe and illustrate the major meteorological phenomena which control the ABL structure and variability (Task 3) and which control pollutant transport and dispersion (Task 4). The purpose of developing a conceptual model is to summarize the current state of knowledge, to provide a basis for testing and evaluating specific hypotheses, to focus continuing analysis efforts on the most important issues, and to identify those processes which must be represented in models.

Note the following regarding conceptual models:

- The controlling processes may differ spatially, and by month, season, and weather pattern.
- The scale of controlling processes vary from synoptic to local.
- The type of controlling processes include synoptic, geographic (e.g., coastline), and thermal.

Example processes to be considered for inclusion in a conceptual model include the following:

- Synoptic weather patterns, including fronts and high/low pressure systems.
- High-pressure induced subsidence (warming).
- Air mass advection.
- Thermal ocean/atmospheric interactions.
- Land/sea breeze processes (especially for distinct shorelines).
- Diffuse shoreline in central Louisiana.

The following sections provide summary information on the technical tasks.

TASK 1 STUDY INITIATION

- Establish a Scientific Review Board (SRB). The SRB members will inspect the progress and the scientific validity of the study and its deliverables, including reviewing the study plan, interim synthesis report, and final synthesis report.
- Prepare and distribute a draft study plan summarizing how we will perform the study tasks and meet the study objectives, review the study plan, and revise the study plan based on comments received.

TASK 2 DATA COLLECTION AND INVENTORY

Database

- A Microsoft Access database will be used to archive the data for this project.
- The database will allow output of data into several different types of formats, including ASCII, comma-separated-value (CSV), and space-delimited, which are capable of being imported into other programs (e.g., ARC/INFO, Excel).
- The database will store:
    - Metadata: to describe the content, quality, condition, and other characteristics of data that help users locate and understand the data.
    - Observations and calculated fields: measurements from surface and upper-air sensors, as well as calculated fields generated as part of Task 3.

  - Three-dimensional fields: contain a reference to the model analysis fields. Storing the actual model output in an Access database is inefficient due to the large amount of data; however, the database will manage the inventory for the model output fields.
- To efficiently monitor and track the contents of the database, automated reporting will be used to generate data availability and data validation levels reports.
- Graphical user interface (GUI) will allow for quick and efficient display and analysis of the database. Several display types are available:
  - Time-series
  - Spatial plots
  - Statistical summary
  - Trajectory plots
  - Cross section plot
  - Output options will allow the users to save displays as files, graphics, or animations.
- Creation of the database will be done on a routine basis (e.g., every quarter). Prior to entry into the database, data will undergo format conversion; standardization of the units, time zones, and time conventions; and Level 1 and Level 2 data validation.

TASK 3 ANALYSIS OF THE ABL STRUCTURE

Objectives

- Characterize the ABL
- Evaluate annual, seasonal, and diurnal variations in ABL structure
- Describe processes that influence ABL structure and variations

Approach

- Describe ABL using measurements
- Describe ABL using vertically averaged variables and bulk theory
- Perform statistical and time-series analyses
- Perform correlations and propose simple relationships using only surface observations
- Describe processes

Issues

Similarities Between Overland and Overwater Boundary Layers

1. The basic boundary layer theories and equations apply over any surface, as long as you are careful about the definitions (i.e., the heat flux used in calculating L must include the effects of the latent heat flux).
2. Mesoscale eddies, with time scales from a minute to an hour, are present over both land and water, and are not observed to diminish even over the open ocean.

3. It is possible to parameterize the entire boundary layer based on simple observations of wind speed near the surface, air-water temperature differences, and relative humidity.
4. There is no substitute for observations through the entire depth of the boundary layer, because elevated inversion layers or shear layers can unexpectedly occur.

Differences Between Overwater and Overland Boundary Layers

1. Roughness length, z_0, is a strong function of wind speed over water.
2. Because of the high thermal conductivity of water and the mixing in the boundary layer of the water, the water surface temperature only slowly reacts to changes in air temperature. As a result, *the stability over water does not follow the typical diurnal cycle characteristic of land. In fact, it can be stable in the day and unstable at night, or it can be stable or unstable for weeks at a time.*
3. The only time strong stability (positive or negative) can occur over water is if there is advection of a warm air mass over cold water or a cold air mass over warm water.
4. Most of the time, the latent heat flux over water is larger than the sensible heat flux. It is essential that the vertical gradient of water vapor be included along with the vertical gradient of temperature in the calculation of any stability parameter such as the Monin-Obukhov length. It is possible to have a temperature inversion and *still have unstable conditions*, due to a decrease of specific humidity with height.

Plusses and Minuses of Available Data

Plusses:

1. Continuous records over three years from two MMS profiler stations, with wind and temperature data (at about 100m resolution) extending from 150 m to about 4 km.
2. Near-surface data from platforms and buoys over the three-year period.
3. Archived ETA NWP mode outputs available for the same time period.
4. Many on-shore data also available.

Minuses:

1. No fast response flux data (e.g., <w'T'>)
2. Wind and temperature measurement at only one height in the lowest 100 m.
3. Insufficient coverage to resolve sea/land breezes, TIBLs, and other local phenomena.

We identified 10 different synoptic weather patterns that influence large-scale flows in the northeastern Gulf (STI work for the NE Gulf Meteorological Study, ongoing, report due out later in 1998). Once several of these patterns are slightly modified to focus on the western and central Gulf, these patterns can be used to classify days during the study period (June 1998 through May 2001). The frequency of these patterns will vary by season. Several of these synoptic classifications show features which dominate winds and transport patterns in the area of interest. Other patterns show more neutral gradients in the offshore and coastal areas of interest, and thus local characteristics would likely dominate flows and transport. The synoptic features also likely influence stability in the regions, and thus strongly influence mixing heights and dispersion characteristics. As part of this task, we will modify the classifications for the western and central Gulf of Mexico, and will classify every day in the three year period; these classifications will be used in other analyses in both Tasks 3 and 4.

TASK 4 DISPERSION ANALYSIS

Objectives

- Characterize the dispersion properties of the ABL.
- Evaluate transport and mixing characteristics of ABL that govern pollutant dispersion.
- Include diurnal and multi-day scales.
- Describe processes that influence ABL transport and dispersion.

Overall Technical Approach

- Describe transport and mixing fields using statistical analyses.
- Describe processes that influence transport and mixing (conceptual model).
- Identify limitations of using homogeneous and equilibrium conditions.
- Recommend improvements to models & observations.

Technical Details of Approach

- Compare observed transport winds with Eta winds. This will occur at location and times when both the observed and Eta winds exist. If differences occur, then we will look into the potential causes.
- Select periods of interest, ensuring representation from various seasons and met classifications (about 1 month/season).
- Generate wind and mixing height fields with diagnostic model (we will likely use CALMET, but we will evaluate various alternatives before proceeding).
- Perform statistical analysis (e.g. averages, perturbations, and cycles) of transport wind, mixing height, and vertical diffusivity fields.
- Separate the results into several regions, such as offshore, near shore, coastal, &and onshore.
- Summarize statistical results and perform a few case studies to investigate similarities and differences among seasons and classifications.
- ID controlling processes by weather classification and season.
- Perform detailed analysis for selected cases.
- Illustrate controlling processes with examples.

One of the goals of this project is to develop a conceptual model of pollutant transport and dispersion in the offshore and coastal environment of the western and central Gulf of Mexico. The conceptual model will describe and illustrate the major meteorological phenomena which control pollutant transport and dispersion. The purpose of developing a conceptual model is to summarize the current

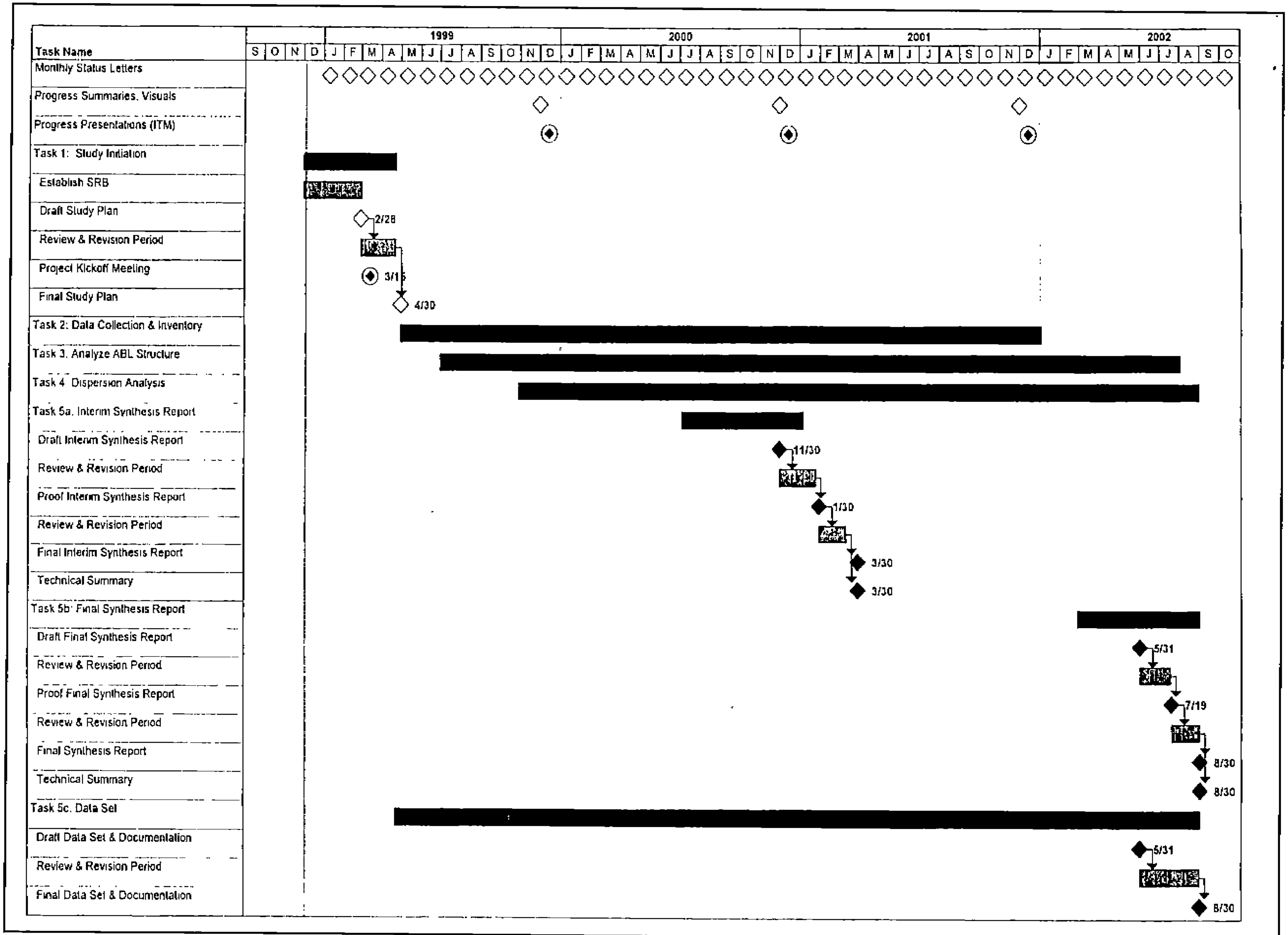

Figure 1C.10. Project schedule for Boundary Layer Study in the Western and Central Gulf of Mexico.

state of knowledge, to provide a basis for testing and evaluating specific hypotheses, to focus continuing analysis efforts on the most important issues, and to identify those processes which must be represented in models.

A schedule for the project is shown in Figure 1C.10.

Dr. Paul T. Roberts, STI Vice President, designs and manages air quality field, data management, and data analysis projects. Most of these projects have involved the use of field data and analysis methods to understand important meteorological and air quality phenomena, and to develop, apply, and evaluate meteorological and photochemical model. Specific projects during which boundary-layer processes over water and shoreline environments were important components include the MMS-sponsored Gulf of Mexico Air Quality Study (southeast Texas and Louisiana and offshore), the Southern California Air Quality Study (SCAQS) and several subsequent data analysis efforts in and around the South Coast Air Basin (SoCAB), the Lake Michigan Ozone Study, and the NARSTO-Northeast Air Quality Study (covering Virginia to Maine, including offshore).

Mr. Timothy S. Dye, STI's Manager of Meteorological Programs, has operated, quality controlled, and analyzed radar wind profiler wind and temperature data for over 11 years. Mr. Dye has extensively used these upper-air data to conduct analyses of pollutant formation, transport, and dispersion. He developed algorithms to estimate mixing height from radar profiler reflectivity and temperature data and has used this technique to understand marine and overland boundary layer structure and evolution in such programs as the Lake Michigan Ozone Study, the Gulf of Mexico Air Quality Study, and the NARSTO-Northeast Air Quality Study. Mr. Dye is co-author of the new EPA guidelines for collecting, quality controlling, and managing the upper-air data from radar profiler/RASS, sodar, and rawinsonde systems and has designed several methods for conducting Level 2 data validation of upper-air data.

Dr. Steven R. Hanna is a specialist in atmospheric turbulence and dispersion, in the analysis of meteorological and aerometric data, and in the development, evaluation, and application of air quality models. He is an AMS Certified Consulting Meteorologist with over 30 years of experience. He has led several research and development projects involving, for example, the statistical evaluations of hazardous gas dispersion models and regional ozone models; the development of models for the dispersion of emissions from tall power plant stacks and from offshore oil platforms; and the analysis of data from large regional field experiments in the Santa Barbara area, in the Lake Michigan region, in the Gulf of Mexico, and in the northeastern United States. He led the development of the OCD Model. From 1988-1997, Dr. Hanna was Chief Editor of the *Journal of Applied Meteorology*, and has published over 100 articles in peer-reviewed journals, six chapters in books, and four books in which he is the primary author.

SESSION 2A

SEA FLOOR MONITORING

Co-Chairs: Dr. Jack B. Irion and Dr. Richard J. Anuskiewicz

Date: December 8, 1998

Presentation	Author/Affiliation
Introduction	Dr. Jack Irion Minerals Management Service Gulf of Mexico OCS Region
Investigations of Live/Hard-Bottom Areas Offshore Florida and Louisiana	Dr. Richard J. Anuskiewicz Minerals Management Service Gulf of Mexico OCS Region
Monitoring Archaeological Sites	Dr. Jack B. Irion Minerals Management Service Gulf of Mexico OCS Region
Biological Characterization and Monitoring of Sonnier Bank	Gregory S. Boland Minerals Management Service Gulf of Mexico OCS Region
The Monitoring and Analysis of Operations Sites Forregulatory Compliance	Mr. Les Dauterive Minerals Management Service Gulf of Mexico OCS Region

INTRODUCTION

Dr. Jack B. Irion
Minerals Management Service
Gulf of Mexico OCS Region

The MMS Seafloor Monitoring Program initially began in 1996 as a means to determine if the oil and gas industry was doing all they should to avoid impact to a protected group of biological features off the coast of Mississippi and Alabama. These features consist of carbonate pinnacles clustered along the shelf break that formed as coral reefs during the last Ice Age. Today, these pinnacles are under 300 feet of water and are an important habitat for red snapper and other game fish. This area of 70 lease blocks is collectively known as the Pinnacle Trend and is protected by MMS stipulation. Industry is required to locate these features using remote sensing surveys and to avoid then during pipeline construction, drilling operations, and platform installation. However, since the pinnacles lay out of sight beneath the sea, we, as an agency, had no real way of knowing if industry was carrying out their responsibility to avoid harming them.. It became necessary, then, to develop a means to monitor industry performance and the effectiveness of MMS mitigations applied to permit applications.

Regulations for implementing the procedural provisions of the National Environmental Policy Act (40 CFR 1505.2) state that "a monitoring and enforcement program shall be adopted and summarized where applicable for any mitigation." The MMS, in order to ensure safety and environmental protection, also has the authority under 30 CFR 250.33 (o) for Exploration Plans and 30 CFR 250.34 (s) for Development Plans to require operators to conduct various monitoring programs. More specific guidance to operators has been and can be provided through Notice to Lessees (NTLs), Letters to Lessees (LTLs), and Lease Sale Environmental Impact Statements (EISs). Presently, monitoring programs can be initiated through NTL 98-11 for chemosynthetic communities, NTL 98-26 for site clearance, the Live-Bottoms (Low Relief) stipulation, and the Live-Bottom (Pinnacle Trend) stipulation.

Several schemes were initially suggested to accomplish the initial goal of monitoring the seafloor in the pinnacle trend. These included using ROV cameras and hiring contractors to survey a single block. Our Regional Supervisor for Leasing and Environment, however, supported an alternative, hands-on approach, that involved purchasing a side-scan sonar and positioning equipment and sending MMS scientists into the field. We believed that an in-house MMS monitoring team would give us more flexibility and control, allow us to respond rapidly to emergency issues, and keep costs down. Using the same budget originally allocated for a single survey in the Pinnacle Trend, the monitoring team completed five separate projects in its first season in 1997 and looked at a variety of environmental and operations issues. When combined with the scientific dive team already in existence, MMS was given eyes to see what kind of job we were doing to protect the submarine environment.

As this project was being realized, added weight was given to the need for developing a monitoring program by the Government Performance and Results Act of 1993, as amended in 1997. This act requires federal agencies to report on their performance in terms of measuring "outcomes" that result from their activities, rather than outputs. More specifically, MMS is required to ask of itself how effective the agency is in ensuring environmentally sound OCS operations. The seafloor monitoring program became an important tool for managing for results and has been expanded beyond its original mandate to assess the Pinnacle Trend to include a sample of virtually all types of mitigations affecting the seafloor.

The second field season of the seafloor monitoring program concluded in November of this year and was notable for achieving a number of successes despite an unusually active hurricane season. In fact, only one proposed project was totally canceled, and this after suffering not one, but three cancellations for weather. The background on this project, which continues monitoring efforts at biologically diverse Sonnier Bank, and is now scheduled for next June.

By combining the technologies of side-scan sonar survey and SCUBA diving, MMS scientists are able to directly study significant seafloor features that come to light as a result of oil and gas industry surveys. In this way, we are able to better apply appropriate mitigative requirements for their protection without being overly restrictive to industry. A good example of this is our assessment of a newly discovered coral habitat off Louisiana. Dr. Rik Anuskiewicz summarizes this project as well of the results of an experiment conducted to compare the effectiveness of high resolution side-scan over photo-documentation surveys in the eastern Gulf.

The seafloor monitoring program has proven to be useful in assessing archaeological features as well as biological ones. By surveying sunken vessels discovered during lease block or pipeline surveys with our high resolution equipment, we are frequently able to distinguish modern wrecks from possibly historic ones. Six wrecks have been assessed in this way; five proved be modern and of no particular significance. One wreck, discovered in 1998, may be historic and will be investigated by the dive team next year. In addition, the monitoring program has assessed several historic wrecks as part of our responsibility for the management of historic wrecks on the outer continental shelf. By locating and identifying historic wrecks, we can reduce the number of blocks where industry is required to search for them using remote sensing survey at 50-meter survey intervals. In this way, we have already eliminated more than 20 blocks from this requirement at an estimated savings to industry of more than a million dollars.

Having this equipment and expertise in-house, we are sometimes able to respond to requests for assistance from other organizations with shared interests. This past summer we were afforded the opportunity to provide assistance to the University of West Florida's exploration for historic shipwrecks in Pensacola Bay. Using our high resolution side-scan we were able to provide UWF with acoustic images of an 18th century Spanish wreck off Santa Rosa Island, and the late 19th century sailing ship *Catharine*. Using our equipment, we were able to relocate and buoy the 439-year-old Emanuel Point wreck in time for a wreath-laying ceremony with the president of Spain to commemorate the establishment of Pensacola by Tristan de Luna. This wreck is one of the original vessels that first brought colonists to Pensacola.

Discovering shipwrecks and exploring coral reefs may seem like a glamorous job, but the seafloor monitoring program also tackles critical operations issues as well. This year alone we have inspected anchor damage from a break away derrick barge, found evidence of an abandoned drill site not properly restored, and examined the site of an oil leak in the vicinity of an artificial reef.

Dr. Jack B. Irion joined the Minerals Management Service in August 1995 with the title of marine archaeologist. Prior to MMS, Dr. Irion served as vice president for Nautical Archaeological Services with the consulting firm of R. Christopher Goodwin & Associates, Inc., in New Orleans, Louisiana. For over 15 years, Dr. Irion provided archaeological consulting services to the Baltimore, Charleston, Mobile, New Orleans, Pittsburgh, Philadelphia, Savannah, Vicksburg, and Wilmington Districts of the Corps of Engineers, as well as to the Maryland Port Administration, and the State of Tennessee. Dr. Irion received his B.A. (1974) and M.A. (1977) in Archaeological Studies from The University of Texas at Austin. He was awarded his Ph.D. from the Institute of Latin American Studies of the University of Texas in 1991. During his career, Dr. Irion has specialized in conducting remote sensing surveys for shipwrecks, which succeeded in locating such historically significant vessels as the C.S.S. *Louisiana*, the sailing barque *Maxwell*, and the steamboats *Princess*, and *Kentucky*. In addition, he has directed numerous diving investigations on historic shipwrecks, including the steamship *Columbus* and the Civil War gunboats *Tawah* and *Key West.* Most recently, he has participated in MMS investigations of the Civil War vessel U.S.S. *Hatteras* and the steam packet *New York.*

INVESTIGATIONS OF LIVE/HARD-BOTTOM AREAS OFFSHORE FLORIDA AND LOUISIANA

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

INTRODUCTION

The following three field investigations are a part of the Gulf of Mexico Region (GOMR) Sea Floor Monitoring Program. These investigations used high resolution side-scan sonar imagery and diver hands-on verification of data to make recommendations about future projects with similar informational needs. These three field projects represent and support new imagery methods to access the presence, absence, and potential impact to hard/live-bottom biological communities living on the sea floor of oil and gas development. Hard/live-bottom communities can be defined as "sea grass communities or those areas which contain biological assemblages consisting of such sessile invertebrates as sea fans, sea whips, hydroids, anemones, ascidians, sponges, bryozoans, or corals living upon and attached to naturally occurring hard or rocky formations with rough, broken, or smooth topography; or areas whose lithotope favors the accumulation of turtles, fishes, and other fauna (Bull 1998)."

DESTIN DOME 56 UNIT EXPORT PIPELINE ROUTE SURVEY

Background

The first field project utilized a dual efforts of high resolution side-scan imagery and MMS diver evaluation to investigate the presence, absence, and potential impact to biological habitat of a proposed Chevron export pipeline. Chevron's initial photo-documentation biological survey of the proposed pipeline route identified one area of hard/live bottom communities. Chevron then resurveyed a segment around the live-bottom area to find a new route that would not impact the biological habitat. The focus of the MMS high resolution side-scan survey was to determine if Chevron's new route would bypass and avoid patches of live-bottoms identified in the initial Chevron survey (Dauterive 1998).

Field Methods

A sonar image of a patch of live bottom that was identified by the initial Chevron photo-documentation survey of the proposed pipeline linear route was captured as a reference image for the side-scan survey of the pipeline reroute. The MMS side-scan survey was conducted using a high-resolution, 300-kHz Marine Sonic Sonar set at a scanning range of 150 meters per scanning channel. Next the MMS side-scan plotted positioning over the proposed reroute by using the Trimble NT200D Differential Global Positioning System (DGPS) with real time position accuracy of ± 5 meters. The sonar DGPS was interfaced with a laptop PC running the GPSNAV navigation program, which provided steering guidance to the helmsman. An anomalous sea floor image was recorded during the survey of the pipeline reroute. A marker buoy was deployed at this spot and the MMS Scientific Dive Team conducted circle and linear search of the area.

Findings

Two teams of divers searched the area around the marker buoy and no identified live-bottom features. The divers reported and described the sea floor as primarily a fine, white, sandy bottom intertwined with large patches a darker brown sand. Initial MMS analysis of the color difference in the sand suggests that the brown patches were like algae attached to larger grains of sand.

SEA FLOOR TOPOGRAPHIC HIGH IN WEST CAMERON AREA, REEF OR NO REEF

Background

An unusual topographic high was identified as a part of routine lease block shallow hazard/archaeological report. This underwater feature trends almost north/south, is approximately 2,000 feet long, 100 foot wide near the center, and rises about 10 to 17 feet off the surrounding sea floor. The purpose of the MMS field investigation was to characterize the features's geologic composition and evaluate the potential hard-bottom biological habitat. This characterization was accomplished by examining seismic, sonar, and fathometeric remote-sensing survey data and integrating these data with divers observations for the following geological reconstruction of this feature.

Features Geology

Based on examination of seismic data, side-scan sonar, direct diver observation, and collected rock samples, this geologic feature appears to be the "up thrown" side of a fault related to the dominant salt diapir. The consolidated fine grain sandstone, siltstone, and mudstone is in well defined bedding planes that define the base of the feature suggest sediment burial at depth and later uplift. The hard calcareous material over this rock is due to subsequent reef building on the sea floor high. Seismic evidence for this fault is obscured due to the attenuation of seismic wavelets by gas permeated shallow sediments in the area (Dempre 1998).

The following biological information and discussion were taken from a trip report prepared by biological oceanographer Greg Boland (Boland 1998) for GOMR in August 1998.

Rock samples collected from the upper portion of the feature were examined by an MMS geologist, and the feature was characterized geologically as a calcareous-like material that appeared to be honeycombed with many open spaces and cavities. The texture was extremely rough and appeared to be biogenic in origin. Diver visual observations of horizontal bedding planes and fine grained sediment under the carbonate cap suggest that the underlying formation is composed of sedimentary rock (claystone or siltstone) that has been broken and uplifted, presumably by the nearby underlying salt diapir. Divers' observations began away from the feature on soft bottom. Small outcrops of hard substrate were first encountered at a depth of about 23.8 m as divers approached the feature. Continuous and solid hard bottom was observed beyond the smaller outcrops at a depth of 22.9 m. The rise in the bottom was abrupt but smooth and not a sharp edge or escarpment.

Near the center of the feature, or essentially the top of the ridge, numerous grooves or small fissures in the substrate ran parallel the orientation of the feature, almost north-south. These grooves ran continuously as far as the divers explored and probably represent expressions of sedimentary strata, uplifted, tilted and exposed. The entire feature was below a distinct nepheloid layer, and underwater visibility was estimated to be 10 m above the nepheloid layer and only 2 m at best on the feature itself (i.e. the bottom).

Feature's Biology

Basic biological overview indicates that the dominant biological characteristic is a near 100% cover of leafy algae. The algae was partially encrusted but also had a substantial branching component forming bushy expressions over 60-70% of the substrate. Many areas were 100% covered in algae, and large patches were easily dislodged from their attachment to the bottom. A number of encrusting invertebrates were also observed including sponges (bryozones and a few hard corals).

Attached fauna was most prominently representated by numerous remnant parts of sea-whips, genus *Leptogorgia* and *Lophogorgia*. The dead stalks were completely encrusted in sediment-laden algae similar to the substrate in general. Approximately 95% of the sea-whips did not show any exposed live tissue. A few hard scleractinian corals were observed including some occasional healthy colonies of ivory bush coral, *Oculina diffusa*. Some of the ivory bush corals were completely white without symbiotic algae, and some were dark brown representing heavy colonization by symbiotic algae. These corals ranged from a few cm to 6 cm. Two colonies of the reef-building coral *Siderastrea* sp. were also seen and measured about 6 cm in diameter.

Other invertebrates observed included an olive shell and several small Murex (at least one was alive). Several fire worms, *Hermodice carunculata* were seen, both on the substrate and on the stalks of dead sea-whips. Inside depressions and small crevasses an occasional short-spined urchins *Echinometra* sp. was observed.

Fisheries—by far, the dominant fish species observed (by biomass) was the red snapper. Many hundreds of red snapper swam circles around the divers at all times, presumably in search for food. Their length ranged from 20-30 cm.

Other fish species observed included:

- One large jewfish, sound only
- Several grey triggerfish
- Numerous juvenile tomtate
- Equal numbers of unidentified juvenile fish, possible vermillion snapper
- Several Beaugregory damselfish
- Several belted sand bass
- Several slippery dick wrasses
- One white spotted soapfish
- One sheephead
- One sand perch
- One juvenile cubbyu

Also seen breathing above the reef structure was one large loggerhead turtle whose carapace length was estimated to be about 75 cm.

Findings

Boland (1998) comments that it appears the ridge feature once supported a relatively diverse hard-bottom community of invertebrates. However, due to unknown changes in the marine environment, the common algae observed on this feature gained a substantial advantage over the other invertebrate components. This dominant algae continued overgrowing and killing around 90% of the sea-whips, as evidenced by their remaining skeletal stalks. Boland also suggests that a large percentage of other encrusting forms such as bryozoans and sponges were also struggling to survive being overgrown by the dominant algae.

At this time, it is difficult to predict whether the present condition at this reef will continue and the algae overgrowth will persist. However, this habitat represents a hard-bottom\live bottom system characterized by a dominant single species of leafy algae. What also must be noted is at least one species of hermatypic or reef-building coral is present; the reef can technically be represented or called a "coral habitat." Boland further indicates that even the existence of only one coral colony represents a narrowly defined set of environmental conditions rare for the surrounding area. Therefore, the reef recently designated "RiknJack Reef" warrants environmental protection equivalent to Sebree Bank off south Texas or similar hard-bottom areas of the Florida panhandle.

PHOTO-DOCUMENTATION SURVEYS VERSUS HIGH RESOLUTION SIDE-SCAN

Background

The GOMR presently requires operators and lessees, subject to the "Live-Bottom" stipulation in the eastern Gulf of Mexico (EGOM), to conduct photo-documentation surveys as a part of a Live-Bottom Report to be submitted to the MMS. GOMR prepared revised guidelines describing the methodology to be employed on these surveys that became effective on 15 February 1989. Under these guidelines, operators are given the option to either "clear" site specific areas or, alternatively, their entire lease block. Site-specific surveys can be conducted in one of two ways. The most commonly used method by the oil and gas industry is a radial pattern consisting of "12 transacts at approximately 30 degrees to each other radiating from the drill site(s) out to at least 1,000 m." Alternatively, surveys can be conducted along a grid pattern of 200 m spacing designed to "coincide with the shape/configuration of each known or suspected hard or live-bottom area within 1,000 m of the proposed drill site(s)." Lease-block surveys are to be conducted along parallel transacts spaced 200 m apart (Irion 1998).

Photo-Documentation Field Methods

Photo-documentation surveys are to consist of both "television" (videography) and color-still photography. Typically, photo-documentation surveys use cameras (mounted in a large sled) that are towed a few feet above the bottom from a vessel traveling about 3 knots. These surveys are complex and costly. The towed equipment, including the mounting sled, weighs about 700 pounds and must be deployed from a vessel at least 100 feet long equipped with a powerful lifting A-frame. None of the photo-documentation contractors in the Gulf performing this service owns their own vessel, so the equipment has to be installed in a contracted vessel generally an oil field supply-type boat. At least a day is required to install the equipment and mobilize the vessel. This includes welding a large hydraulic winch onto the deck, installing the complex electronic array into the boat, and testing and troubleshooting equipment before departure.

Problems in Data Collection and Interpretation Using Photo-documentation

Despite the of effort required to conduct an optical survey of this nature, these surveys are limited in their ability to locate and document hard-bottom features by two variables; 1.) the clarity of the water and 2.) survey line spacing interval. In both the Destin Dome and Pensacola areas there is normally present at the sea floor a nepheloid layer, which is a turbid zone of suspended sediment particulates that can extend 3 to 6 m into the water column. The suspended particulates restrict underwater visibility to about 3 m or less. As a result, the only part of the sea floor that is imaged during a typical lease block survey is 25 survey line swaths about 3 m wide spaced 200 m apart. A quick calculation of block area coverage indicates that only about 0.5% of the total surface area of the block is photo-documented. Any hard-bottom areas that are less than 200 m wide and fall in between the survey lines would go undetected.

Better Technology Produces Better Survey Data

Because of the insignificant sample size and apparently limited effectiveness of the photo-documentation survey, MMS and Chevron U.S.A., Inc. entered into a cooperative agreement to explore the use of high resolution acoustic imaging (e.g. high resolution side-scan sonar) equipment in lieu of standard optical imaging systems for live-bottom surveys in the eastern Gulf.

In August 1998 MMS marine scientists took part in a simultaneous photo-documentation and high resolution sonar survey in Destin Dome Area, Block 1. On behalf of Chevron U.S.A., Inc., Continental Shelf Associates (CSA) was contracted to conduct a standard photo-documented survey. The following is a short description on how a side-scan system works. Side-scan sonar transmits sound waves to both sides of a towed sensor and measures the rate at which these waves reflect as echoes off targets on the bottom. Unlike optical cameras, imaging systems that rely on the propagation of sound under water are unaffected by water turbidity. The rate of reflection off objects of varying density is measured and processed by the instrument to produce an image of the sea floor.[1] The typical side-scan sonar used for lease block surveys in the Gulf of Mexico is a 100 kilohertz (kHz) instrument. The system employed by MMS for this investigation utilizes a Marine Sonics 300 kHz tow-fish transducer. The higher frequency sonar produces a clearer image of the sea floor, which makes it possible to distinguish details and sea floor textural changes not visible to the lower resolution instrument. There is, however, a trade-off in range, which is related to the physics of how sound travels through water. A medium frequency 100 kHz system can image a survey swath of the sea floor 600 m to either side of the towed sensor. The effective range of the 300 kHz system is about 150 m to each side. If we were to use the standard photo-documentation line-spacing interval of 200 m, the 300 kHz side-scan can image 100% of the sea floor with 50% overlap. This would be accomplished in the same amount of survey time required to sample only 0.5% of the sea floor using the standard photo-documentation methodology (Irion 1998).

A question to ask when comparing these two sea floor scanning system is: "Can the side-scan really 'see' things the camera misses?" Based on our field work and observations the answer to that question is "yes." As previously described, the towed camera array only "sees" what is directly beneath it. The side-scan, on the other hand, can image objects up to a 150 m to either side of the tow-fish. As a result, small, discreet hard-bottom areas that would be missed by the camera are easily

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[1] The faster the sound pulses (frequency), the greater are the number of waves that pass a point. Frequency is measured in cycles (or waves) per second. One cycle per second is called a Hertz (Hz).

distinguished in the side-scan record. Sonar images taken by MMS illustrate hard-bottom areas detected by our side-scan survey in Destin Dome Block 1 that were not detected by CSA's photo-documentation survey. One image was a small, rocky outcrop measuring about 7.5 m by 4 m. Although it is relatively small, the fact that it serves as a biological habitat is clear from the school of fish that are seen clustered about it. High frequency sonar often shows marine fauna in the water column. Another MMS sonar image was a larger patch of exposed, low-relief hard bottom rising less than a meter off the sea floor and measuring approximately 1,500 m^2 in area. Again, neither the small outcrop nor the large, nearly football field-size patch of hard bottom were detected in the photo-documentation survey, or in an earlier hazards survey conducted by CSA using medium frequency 100 kHz sonar.

Since adverse weather conditions cut short MMS's participation in the CSA survey, we re-scheduled an independent investigation in September 1998 to collect additional images of hard-bottom features off Florida. The first feature to be imaged was a significantly large ridge bisecting nearly the entire block in Destin Dome Block 56. This feature, which rises some 5 m off the sea floor, was clearly detected by the side-scan, which also provides an instant appreciation for its size and shape that the camera would not. The second hard bottom imaged during this survey is a popular local dive spot, known as "Green's Hole," located just a few miles from Pensacola Bay. This feature consists of two rocky outcrops occupying an area of approximately 780 m^2 that support a rich diversity of marine organisms. Because of its relatively small area, a feature such as Green's Hole likely would not have been detected by photo-documentation survey alone.

Findings

Based on our observations, we believe that high-frequency side-scan sonar (300 kHz or greater) offers a means of locating and documenting the extent of hard-bottom areas in the eastern Gulf of Mexico that is superior to those photo-documentation surveys presently required by MMS. Side-scan will likely not, however, detect such live-bottom areas as algal mats. However, these features are transitory and non-permanent, and according to our marine biologists, impacts to them would likely be short-term and reversible. What we believe to be one minor shortcoming is more than mitigated by many major advantages. For example, using the presently required survey-line spacing of 200 m, 100 percent of sea floor can be imaged acoustically as opposed to only about 0.5 percent using optical systems only. In addition, high-resolution sonar can distinguish subtle textural changes in the sea floor and low-relief features that 100 kHz systems set on the maximum range scale will not. Furthermore, most geophysical survey companies operating in the Gulf presently employ either Klein or EdgeTech (EG&G) sonars with dual-frequency 100/500 kHz transducers. By a simple flip of a switch, the same units that are presently used in the 100 kHz mode for hazards surveys can be operated in a high-resolution 500 kHz mode. Finally, by requiring a slightly tighter line spacing (e.g. 200 m as opposed to 300 m) for the hazards surveys in the EGOM, hard-bottom areas could be accurately mapped during this stage of data gathering rather than requiring a second, costly survey.

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Rik 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.

MONITORING ARCHAEOLOGICAL SITES

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Minerals Management Service
Gulf of Mexico OCS Region

Archaeological sites are among the resources on the Outer Continental Shelf (OCS) that are managed by MMS. These seafloor features generally are reported to MMS as "potential" sites by the oil and gas industry after they conduct remote-sensing surveys within their lease blocks. Potential sites may relate to either possible historic shipwrecks or prehistoric sites dating to the last Ice Age when sea level was lower than it is today. Possible shipwreck sites include areas either where anomalous readings of ferrous metals were detected or where the side-scan sonar image shows some unusual bottom feature that resembles a vessel hull or shipwreck debris. Possible prehistoric sites are identified in the subbottom record as relict landforms where early man was likely to have camped, such as channel margins, river terraces, levees, and point bars. It is generally impossible to establish from the remote-sensing records alone if any of these "potential" sites are, in fact, historic or prehistoric sites.

Lacking this vital information, MMS establishes zones of protection around the potential sites identified in the remote-sensing record and directs industry to avoid these features during its operations. By performing monitoring surveys to verify that industry complied with these permit requirements, MMS also has been able to determine whether many of these "potential" shipwreck sites are actual historic sites worthy of federal protection. In most instances, these sites have been found to be modern and can be dismissed as mere hazards. However, a number of significant historic sites have been located and documented on the federal OCS in the Gulf of Mexico as a result of cooperation between industry, the MMS, and private citizens. This paper discusses some of the significant sites that have been discovered on the OCS and their importance to the history of the Gulf of Mexico. These sites include a steamship that was one of the first links of trade with a fledgling Republic of Texas, the Civil War wreck of the USS *Hatteras*, a vessel we believe may have been built as a Civil War blockade Runner, and numerous casualties of the German submarine Wolf Packs during World War II.

THE STEAMSHIP *NEW YORK*

History of the Vessel

The *New York* was constructed in New York City in 1837 for the Southern Steam Packet Company, a partnership formed between J. P. Allaire, Charles Morgan, and John Haggerty. Vessel Registration No. 340 (National Archives), dated 13 October 1843, identifies the vessel as a steamboat 165 feet long, with a beam of 22 feet, and a depth of 10 feet. It was described as having one deck and two masts. A drawing of the ship on file in the Mariner's Museum in Newport News, Virginia, shows a cross-head type steam engine (Figure 2A.1).

During 1837 and 1838, the *New York* made regular trips between New York and Charleston, South Carolina (Heyl 1969, 225). After the Southern Steam Packet Company was dissolved, the vessel was taken over by Morgan and transferred to New Orleans, where it was engaged in trade between that city and Galveston, in the newly independent Republic of Texas. Her first voyage under Morgan was undertaken November 1838, under consignment to McKinney & Williams, agents (Hayes 1971, 323). Fierce competition soon broke up Morgan's monopoly on the Galveston-New Orleans trade, and he responded by extending the *New York*'s route to include New York City. In May 1839, the *New York* undertook the first regular steamship service between Galveston and the Port of New York, with stops at Key West and Charleston. The ship was advertised to make the voyage in eight days and had accommodations for 200 passengers. The cabin rate between Galveston and New York was $110.00 (Hayes 1971, 326).

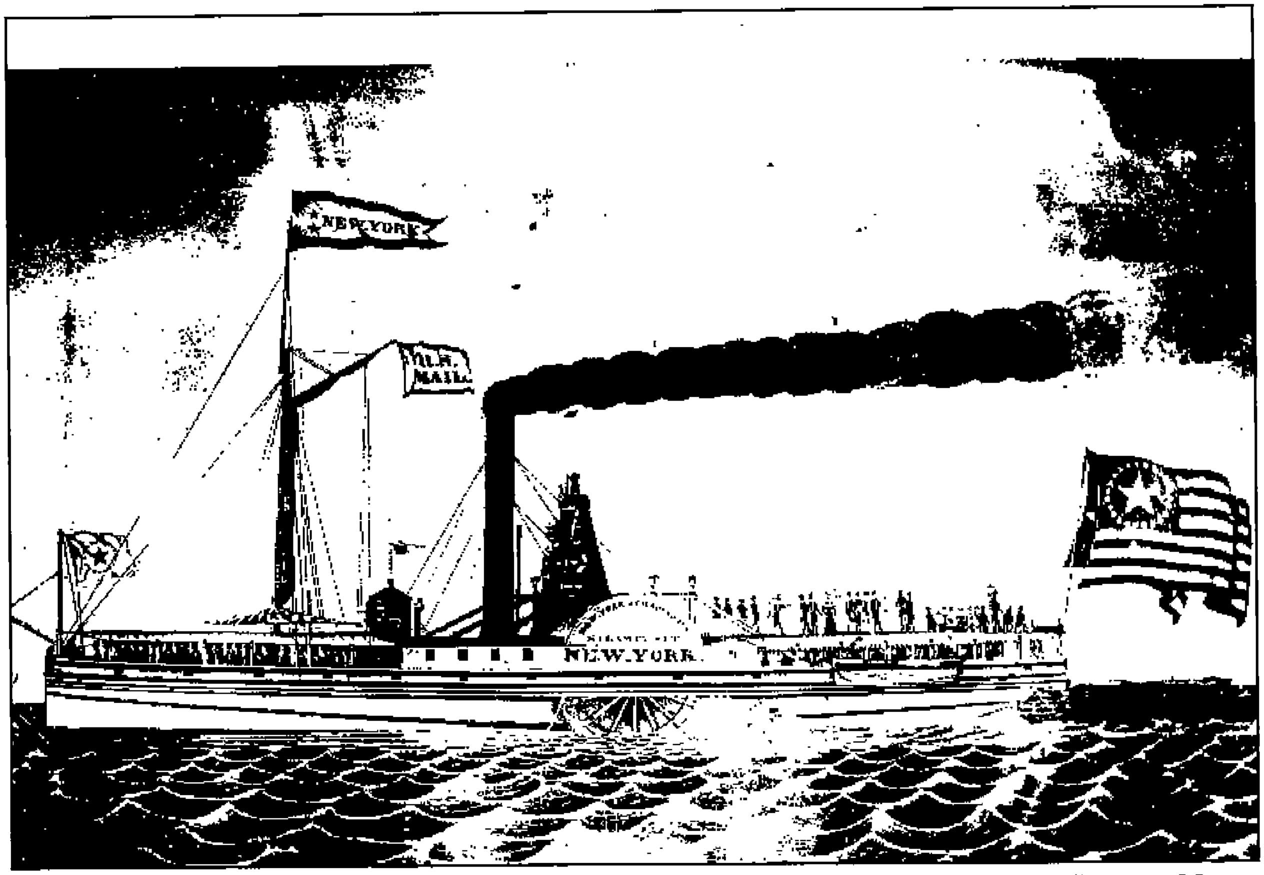

Figure 2A.1. Drawing of the steamship New York. Courtesy Mariners' Museum, Newport News, Virginia.

The *New York* departed Galveston for what was to become her final voyage on 5 September 1846. By 10 p.m. that evening, she came to anchor in heavy seas some 50 miles eastward of Galveston, having unknowingly sailed into the path of a hurricane. After a fearsome pounding by seas and wind, which lifted the promenade deck, stove in the starboard guard and wheel house, carried away the smoke stack, and sprang the hull, the *New York* foundered in 10 fathoms of water at 6 a.m. on the morning of September 7 (*Daily Picayune*, 10 September 1846). Seventeen passengers and crewmen, including five children, were lost when the ship went down. The remaining survivors clung to rafts fashioned from a portion of the promenade deck and other wreckage for more than 12 hours until they were rescued by another steamer, the *Galveston* (*New Orleans Gazette*, 10 September 1846).

Discovery of the Wreck

A group of amateur divers from New Iberia, Louisiana, began searching for the wreck of the *New York* in 1985. Working only from the sparse clues contained within the survivors' accounts published in the New Orleans newspapers in 1846, the divers deduced the general location of the wreck site. They subsequently interviewed shrimpers who worked in the area to obtain information on the location of net hangs.[1] Over the course of the next five years, the team systematically tested each hang site in a ten-mile square area using a fish finder to locate targets above the seafloor. After a supreme amount of effort and patience, utilizing equipment that is primitive by hydrographic surveying standards, the divers discovered in 1990 a wreck they believed to be that of the *New York*. Materials recovered from the site, including coins and a mortising machine patented in 1836, were consistent with the 1846 sinking of the steamer. Subsequent examination of the site by MMS confirmed the presence of a low pressure steam engine at the site, which also is consistent with the cross-head engine mounted in the *New York* (Figure 2A.2).

MMS Involvement with the *New York*

The High Island Area lease block in which the *New York* lies was surveyed by an oil and gas company for shallow hazards in 1988 at a line spacing of 150 meters, the survey interval required by MMS at the time for all blocks in the archaeological high probability area. The survey recorded a magnetic anomaly with a perturbation of 100 gammas over the wreck site, but the consulting archaeologist at the time did not associate it with the location of a significant historic shipwreck. Subsequently, a study conducted for the MMS with the purpose of determining high probability areas for the location of historic wrecks in order to reduce the survey interval for those blocks from 150 meters to 50 meters placed the wreck of the *New York* in Vermilion area, more than 160 kilometers away from its actual location. As a result, survey requirements for the block containing the wreck site were reduced to 300 meters, further reducing the chances that MMS would have ever identified the site. Fortunately, the leader of the team that discovered the wreck shared the location of the site with MMS in the interest of preserving it from inadvertent destruction by oil and gas development in the block.

MMS first visited the site of the wreck in July 1997, for the purpose of identifying the wreckage and conducting an intensive remote sensing survey in order to assess the site's size and extent. There was a particular concern to investigate the possible relationship between other magnetic anomalies discovered during the 1988 survey and the shipwreck.

Survey was conducted along north/south tracklines spaced 30 meters apart over an area 1,500 feet wide (east-west) by 4,000 feet long (north-south). Survey instrumentation included a Geometrics G-866 proton precession magnetometer and a Marine Sonics Seascan 600 kHz side-scan sonar. Positioning control was maintained with a Trimble NT200D differential GPS receiving the U.S. Coast Guard differential beacons with an accuracy of ±10 meters. The side-scan sonar receives positioning input from the DGPS and links the image files with the positioning files. The magnetometer was time synchronized to the DGPS and magnetic data were output to a computer for storage. The time-synchronized magnetic and positioning files were later merged in post-processing to produce a single X, Y, Z coordinate file. The resulting file was contoured using *Surfer* software. Magnetic contouring revealed that wreck debris was scattered over the seafloor for a distance of

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[1] Many shrimpers maintain personal logs of obstructions within the areas in which they operate. These hangs often go unreported since this knowledge provides them a distinct economic advantage over competitors.

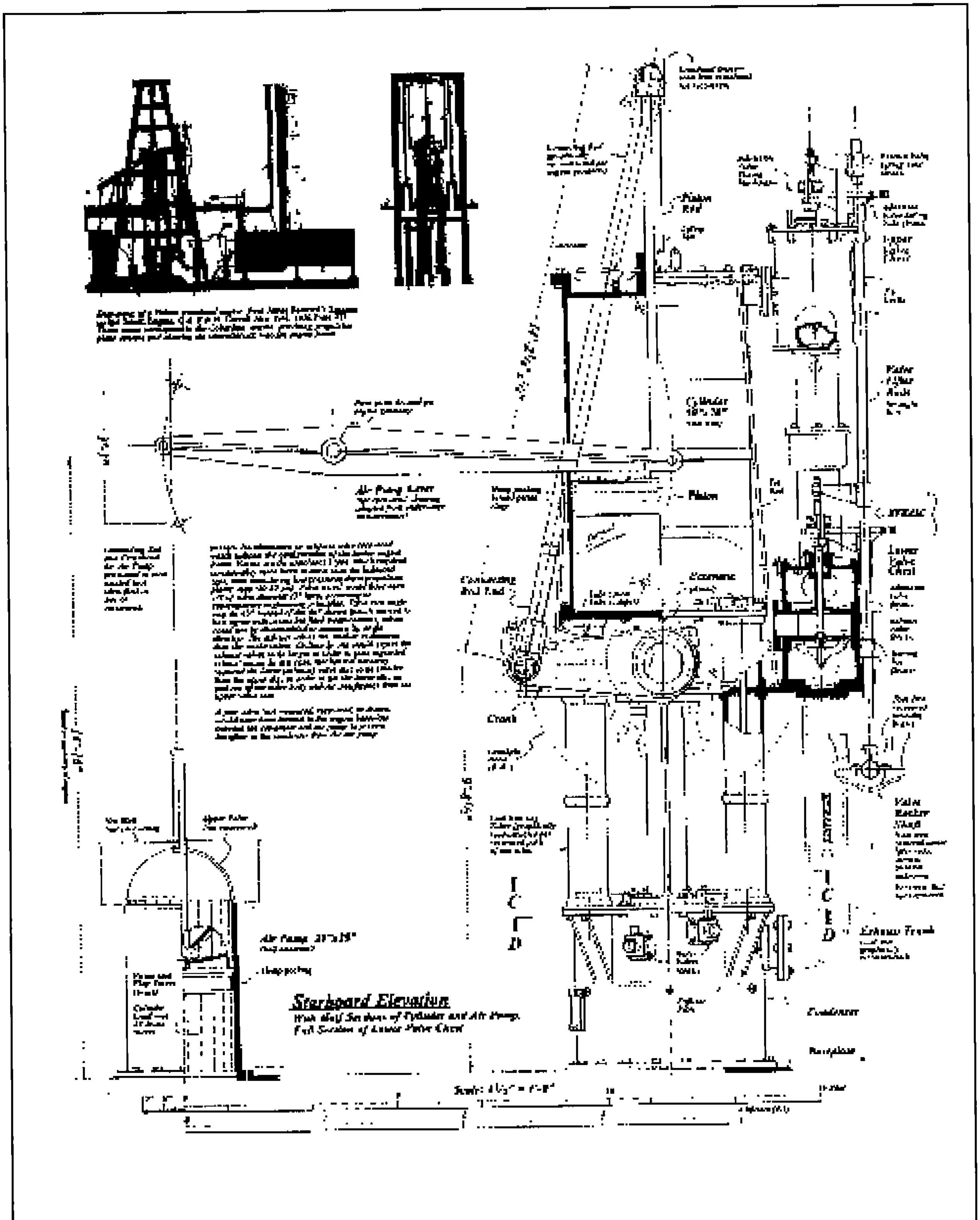

Figure 2A.2. Example of a crosshead steam engine, ca. 1828.

about 450 meters. The principal areas of magnetic perturbation centered over the hull (containing the steam engine) and a paddle wheel to the east (Figure 2A.3). Several small, concentrated anomalies were observed curving to the south east from the main wreck site. At present, none of these anomalies have been tested archaeologically.

Conclusions

The wreck of the *New York* serves as an important lesson for the MMS/GOMR archaeological program. The fact that the wreck site lies outside the currently designated high probability area for historic shipwrecks suggests that the model on which this designation is based needs to be reevaluated. Secondly, it highlights the importance of developing better public outreach to the sport diving community and other maritime interests to enlist their trust and cooperation in helping to locate historic wrecks in the Gulf of Mexico. It is unlikely that MMS would have discovered this nationally significant site without their assistance and cooperation. Finally, the analysis of the wreck by MMS demonstrates that the potential site size for a shipwreck on the OCS can exceed 24 ha (61 acres) of bottom land and be characterized by multiple, individual magnetic anomalies scattered over a wide distance. Since the majority of vessels that wrecked on the OCS did so as a result of foundering and being literally torn apart during a violent storm, this pattern may be expected to be repeated at other sites and should be considered as a general rule to guide decisions relating to activity avoidance zones.

THE WRECK OF THE *HATTERAS*

A number of important Civil War vessels have been located in state waters, such as the Confederate ironclads CSS *Louisiana* in Plaquemines Parish, Louisiana, and the *Huntsville* and *Tuscaloosa* in the Mobile River. The remains of the Union ironclad *Tecumseh,* whose sinking by a Confederate mine prompted Farragut's famous order "Damn the torpedoes, full speed ahead!" are well known off Fort Morgan, Alabama. Only one U.S. warship, however, was sunk at sea in the Gulf. This important shipwreck, the USS *Hatteras*, has been the subject of repeated investigations by the MMS, the Texas Historical Commission, and Texas A&M University at Galveston.

The USS *Hatteras* was a side-wheel steamer acquired by the Navy in 1861 and armed with four 32-pounder cannon (a 20-pounder rifled cannon was added later). After distinguished service in the South Atlantic Blockading Squadron, the vessel was transferred to the Gulf Blockading Squadron on 26 January 1862. In less than a year, the *Hatteras* captured seven Confederate blockade runners off Vermilion Bay, Louisiana. Early in 1863, she was ordered to join the squadron under Rear Admiral David Farragut, who was attempting to retake the key Texas port of Galveston, Texas. The Civil War in the Gulf is defined by the Northern strategy of the blockade of Southern ports and the daring attempts by Confederate vessels to run this blockade.

As the blockading squadron lay off the coast on the afternoon of 11 January 1863, a set of sails was sighted just over the horizon and the *Hatteras* was ordered to give pursuit. She chased the intruder for four hours, closer and closer into shore, and farther and farther from her supporting fleet. Finally, as dusk was falling, the *Hatteras* came withing hailing distance of the square-rigged, black-hulled

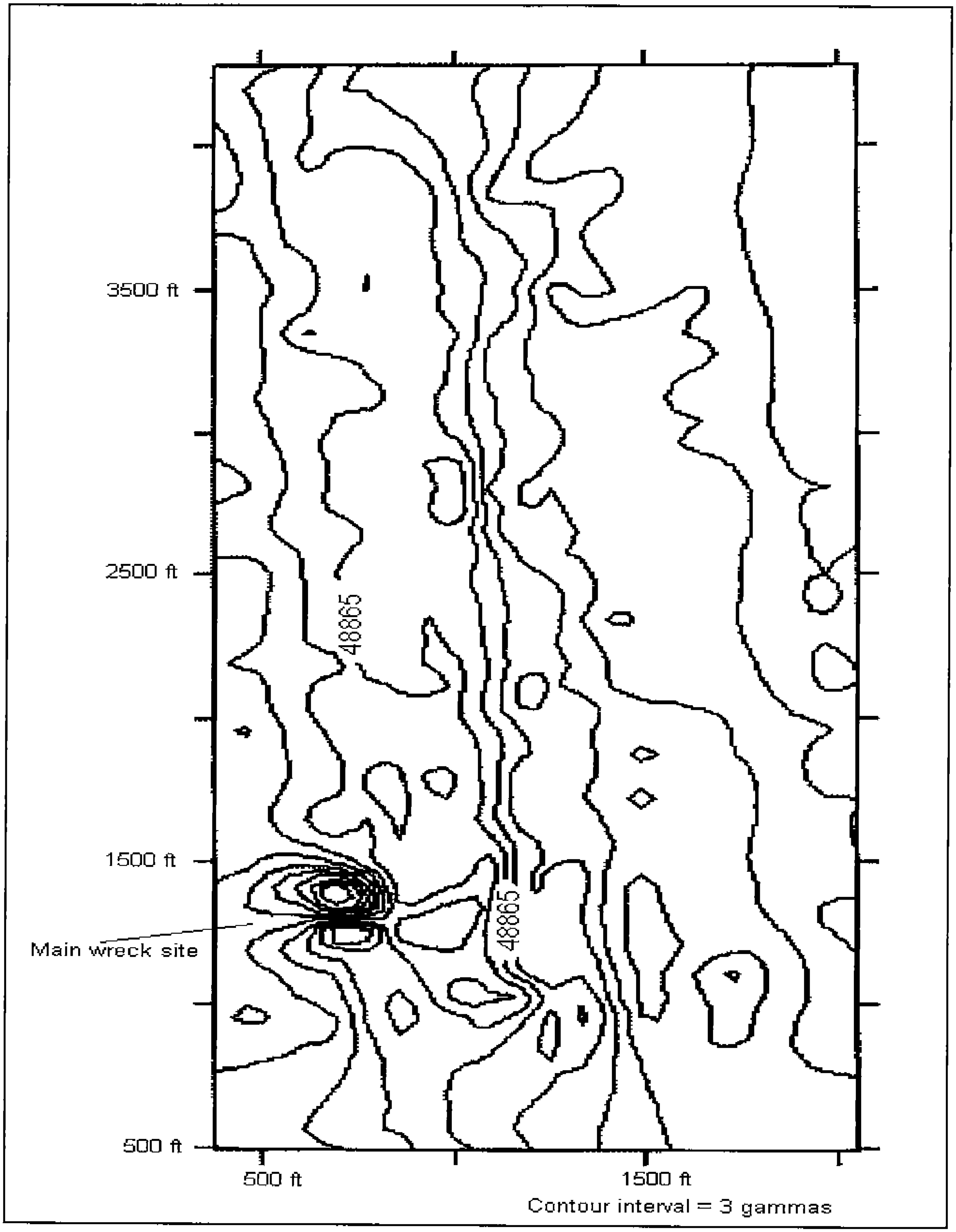

Figure 2A.3. Magnetic contour map of the wreck site of the New York.

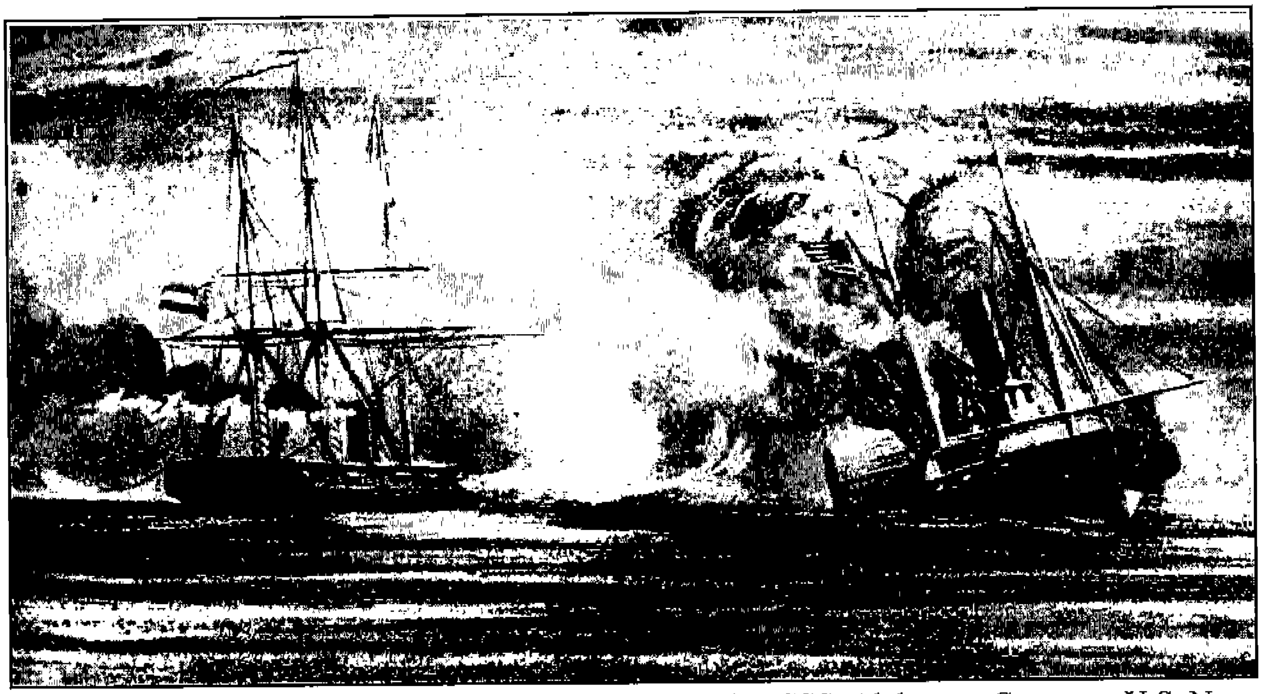

Figure 2A.4. The sinking of the USS Hatteras by the CSS Alabama. Courtesy U.S. Navy Photographic Center.

vessel. Commander Homer C. Blake demanded to know the identity of the ship. "Her Britannic Majesty's Ship *Vixen*," came the reply. Blake ordered one of *Hatteras*' boats launched to inspect the "Britisher." Almost as soon as the boat was piped away, a new reply came from the mystery ship, "We are the CSS *Alabama*!" A broadside from the Alabama's guns punctuated the reply. Within 13 minutes, the *Hatteras*, sinking rapidly, surrendered (Figure 2A.4).

The *Hatteras* today rests in 58 feet of water about 20 miles off Galveston. Her 210-foot long iron hull is completely buried under about three feet of sand. Only the remains of her 500-horsepower walking beam steam engine and her two iron paddle wheels remain exposed above the sea floor. Since the site's discovery in the 1970s, MMS has engaged in periodic monitoring of the wreck to ensure that it is not damaged by surrounding oil and gas lease development. Although the wreck remains the property of the U.S. Navy, MMS has joined forces with the THC and Texas A&M at Galveston to preserve this important archaeological treasure for posterity.

The wreck of the US *Hatteras* is an integral part of the story of the Civil War on the Texas coast, the defense of which is regarded as one of the greatest military feats of the Confederacy. The ship's dramatic history, along with the fact that the remains of the vessel are virtually intact, make it one of the most important underwater archaeological sites in the United States.

HORN ISLAND SHIPWRECK

Another wreck possibly associated with the Civil War in the Gulf was recently documented by MMS. Loran C coordinates of an historic side-wheel steamship off Horn Island, Mississippi, were

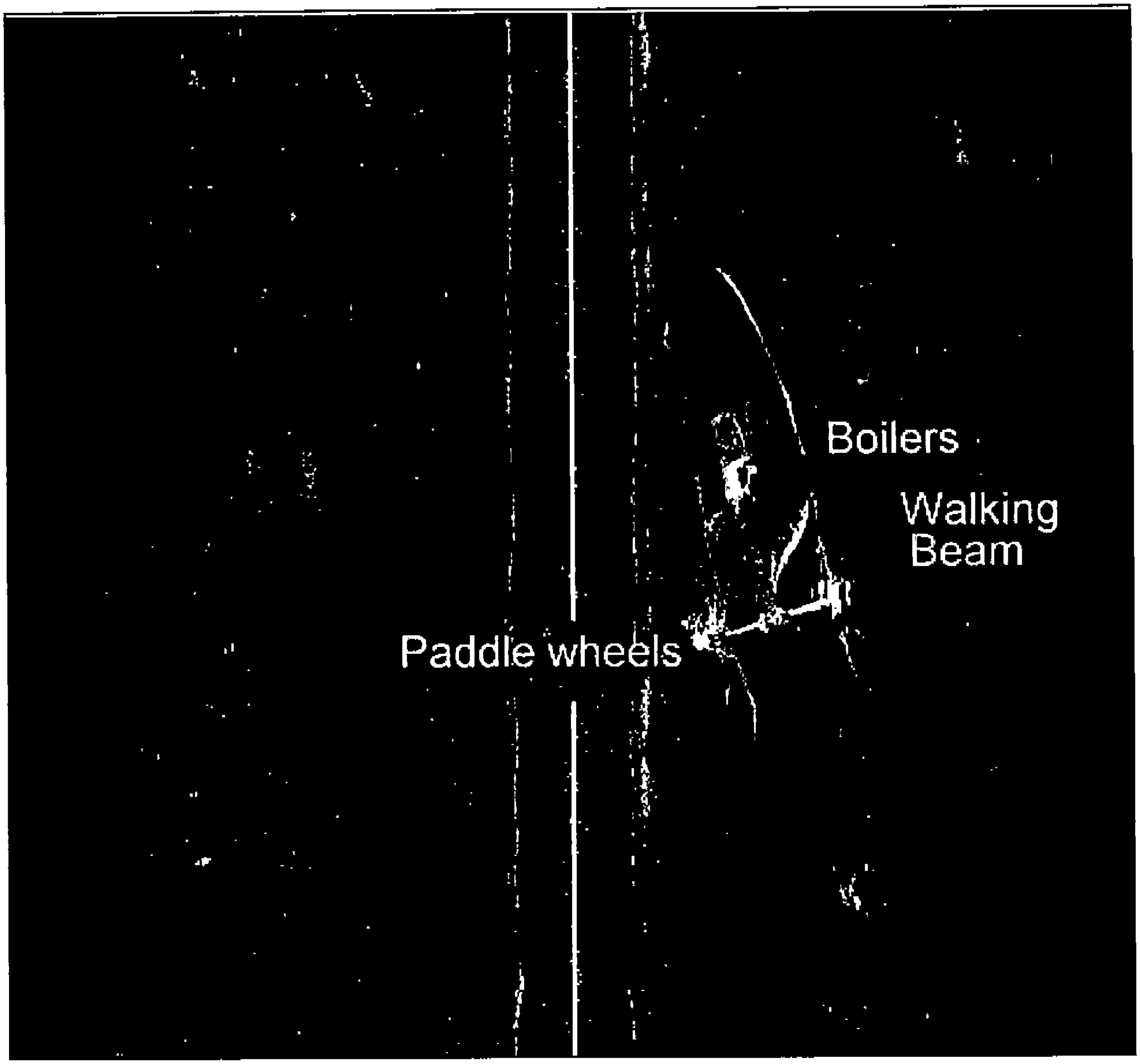

Figure 2A.5. Side-scan sonar image of the Horn Island shipwreck (22HR843).

provided to MMS by an informant. Because of the inherent inaccuracy of Loran C, there was a possibility that this site could lie in federal waters. Side-scan survey and DGPS positioning confirmed that the vessel lies in Mississippi waters. Information about the site was relayed to the Mississippi State Historic Preservation office, who had no information about the vessel in their archaeological site records. The site has been assigned a trinomial designation of 22HR843.

The Horn Island shipwreck is a side-wheel steamship with an apparently intact walking beam engine and two large boilers visible above the seafloor. From the side-scan image, the vessel measures 53.6 meters long by 10 meters wide (Figure 2A.5). Local informants report that it has an iron hull, although this has not been confirmed. Research presently is being conducted to identify the wreck, which most likely dates to the last half of the nineteenth century. Preliminary research suggests that the vessel may be the *Heroine*, which was built in Glascow in 1862 as a blockade runner (Way 1983, 213). After the Civil War, the vessel was used as a towboat in New Orleans and after 1880 was converted into a passenger boat on the New Orleans-Bay St. Louis-Biloxi run. The *Heroine* disappears from the historical record after 1906, which coincides with a major hurricane that made landfall on the Mississippi coast. Could the *Heroine* have been lost in this storm? Is the Horn Island Wreck the last remains of this vessel? Field work to be conducted as part of the seafloor monitoring program next summer may answer these questions. Because of its apparently intact condition, the vessel should be considered to be potentially eligible to the National Register of Historic Places.

WORLD WAR II SHIPWRECKS

Federal law defines an historic site as at least fifty years old. As a result, wrecks associated with World War II now meet that criterion. Nearly all the shipwrecks in the Gulf from that period relate to one cause—attack by the German submarines known as "U-boats." U-boat comes from the German word "Unterseeboot."

During the years 1942 and 1943, a fleet of more than 20 German U-boats cruised the Gulf seeking to disrupt the vital flow of oil carried by tankers from ports in Texas and Louisiana. They succeeded in sending 56 vessels to the bottom; 39 of these are now believed to be in state or federal waters off Texas, Louisiana, and Florida. After their initial, devastating success, U-boat attacks in the Gulf became rare by the end of 1943 after merchant vessels began cruising in armed convoys. The opening of the "Big Inch" pipeline from Texas to New Jersey also contributed to freeing the war effort from relying on ships to transport crude oil.

At least 13 of the U-boat casualties have been discovered, largely through the efforts of the oil and gas surveys. These include the *Cities Service Toledo*, the *Sheherezade*, the *R. W. Gallagher*, the *R.M. Parker*, the *David McKelvey*, the *Hamlet*, the *Heredia*, the *Halo*, the *Bayard*, the *Benjamin Brewster*, the *Gulf Penn*, the *Alcoa Puritan*, and the *Robert E. Lee*. All of these wrecks have substantial physical remains on the seafloor and principally were located using side-scan sonar. The depths of the wrecks range from as little as 36 feet (*Benjamin Brewster*) to more than 4,000 feet of water (*Robert E. Lee* and *Alcoa Puritan*).

The *Cities Service Toledo*, lost in the South Marsh Island Area, is fairly typical of the losses to American shipping during the U-boat war in the Gulf (Figure 2A.6). The *Toledo* was an 8,192-ton steamship built in 1918 (Browning 1996, 140). On 10 June 1942, it left Corpus Christi, Texas, carrying 84,000 barrels of crude oil bound for Portland, Maine. The vessel sailed alone and plied a nonevasive course, making it a sitting duck for the *U-158* under the command of *Kapitänleutant* Erich Rostin. Just two days before, Rostin had sunk the freighter *Hermis* and the tanker *Scheherezade*.

Twenty miles east of the Trinity Shoals Gas Buoy, the *U-158* fired two torpedoes that struck two seconds apart on the starboard side amidships in the #6 and #7 tanks at 1:50 a.m. on 12 June (*Times-Picayune*, 17 June 1942). The vessel immediately listed to starboard and soon was struck by two more torpedoes in the #4 and #5 tanks. The last torpedo was an incendiary that caused the ship to

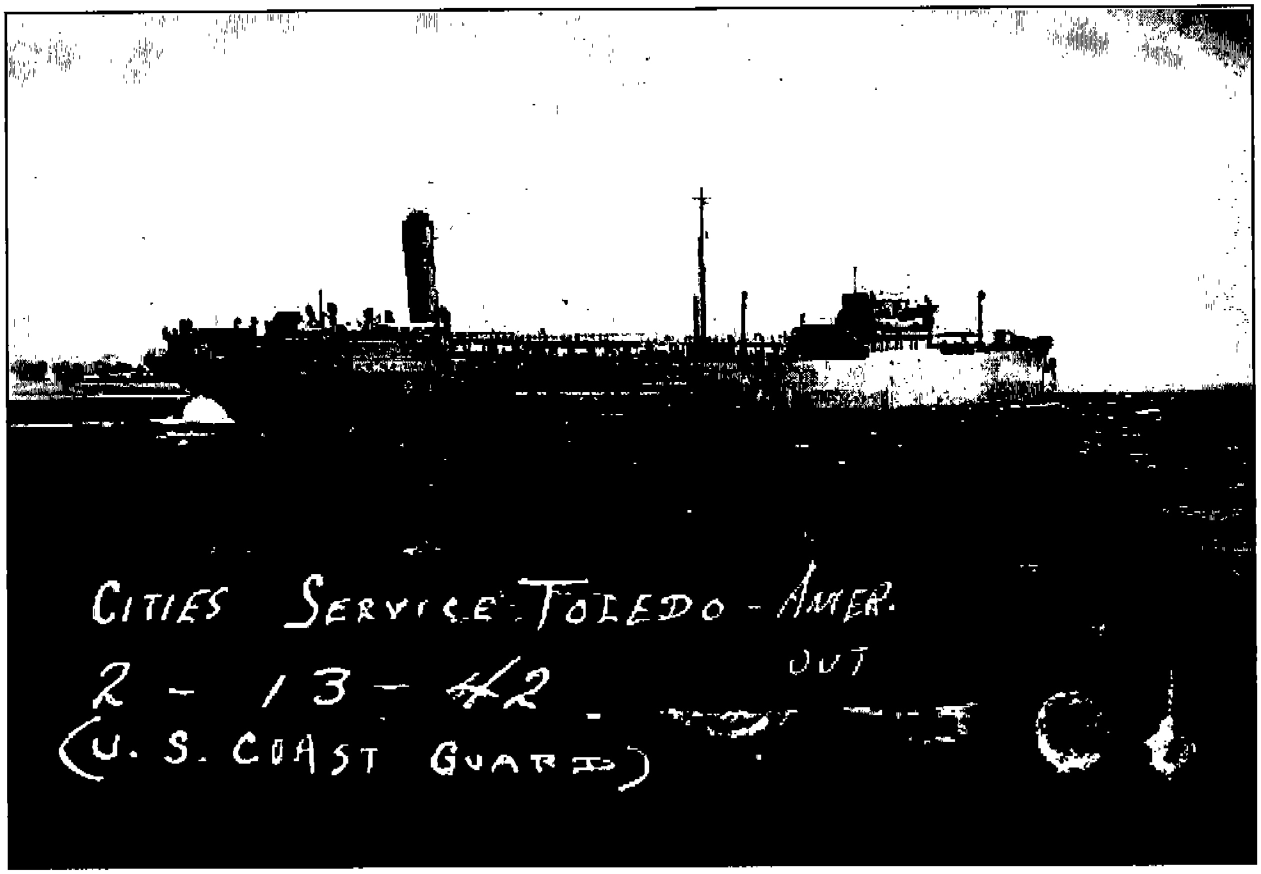

Figure 2A.6. The SS Cities Service Toledo.

burst into flames. The Navy gun crew manned their single 5" bow gun as long as possible and fired 3 rounds at a light they believed to be the submarine. Ceasing after the gun's recoil began to tear the plates from the deck of the badly listing ship, the nine men of the gun crew abandoned the vessel with the rest of the crew of eight officers and 28 men. The explosion and fire had destroyed the life rafts and two of the ship's boats. A third boat was launched but the crew could not clear it from the flaming water surrounding the stricken ship and were forced to abandon it. Seventeen men abandoned the ship in the remaining lifeboat and were rescued by the Norwegian tanker, SS *Belinda,* several hours later. Eight hours after the attack, the tankers SS *Gulf King* and SS *San Antonio* rescued the surviving 13 men in the water. Fifteen men were lost in the attack, including one officer, ten crewmen, and four armed guards. One of the survivors, who had abandoned a law career for life as a naval gunner, commented from his bed in a Marine hospital: "Law is easier any day" (*Times Picayune,* 17 June 1942).

One of the worse casualties in human terms of the U-boat war in the Gulf was the *Heredia*, a 4,700 ton freighter owned by the United Fruit Company (Figure 2A.7). The *Heredia* was bound for New Orleans from Puerto Barrios, Guatemala, with a cargo of 40,000 stems of bananas and 5,000 bags of coffee when she was attacked by the U-506 on 19 May 1942 (Navy Dept.1942a; Browning 1996, 111). Three torpedoes struck the vessel, causing her to plunge beneath the sea stern first within three minutes. Thirty-six men lost their lives in the attack. Among the 23 survivors were two children, a

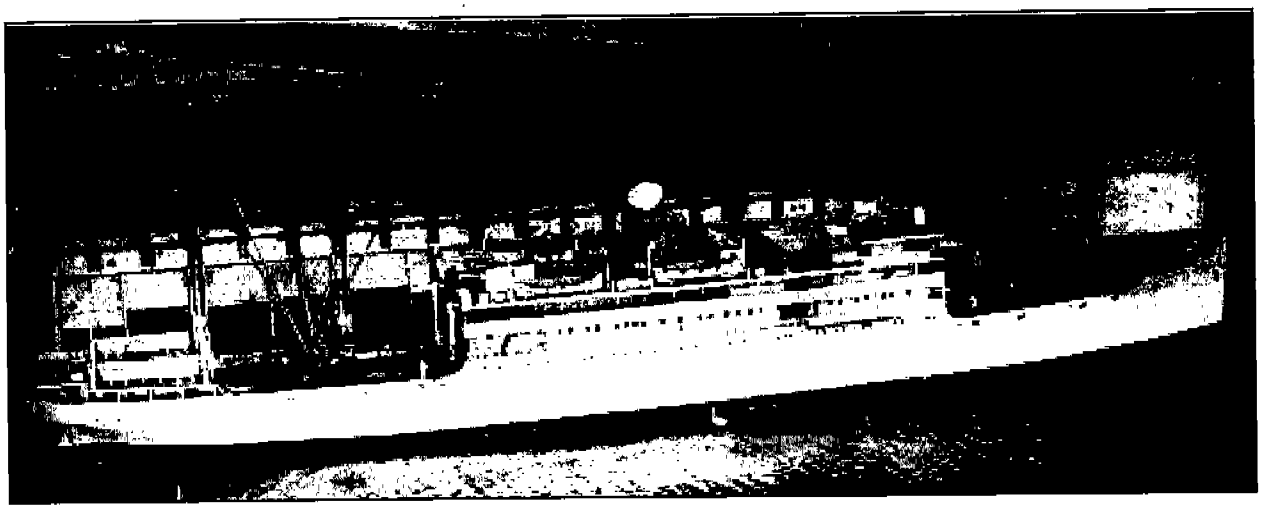

Figure 2A.7. The SS Heredia.

9-year-old boy and an 11-year-old girl, who later recounted that sharks approached her close enough to tickle her feet as she clung to a hatch cover for 15 hours awaiting rescue (*Times-Picayune*, 25 May 1942). In only ten days between 10 May and 20 May 1942, the same U-boat also sank the tankers *Aurora*, *Gulfpenn*, *David McKelvey*, *William C. McTarnahan*, *Sun*, *Gulfoil*, and *Halo* (Wiggins 1995, 234f). The captain of *U-506*, Erich Würdemann, was subsequently awarded the Iron Cross (First Class) and, later, the coveted Knights Cross. Würdemann was responsible for sinking 16 vessels during his career, costing the Allies nearly 87,000 tons of shipping, before the U-506 was itself sunk by an US B-24 Liberator aircraft off Vigo, Spain on 12 July 1943.

Between May 1942 and December 1943, German U-boats harassed American shipping in the Gulf with near impunity. Only one Nazi submarine, the *U-166*, is believed sunk in the Gulf; it has yet to be discovered (Figure 2A.8). The U-166 was commissioned on 23 March 1942. It departed Kristianstad, Norway, on its first patrol to the North Atlantic under the command of *Oberleutnant* Hans-Günther Kuhlmann on 1 June. Returning to base at Lorient, France, on 10 June without scoring any successes, the *U-166* departed for the Gulf seven days later. Kuhlmann's first victim in the Gulf was the *Carmen*, a small freighter registered in the Dominican Republic. Two days later on 13 July the *U-166* claimed as its second kill the *Oneida*, an unarmed 2300-ton freighter owned by the Ford Motor Company that was steaming in ballast for Punta Gorda, Cuba. The American trawler *Gertrude* was Kuhlmann's third victim. Probably stung by the failure of his first cruise, and the frustrating lack of important targets as his second cruise neared its end, Kuhlmann was no doubt elated when the 5,184-ton passenger steamer *Robert E. Lee* unwittingly sailed into his path. The *Robert E. Lee* was sailing from Port-of-Spain, Trinidad, to New Orleans under escort of the *PC-566.* Aboard the vessel were 268 passengers who, ironically, were mostly survivors of other sinkings. Lookouts on the *Robert E. Lee* spotted a torpedo 200 yards before it struck just aft of the engine room (Browning 1996, 194). The explosion destroyed the #3 hold and vented through the B and C decks, wrecking the engines, the radio equipment, and the steering gear. The ship sank stern first within 15 minutes as the *PC-566* began dropping depth charges (Figure 2A.9). One of the *Robert E. Lee*'s officers, nine of her merchant crew, and 15 passengers died in the attack. Survivors were picked up by the *PC-566*, the *SC-519*, and the tug *Underwriter* and transported to Venice, Louisiana.

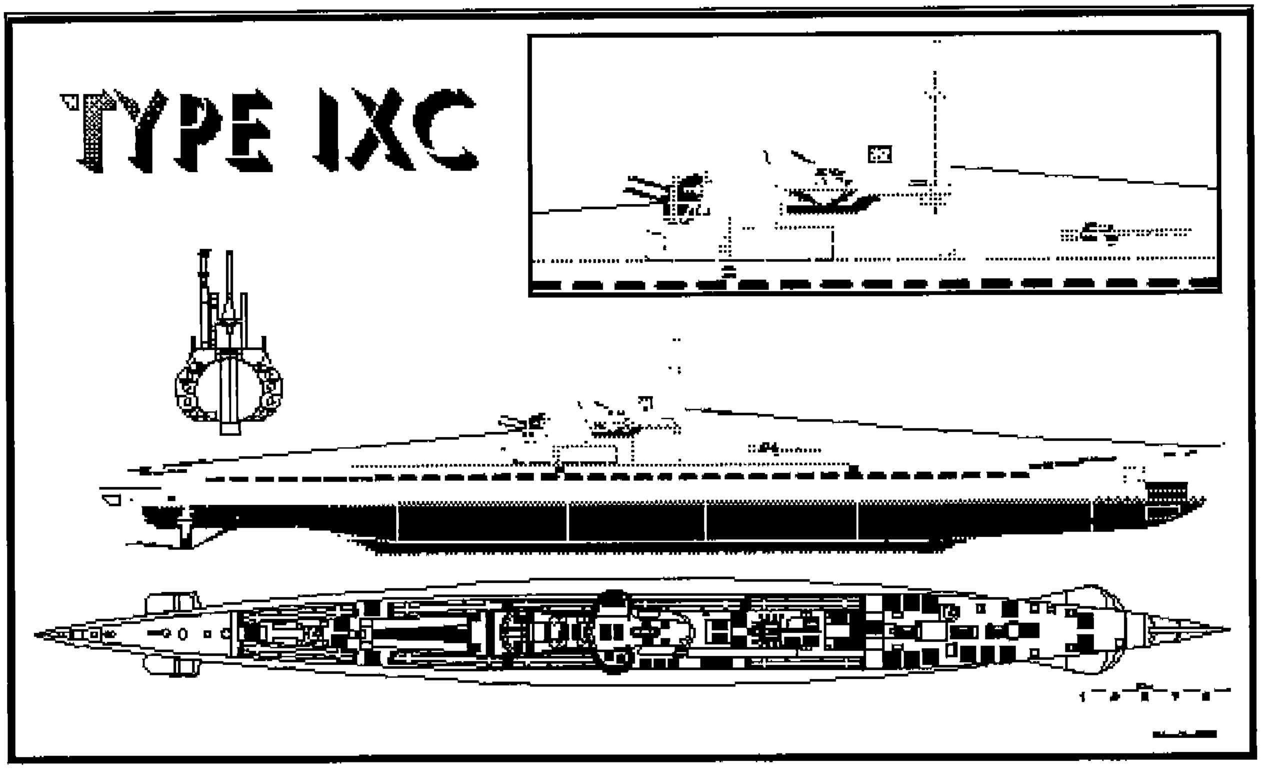

Figure 2A.8. A Class IXC German U-boat, the same type as the U-166.

What became of the *U-166* after the attack on the *Robert E. Lee* remains a mystery. This much is known for certain: the submarine never returned and was presumed lost. The crew of the *PC-566* reported that a small oil slick followed their depth charges (Navy Dept. 1942b), but this was a common tactic employed by submariners to trick their attackers into believing that the boat was damaged. Two days after the attack on the *Robert E. Lee*, the crew of a J4F-1 Grumman torpedo plane spotted an U-boat on the surface in shallow water 20 miles south of Isles Dernieres, Louisiana, in what is now South Timbalier Area. As the plane turned to attack the submarine, it was spotted by the Germans and the sub crash-dived. After launching their 325-pound depth charge from an altitude of 250 feet, the aviators saw a sheen of oil come to the surface and believed that they had damaged the sub. However, it is hard to imagine that the sub would have remained undiscovered in only about 60 feet of water after 56 years. In fact, it is not even certain that the sub spotted by the flyers was the U-166. Declassified German documents reveal that there were five U-boats patrolling the Gulf in August 1942. It seems more likely that the *U-166* was damaged by the depth charges from the *PC-566* and sank somewhere in the deep abyss of Mississippi Canyon. Our best hope for finding the lost sub now is the deep water exploration currently being undertaken by the oil and gas industry.

The discovery of and continued research on World War II shipwrecks in the Gulf gives us a new appreciation for the strategic importance of this region to the war effort. At great personal risk, the U.S. Merchant Marine kept up the flow of oil to fuel the Allied war machine. The evidence of their sacrifice lies beneath the waves on the Outer Continental Shelf. These wrecks deserve our protection not only as war graves, but as silent monuments to the courage of the Merchant Marine and the role of the Texas and Louisiana oil industry in the defeat of the Axis powers.

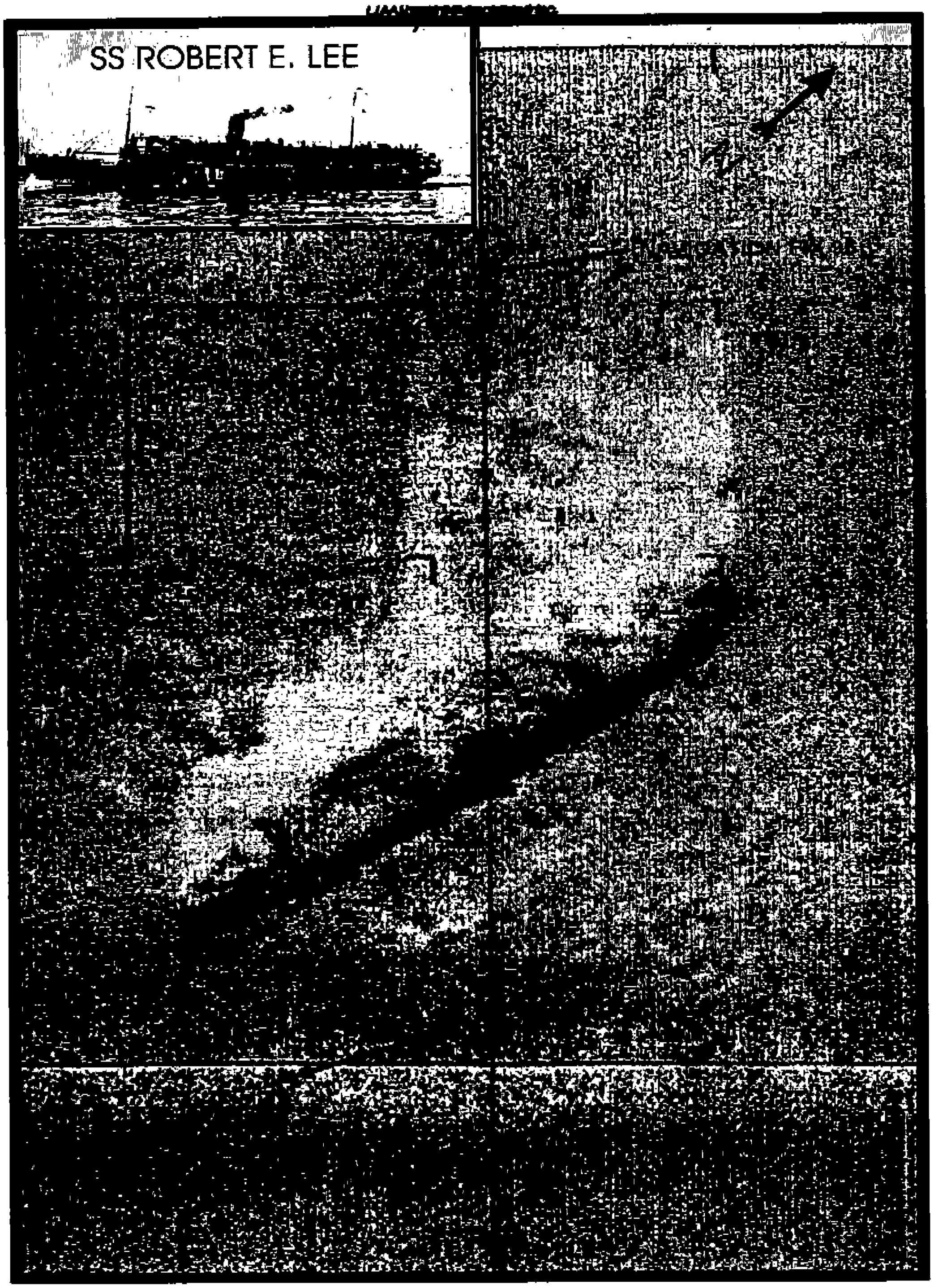

Figure 2A.9. The SS Robert E. Lee, superimposed over the side-scan sonar record of the shipwreck. Courtesy John E. Chance & Associates, Inc.

CONCLUSIONS

The Seafloor Monitoring Program is having a significant effect on our ability to interpret and understand underwater archaeological remains in the Gulf of Mexico. Not only can we proactively insure that MMS avoidance mitigations actually are applied, but we can, for the first time, take the opportunity to examine remote sensing targets in the field to determine if they are, in fact, historic shipwrecks or merely modern debris. By developing a better understanding of what shipwrecks in the Gulf actually look like, we are able to make better, and we hope, less restrictive management decisions to insure their preservation for future generations of Americans.

AUTHOR'S NOTE

The Horn Island shipwreck (22HR843) discussed here was posited at the time of the ITM to be the wreck of the *Heroine.* Since that time (1998) the MMS has sponsored additional fieldwork and historical research at the site to identify the vessel. Subsequently, the shipwreck has been identified positively as the *Josephine.* The *Josephine* was constructed by Harland & Hollingsworth in Wilmington, Delaware, in 1867 and sank during a winter storm on 8 February 1881. The vessel was operated by the Charles Morgan Line, the principal steamship line serving the Gulf Coast throughout most of the nineteenth century.

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Dr. Jack B. Irion joined the Minerals Management Service in August 1995 with the title of marine archaeologist. Prior to MMS, Dr. Irion served as vice president for Nautical Archaeological Services with the consulting firm of R. Christopher Goodwin & Associates, Inc., in New Orleans, Louisiana. For over 15 years, Dr. Irion provided archaeological consulting services to the Baltimore, Charleston, Mobile, New Orleans, Pittsburgh, Philadelphia, Savannah, Vicksburg, and Wilmington Districts of the Corps of Engineers, as well as to the Maryland Port Administration, and the State of Tennessee. Dr. Irion received his B.A. (1974) and M.A. (1977) in Archaeological Studies from The University of Texas at Austin. He was awarded his Ph.D. from the Institute of Latin American Studies of the University of Texas in 1991. During his career, Dr. Irion has specialized in conducting remote sensing surveys for shipwrecks, which succeeded in locating such historically significant vessels as the C.S.S. *Louisiana*, the sailing barque *Maxwell*, and the steamboats *Princess*, and *Kentucky*. In addition, he has directed numerous diving investigations on historic shipwrecks, including the steamship *Columbus* and the Civil War gunboats *Tawah* and *Key West.* Most recently, he has participated in MMS investigations of the Civil War vessel U.S.S. *Hatteras* and the steam packet *New York.*

BIOLOGICAL CHARACTERIZATION AND MONITORING OF SONNIER BANK

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Gulf of Mexico OCS Region

ABSTRACT

Sonnier Bank is a siltstone mid-shelf bank resulting from salt diapirism similar to most other topographic features along the northern Gulf of Mexico continental shelf. Though not a true coral reef, a remarkable biota of more than 100 species of fish and a nearly 100% cover of attached invertebrates including eight species of coral are represented. Sonnier Bank is very similar to, and in many respects better developed than Stetson Bank, which is now part of the Flower Garden Banks National Marine Sanctuary.

The Minerals Management Service (MMS) has initiated a program to further characterize the biota and community stability at Sonnier Bank. This program is part of a multiyear monitoring effort. Repetitive photographic stations installed by a previous project of the nonprofit organization Gulf

Reef Environmental Action Team (G.R.E.A.T.) are being utilized similar to the ongoing Flower Garden Banks long-term monitoring project. Initial components of the program include continuing repetitive photographic samples, habitat mapping and characterization, quantitative quadrat counts, an *in situ* thermistor, and diver-performed fish census.

The initial results from a limited number of repeated quantitative photo stations indicate a very dynamic benthic community with the dominant sessile invertebrate fauna exhibiting substantial changes in percent cover on an annual basis. Reef fish and invertebrate census data will be addressed.

INTRODUCTION

Sonnier Bank, located 128 km south of Vermilion Bay, Louisiana (28° 22.2' N, 92° 27.08' W), is a siltstone mid-shelf bank resulting from salt diapirism similar to most other topographic features along the northern Gulf of Mexico (GOM) continental shelf. Sonnier Bank was formerly named Three Hickey Rocks by Texas fishermen and sport divers prior to the mid 1970s. It was named after Farley Sonnier around 1977 in honor of his extensive work with Gulf of Mexico fish fauna (Mr. Sonnier passed away in 1987). Sonnier is the fourth and probably only other offshore bank located in clear continental shelf waters that can be easily visited by recreational scuba divers. The East and West Flower Garden and Stetson Banks being the other three, are now all part of the Flower Garden Banks National Marine Sanctuary. Claypile Bank is the next shallowest GOM topographic feature with its peak coming to within only 42 m of the surface, a very deep dive for most scuba divers.

The first scientific investigation of Sonnier Bank was performed in 1977 as part of a BLM (now MMS) funded study by Texas A&M University using the research submersible *Diaphus* as part of the Northwestern Gulf of Mexico Topographic Features Study (Bright and Rezak 1978). Until the efforts of the Gulf Reef Environmental Action team (G.R.E.A.T.) and MMS in 1996, there had been no attempts to revisit this diverse topographic feature for research purposes.

Environmental concerns for topographic features in the Gulf of Mexico relating to the long-term effects of oil and gas production activities are the responsibility of MMS. An oil and gas lease stipulation has established no-activity zones around topographic features including Sonnier Bank since 1973. In addition to this stipulation, MMS has also funded monitoring efforts at a number of features, primarily the Flower Garden Banks. Recently, MMS has become actively involved in a field monitoring program using in-house resources and personnel. As a part of this initiative, Sonnier Bank will be visited on an annual basis to further characterize the biota and community stability as part of a multiyear monitoring effort.

General Description

The most prominent characteristic of Sonnier Bank is the physical nature of this topographic feature. Pinnacle formations rise steeply from a surrounding bottom depth of approximately 61 m coming to within 18 m of the surface in one location. The similarity of surficial geology between Sonnier and Stetson Banks was noted as early as 1976 by Bright *et al.* (1976) prior to Texas A&M having visited what was then called Three Hickey Rocks (using underwater photographs). The numerous individual peaks are believed to be the result of the collapse of the crest of the underlying salt diapir (Rezak *et al.* 1983). Two of approximately eight peaks occurring within the total area of Sonnier Bank have been investigated; both of these rise to a depth of less than 22 m. It is believed that at least one other peak is shallower than 40 m (where reasonable duration research dives could be performed) and will be investigated during the next effort scheduled for 1999.

The initial study site chosen and worked on exclusively during 1996 is the only one depicted on existing bathymetric charts shallower than 42 m. The total area of the bank rising above the surrounding bottom of 60 m is approximately 600 hectares, but this site encompasses an area only 0.3 hectare above the 30-m contour. During year two, a second small site not appearing on charts was investigated and found to rise to within 18 m of the surface. Located only about 150 m to the north of Peak 1, it was designated Peak 2. This peak is even smaller with an area above the 30 m contour encompassing only about 0.1 hectare.

METHODS AND RESULTS

Fish Census

Fish community census data was obtained by the "Roving Diver Technique" during two separate years to date. The technique utilizes teams of trained divers who record species and relative abundance (four ranks) of all reef fish species seen around the reef throughout their dive. This is the same technique used to perform fish census reported in these proceedings for the Flower Gardens and Stetson Banks by Pattengill (1998). After returning to the surface, observations are transferred to optically read data forms developed by the Reef Environmental Education Foundation (REEF). Surveys were only conducted in the immediate vicinity of each peak. During 1996, only the 22-m peak was investigated on 1-2 July; and on 30 September-1 October 1997, both the 22-m and the 18-m peaks were surveyed.

During the 1996 census, a total of 109 species of fish were identified by census teams. In 1997 a total of 104 species of fish was reported by Childs (1997), 89 species at the shallower 18-m peak and 80 species at the 22-m peak. Although five fewer species overall were observed in 1997, a total of 16 new species was reported raising the two-year total to 125 taxa. The most abundant taxa was the creolefish (*Paranthias furcifer*). Similar to Stetson Bank, this plankton-feeding serranid was observed in large groups at the edges of the peak features. Cocoa damselfish (*Stegastes variabilis*) were also very numerous but a distant second in terms of relative numbers. One other notable species observed in moderate numbers was red snapper (*Lutjanus campechanus*). This species is rarely seen above 30 m at the Flower Gardens or Stetson Banks but was common at the edges of the peaks. Habitat associations of observed species was dominated by those closely associated with reef structures while 17% of the species were epipelagic in nature, those species that do not have a close affinity to reef structures such as mackerals and cobia.

Invertebrates and Algae

General characterizations of the Sonnier Bank benthic communities were made by this author in 1996 and reported to MMS by Gittings and Harper in 1997. Cover of living organisms on pinnacle substrate is extremely high, close to 100% in many areas and generally exceeding 70% dominated by a variety of species of sponges, algae, and also the fire coral, *Millepora alcicornis*. Sponge cover was dominated by the stinging sponge *Neofibularia nolitangere.* Large ball sponges of the genera *Ircinia* were also commonly observed. Dozens of other sponge species, which are not reliably identified *in situ,* have been noted during both sampling years. Gittings and Harper (1997) reported the dominant algae species as the brown alga *Lobophora variegata.* Other algal species were also common including the brown alga, *Dictyota*. On the crest of some of the pinnacles, sabellid worms were very abundant. Night observations noted unusual concentrations of the fireworm *Hermodice caruncualta* covering the bottom, at least several per square meter over most areas.

Mollusks were abundant on both peaks dominated by small ceriths (*Cerithium* spp.) very similar to Stetson Bank. A number of other mollusk taxa, including cowries, arc shells, pen shells and a number of thorny oysters, were also noted during both years . Thorny oysters are a prized catch for collectors, and their abundance may indicate the degree of isolation Sonnier Bank derives as a result of its distance from shore and major ports.

Scleractinian corals reported during 1996 included small colonies of *Oculina diffusa*, *Stephanocoenia intersepta*, *Phylangia americana, Madracis decatus,* and *M. mirabilis*. Two additional scleractinian coral species were reported by Gittings and Harper in 1997. These included *M. pharensis* and *Siderastrea radians*.

Other large motile invertebrates were recorded, although no systematic surveys have been performed to date. Other observations will not be detailed here; however, several very large spiny lobsters (*Panulirus argus)* are of particular note. In addition to the repetitive photographic station, quantitative surveys of large motile invertebrates (*e.g.*, lobsters and urchins) will be incorporated into the monitoring efforts beginning in 1999.

Repetitive Station Photography

Repetitive photographic stations installed by a previous project of the nonprofit organization Gulf Reef Environmental Action Team (G.R.E.A.T.) are being utilized similar to the ongoing MMS/NOAA-funded Flower Garden Banks long-term monitoring project. A total of 20 permanent station marking pins were installed in 1996. Each station is photographed from a height of 1.05 m using a fixed camera framer, a 15-mm wide angle Nikonos lens, and two 225 watt-second strobes. The base of the 1.05-m post is placed at the pin anchored in the bottom. The framer has a compass and bubble level located next to the camera to accurately align the camera. The bubble level is centered and the compass oriented to the north prior to each station photograph. The resulting image includes an area of 2 m^2.

During the two-day effort in 1997, only a few stations were relocated and photographed. It is believed that most all of the station pins and tags were heavily overgrown by sponge and algae. Initial interpretation of repeated images indicates that the growth and percent cover of benthic biota is highly variable with substantial changes in sponge and algal cover over a one-year time span. With the use of underwater maps and landmarks, it is believed that most all the installed stations can be relocated in the future.

Recording Thermistor

An *in situ* electronic thermistor programmed to record water temperature every 4 hours was installed at the site of the anchor mooring on 1 July 1996. It was not relocated during the 1997 field effort due to probable overgrowth of sponge and algae. However, it does have the capability of obtaining data for one additional year until MMS is able to return to the bank and perform a more intensive search for the small instrument. Three new thermistors will replace the one on site during the upcoming 1999 effort. One unit will be located on the crest of the 18-m Peak 2, and the other two will be installed at a new deep site (40 m depth) and at the previously used shallow site (25 m) on the 22-m Peak 1. Temperature data recovered from these instruments will be a valuable tool for interpretation of relationships between potential climate change and change in community composition.

SUMMARY

Initial components of the program have included quantitative repetitive photographic samples, habitat mapping and characterization, a recording *in situ* thermistor and diver-performed fish census. Continuing future monitoring efforts will include the following components:

- continued sampling of 2 m^2 repetitive photographic stations;installation of permanent station markers for repetitive photography on the shallow Peak 2;
- benchmark installation for four 100 m video transects located on two peaks;
- installation of additional recording thermistors;
- macroinvertebrate surveys;
- continued fish census; and
- ROV surveys of communities below 40 m on at least two pinnacles.

Bright and Rezak (1978) described Sonnier Bank as very healthy with "no evidence of past mass mortalities or large scale deleterious environmental effects attributable any cause." There had been at least nine exploratory wells drilled within 9 km of the bank during the 1960s prior to their report. The observations of Bright and Rezak are very similar to what has been found at Sonnier Bank 20 years later. At least six active oil and gas platforms are currently operating within 15 km of the bank, and Vermilion Block 305 is currently an active lease, although no planned exploration drilling activities are known. The MMS topographic feature stipulation, including a no-activity zone and shunting of discharges within a 4-mile zone, may play a significant role in future protection of Sonnier Bank. Continued monitoring efforts at this unique topographic feature will provide resource managers and scientists with insight into natural changes, as well as the potential impacts from the long-term energy development in the surrounding area.

ACKNOWLEDGMENTS

A large portion of the information obtained during these studies was collected by many different individuals. Fish census data was coordinated by Dr. Ann Bull in 1996 and Jeff Childs in 1997. Biological characterization data was also obtained by Drs. Steve Gittings and Don Harper in 1997. Mr. Les Dauterive coordinated MMS participation during both field efforts. The Gulf Reef Environmental Action Team (G.R.E.A.T., Houston, Texas) coordinated the initial project in 1996 and provided the funding for materials and a portion of ship time. The MMS funded one day of ship time in 1996 and the entire cruise in 1997. The initial long-term thermistor was donated to the project by the author.

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Greg Boland is a biological oceanographer with Minerals Management Service's Gulf of Mexico OCS Region, New Orleans. He started at MMS in April of 1998 after 10 years as a Senior Research Associate with the Department of oceanography at Texas A&M University (where he previously received his Master's in Oceanography) and a previous 10 years with the consulting firm of LGL Ecological Research Associates in Bryan, Texas. His current professional interests include coral reef and chemosynthetic community ecology and energy platform communities. At MMS, Mr. Boland

is currently an analyst for fisheries and deepwater benthic community issues and is also a member of the MMS scientific dive team.

THE MONITORING AND ANALYSIS OF OPERATIONS SITES FOR REGULATORY COMPLIANCE

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In response to the Government Performance and Results Act and reports of anchor scars and associated seafloor impacts on nearby Biological Pinnacles offshore Alabama, the Minerals Management Service (MMS) last year started a program to monitor the seafloor for impacts that could be associated with oil and gas development. Dr. Jack Irion and Dr. Rik Anuskiewicz, marine archaeologists, were designated principal investigators and managers of the program. The Region purchased a Marine Sonic Technology SeaScan sonar system and Digital Global Positioning System for program implementation and systematic survey and search of seafloor impacts. In addition to Drs. Rik and Jack, the Region's dive team has provided the necessary field support and visual ground-truthing for verification of the side-scan sonar images.

An important part of the MMS Seafloor Monitoring Program has been the application of the side-scan sonar technology for surveying the seafloor and underwater operations activity sites for possible industry violation of MMS operations compliance regulations. This is not to say that the industry is willfully violating their underwater operations responsibility, but non-compliance of regulatory requirements do occur, be they willful or not. The MMS has had a long standing inspection program for monitoring the drilling and production operations aspects of the offshore program and incidences of non-compliance (INCS) with regard to this activity are occasionally issued. The survey of underwater operations sites is the first effort by MMS to police the industry's underwater operations activities.

The success of the MMS Seafloor Monitoring Program is a function of the scientific expertise available to operate the program, available time on the part of the MMS staff to do the work, and offshore conditions in which a monitoring project can be safely and successfully accomplished.

Over the past two summers the Region's Seafloor Monitoring Program team has used the SeaScan sonar system technology to survey a variety of field operations sites and locations. The team's objective is to provide Field Operations with empirical data of seafloor anomalies and obstructions for evaluation of possible violations of compliance with MMS operations regulation.

In close working coordination with the office of Field Operations, the seafloor monitoring team conducted field projects applicable for survey by the SeaScan sonar system. Side-scan sonar surveys were conducted at:

1. Seafloor well stubs and subsea well completions
2. Site-Clearance locations
3. A debris field near a well site location
4. An oil leak near an artificial reef site

SEAFLOOR WELL STUBS AND SUBSEA WELL COMPLETIONS

The seafloor monitoring team's efforts to side-scan the seafloor to determine well stub exposure at or above the seafloor, presence of protective dome covers over the well stub, or evidence of trawl hangs and shrimp trawl damage, have so far produced minimal results. This we believe was due partly to incorrect location coordinates in the well stub data base, and the difficulty in surveying for and locating these sites. The survey for a sub-sea well completion did produce an image of the sub-sea completion tree, surface buoy, and anchor chain marking the sub-sea completion site. An attempt by the MMS divers to follow the surface buoy anchor chain to the subsea tree for visual verification was abandoned. The anchor chain was immediately lost in the very fine, unconsolidated bottom sediment, reducing the visibility at the seafloor to zero.

SITE CLEARANCE LOCATIONS

The seafloor monitoring team's efforts to scan the seafloor at site clearance locations for verification that the seafloor is free of operations debris produced some results. Two site clearance locations were examined by the side-scan sonar survey. At one location a large depression, believed to be the abandoned well site location was observed and some small hard returns in the acoustic record may indicate small debris on the seafloor. At the other location a shell mat or drill cuttings pile surrounding a seafloor depression showed clearly as a bright spot in the acoustic record because of the difference in the hardness between the mat or and/or pile and the surrounding sediment. An approaching squall precluded the MMS dive team from conducting a visual ground-truthing survey at these site clearance location.

A DEBRIS FIELD NEAR A WELL SITE LOCATION

Review of a routine site-specific hazard block survey revealed a debris field on the seafloor near a proposed drill site. Since the debris field appeared to be oil field related and a potential hazard to navigation, the site was surveyed and investigated by the seafloor monitoring team. The side-scan survey revealed 2 parallel rows of seafloor protrusions with 3 protrusions in each row. The rows are 60ft apart and the protrusions are 50ft apart in each row. A central cluster of debris was observed on the acoustic record between the rows of protrusions. MMS divers were dispatched to visually investigate the composition and vertical height of the protrusions. The divers found the protrusions to be heavy concreted steel piles protruding 5-6ft above the bottom of the seafloor. Upon our return to the office, search of the lease block file for past operations revealed that the location of the debris field corresponded to a well which was drilled, plugged and abandoned in 1980. The piles were found to be pin piles placed as skirts around a drilling barge that was commonly use to drill wells in shallow water in this area. The central cluster of debris was probably the location of the well. Because the site presents a potential hazard to navigation and conflict with commercial shrimp trawling the location's precise Digital Global Positioning System (DGPS) coordinates were provide to the U.S. Coast Guard's automated Wreck and Obstruction Information Service for publication as a Notice to Mariners. Our Field Operations office is investigating for the identification of the responsible operator for removal of the seafloor obstruction.

OIL LEAK NEAR AN ARTIFICIAL REEF SITE

The Texas Parks and Wildlife Artificial Reef Program office requested MMS assistance in pinpointing an oil leak near their Matagorda liberty ship artificial reef site offshore Texas. The liberty ships, an oil and gas well, or a pipeline were suspected sources of the leak. In response to the request, the seafloor monitoring team conducted a side-scan sonar survey and captured images of the three liberty ship reefs. Review of the MMS lease file records shows no oil and gas well was ever drilled on this lease and no pipelines exist in the lease. A positioning fix over the point where the oil was observed to come to the surface indicated that the leak is likely coming from the bow of the southern most ship. The surface expression of the leak was some 140 ft from the DGPS center coordinates of this ship. The side-scan sonar acoustic record indicate that there are no other possible sources for the leak visible on the seafloor.

Weather this past summer has disrupted the team's effort to accomplish projects scheduled this year. However, the MMS Seafloor Monitoring Program has been funded for fiscal year 1999 and the seafloor monitoring team will continue its work and improve its capabilities to survey for impacts to the seafloor associated with oil and gas development in the Gulf of Mexico.

Les Dauterive is a Senior Staff Environmental Scientist with the Minerals Management Service (MMS), Gulf of Mexico OCS Region, Office of Leasing and Environment (LE). Les has been with the MMS for 24 years. Prior to his present position Les was a supervisor for 15 years in the Environmental Operations Section of LE, which is responsible for the supervision of MMS's review and environmental assessment of industry's operations activity. Presently, Les is the MMS Diving Safety Officer responsible for the management of the MMS Scientific Diving Team and Program, and is the Region's Artificial Reef coordinator responsible for the liaison and coordination of the Gulf's Rigs-to-Reefs program. Les is an avid SCUBA diver and certified Dive Master with over 20 years of diving experience. He is a member of the American Academy of Underwater Scientists and has managed MMS scientific diving operations throughout the Gulf for the protection of biological natural reefs and banks, and for the assessment of oil and gas production and retired platforms as artificial reefs. Les is a graduate of the University of Southwestern Louisiana with a B.S. degree in biology and is also a graduate of McNeese State University with a M.S. degree in environmental science. Les has received the U.S. Department of the Interior's (USDOI) *Point of Light* award for his leadership of the MMS dive team's participation as volunteers in the Aquarium of Americas

(AOA) diver naturalist program, and is a member of the AOA Dive Safety Board. Les also received the USDOI Safety Management Award in recognition of his outstanding achievement in the MMS diving safety program.

SESSION 2B

FISHERIES MANAGEMENT AND BIOLOGY

Chair: Mr. Gregory Boland
Co-Chair: Dr. Ann Scarborough Bull

Date: December 8, 1998

Presentation	Author/Affiliation
Essential Fish Habitat (EFH)	Mr. William Jackson National Marine Fisheries Service
A Reef Fish Monitoring Program at the Flower Garden Banks National Marine Sanctuary, Northwest Gulf of Mexico—Baseline Results	Dr. Christy V. Pattengill-Semmens Texas A&M University Department of Biology
Sharks and Rays of Stetson and the Flower Garden Banks	Mr. Jeff Childs Department of Wildlife & Fisheries Sciences Texas A&M University
Fish Community Structure: Mississippi/Alabama Pinnacle Trend	Dr. Kenneth J. Sulak Mr. Douglas C. Weaver Florida Caribbean Science Center U.S. Geological Survey – Biological Resources Division Dr. Steve W. Ross North Carolina National Estuarine Research Reserve Center for Marine Research
Trophic Subsidies in the Twilight Zone: Food Web Structure of Deep Reef Fishes along the Mississippi- Alabama Outer Continental Shelf	Mr. Douglas C. Weaver Dr. Kenneth J. Sulak Florida Caribbean Science Center U.S. Geological Survey – Biological Resources Division
Status of the Gulf of Mexico Red Snapper Stock: Another Perspective	Dr. Benny J. Gallaway LGL Ecological Research Associates, Inc.

ESSENTIAL FISH HABITAT (EFH)

Mr. William Jackson
National Marine Fisheries Service

"One of the greatest long-term threats to the viability of commercial and recreational fisheries is the continuing loss of marine, estuarine, and other aquatic habitats. Habitat considerations should receive increased attention for the conservation and management of fishery resources of the United States."

—Magnuson-Stevens Act, 1996

MANAGEMENT OF MARINE FISHERY RESOURCES

Living marine resources constitute valuable and renewable resources that contribute to the food supply, economy, welfare, health, and recreational opportunities of the nation. In 1976, the Magnuson Fishery Conservation and Management Act (Magnuson Act) established a management system to more effectively utilize the marine fishery resources of the United States. It established eight Regional Fishery Management Councils (Councils), consisting of representatives with expertise in marine or anadromous fisheries from the constituent states. In order to develop fishery management plans (FMPs) for the conservation and management of fishery resources, Councils use input from the Secretary of Commerce (Secretary), the public, and panels of experts. After approval by the Secretary, the National Marine Fisheries Service (NMFS) implements and enforces the management measures in the FMP.

As amended in 1986, the Magnuson Act required Councils to evaluate the effects of habitat loss or degradation on their fishery stocks and take actions to mitigate such damage. In 1996, this responsibility was expanded to ensure additional habitat protection.

On 11 October 1996, the Sustainable Fisheries Act (Public Law 104-297) became law which, among other things, amended the habitat provisions of the Magnuson Act. The re-named Magnuson-Stevens Act (Act) calls for direct action to stop or reverse the continued loss of fish habitats. Toward this end, Congress mandated the identification of habitats essential to managed species and measures to conserve and enhance this habitat. The Act requires cooperation among NMFS, the Councils, fishing participants, Federal and state agencies, and others in achieving the essential fish habitat (EFH) goals of habitat protection, conservation, and enhancement.

Identification of EFH and Threats to EFH

The Secretary, acting through NMFS:

- must develop regulatory guidelines that assist Councils to incorporate EFH provisions into all FMPs, i.e., the description and identification of EFH, identification of adverse impacts to EFH from both fishing and non-fishing sources, and identification of measures to further the conservation and enhancement of EFH.

- in consultation with participants in the fishery, must provide Councils with recommendations and information for the preparation of EFH amendments.
- will coordinate with Federal and state agencies, industry and conservation groups to reduce threats to EFH.
- must review relevant Department of Commerce programs to ensure they further the conservation and enhancement of EFH.

The Councils, in accordance with NMFS's guidelines:

- must amend their 36 current FMPs with EFH provisions by the statutory deadline of 11 October 1998. Any new FMPs developed after the deadline must also meet these standards. NMFS must also amend its 3 Secretarial FMPs in the same manner.
- must identify EFH in narratives and on maps using the best information available. They should develop partnerships with Federal and state resource agencies, researchers, and other interested parties to foster the exchange of information on distributions of managed species, distributions of habitats and threats to these habitat, to assist in the description and identification of EFH.
- must act to minimize adverse impacts on EFH from fishing activities, to the extent practicable.
- must identify potential non-fishing sources of adverse impacts on EFH, and should work within watershed planning structures to further the goals of EFH.
- should develop proactive measures and partnerships to enhance and restore lost or degraded EFH.

Coordination, Consultation, and Recommendations on EFH: The Magnuson-Stevens Act and NMFS regulations require interagency coordination and consultation to further the conservation and enhancement of EFH:

- After EFH amendments have been approved, NMFS will distribute to agencies and other parties information and maps detailing the locations and potential threats to EFH.
- Federal agencies must consult with NMFS regarding any action or proposed action that may adversely affect EFH. The regulations strongly encourage using existing procedures for environmental reviews in order to streamline this process. In the absence of an existing process, the regulations establish procedures to accomplish the mandated consultations.
- Any Council(s) may comment and make recommendations to NMFS and any Federal agency undertaking actions that may adversely affect the habitat, including EFH, of any fishery resource under its authority; and must comment if the action may adversely impact the habitat of an anadromous fishery resource under its authority.
- After receiving information from a Council or Federal or state agency concerning an action or proposed action that would adversely affect any EFH, NMFS must recommend measures to the Federal or state agency to conserve such habitat.

- Within 30 days of receiving a NMFS EFH recommendation, a Federal agency must respond in writing to NMFS and any Council(s), if appropriate. The response should detail the measures that will be taken to avoid, mitigate, or offset the adverse effects to EFH and explain the reasons for any actions inconsistent with the NMFS EFH recommendations.

Streamlining the consultation process:

- NMFS currently participates in interagency environmental coordination or consultation processes under the Fish and Wildlife Coordination Act, the National Environmental Protection Act, the Endangered Species Act, the Federal Power Act, and the Clean Water Act for many of the actions that will be covered under the EFH mandate. Where these existing processes can satisfy the requirements of EFH consultations, such procedures will be used to meet the consultation requirements of the Magnuson-Stevens Act.
- The regulations outline a flexible system of consultation procedures if no existing processes are available. It ensures that the level of consultation is commensurate with the action's potential impact on EFH:
  - Programmatic Consultation for specific agency programs consisting of similar actions that may adversely affect EFH.
  - General Concurrence for categories of actions with minimal adverse effect on EFH.
  - Abbreviated Consultation for individual actions with minor adverse effects on EFH.
  - Expanded Consultations for review of projects with the potential for substantial adverse impacts on EFH.

NMFS is committed to working with the Councils, affected Federal and state agencies, fishing and non-fishing industries, conservation groups, academia, land owners, and the general public to ensure that EFH provisions are understood and well coordinated, thereby providing effective protection for essential fish habitats as Congress envisioned. NMFS will seek working agreements with organizations and provide many avenues for public input to the EFH process. Partnerships with other Federal agencies, state resource agencies, and non-governmental organizations will enhance the process.

For further information contact: Office of Habitat Conservation, NOAA/NMFS, 1315 East West Highway, Silver Spring, MD 20910. (301) 713-2325; FAX (301) 713-1043.

August 1998

A REEF FISH MONITORING AT THE FLOWER GARDEN BANKS NATIONAL MARINE SANCTUARY, NORTHWEST GULF OF MEXICO—BASELINE RESULTS

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ABSTRACT

The reef fish populations of the Flower Garden Banks (FGB) and Stetson Bank (SB) above 30 m were assessed to establish a database of information for long-term use in the Flower Garden Banks National Marine Sanctuary (FGBNMS). Data generated from two different visual census methods collected semi-annually for three years were used to evaluate diurnal fish assemblage structure and persistence. The suitability of data collected by divers participating in a volunteer fish monitoring program and the role these data can play in the management of the FGBNMS were also evaluated. Through the course of this study, 789 visual fish surveys were completed and 177 species were documented. Forty-five species were new records for the FGBNMS, including a unique color phase of one species. Similarity in the fish assemblages of the FGB and SB indicated a common species pool. Differential recruitment success, settlement success and seasonal attrition occurred between the banks and most likely were driven by food and habitat availability and the physical environment. Analyses revealed relatively high levels of stability in species abundance. This dataset provides a benchmark for future assessments of disturbance and recovery and provides insight into the stability of an assemblage measured at a large spatial scale. Non-expert volunteers were able to produce survey results comparable to those of experts. The larger sample size of non-experts increased the statistical power for many species' estimates of abundance. Volunteer monitoring can provide a valuable source of data, and also invokes a sense of ownership in the resource.

INTRODUCTION

Detecting changes in a natural community is essential to effective conservation (Spellerberg 1991), and monitoring data are vital to this effort. Effective policy depends upon objective data, as both a basis for management decisions and to evaluate the effectiveness of existing regulations (Gittings *et al.* 1997). As resource managers and scientists attempt to address the increasing pressures placed on natural areas, such as coral reefs, monitoring data will be required to assess community health. In addition, long-term monitoring facilitates the understanding of ecosystem processes and establishes a baseline that can be used to assess natural and anthropogenic impacts (Spellerberg 1991).

Coral reef ecosystems are complex, as are the inter-relationships between habitat, biotic and abiotic components. Because of this complexity, components of the system are often used as indicators of

changes. Fish abundance and diversity can reflect reef conditions because reef fish are mobile and many species depend on specific types of food and substrate (Sale 1991; Reese 1993).
Most reef fishes have a life cycle that includes sedentary, reef-associated juveniles and adults, and a planktonic larval stage that will spend 2-10+ weeks in ocean currents. Therefore, local recruitment success is affected by reproductive success at other reefs and hydrographic conditions. The level of local retention varies among sites and usually is minimal. This bipartite life cycle introduces a large amount of natural variation into fish assemblages. Because of this inherent natural variability, baseline information is necessary to establish the level of natural variation in fish presence and abundance before one is able to detect significant departures from a previous state, and is necessary to make reasonable and accurate assessments of community health in the face of natural and anthropogenic impacts. The level of variation, or persistence, of a system varies among sites, and has been documented ranging from high (Sale *et al.* 1994) to minimal (Smith 1978; Gladfelter *et al.* 1980; Ogden and Ebersole 1981; Grossman *et al.* 1982). It is especially useful to characterize the temporal dynamics or variability in undisturbed systems to be able to assess future change.

Traditionally, monitoring natural resources has been done primarily by scientists. As time, financial resources, and personnel become more limited, the use of trained and experienced volunteers in monitoring is increasing. In addition, community-based monitoring programs such as the Reef Environmental Education Foundation, Reef Check, Reef Keepers, and Center for Marine Conservation's Underwater Cleanup are gaining momentum. These volunteer programs provide a large amount of information on a greater geographic and temporal scale that would otherwise be unavailable, while increasing public awareness about resources and involving the public in science. In addition, participants gain a sense of ownership that is vital to the success of resource management and protection. Despite these advantages, valid concerns regarding the quality and application of the data exist.

The fish assemblages of the Flower Garden Banks and Stetson Bank, northwest Gulf of Mexico, were visually censused semi-annually for three years in order to evaluate the diurnal fish assemblage structure and persistence and to establish a baseline of information against which future change can be measured (Pattengill 1998). In addition, field survey time for this project was often shared with a volunteer-based fish monitoring program. This summary presents the results from this reef fish monitoring project and discusses the use of fish monitoring as a management tool.

METHODS

Study Area

High-relief banks occur throughout the northwestern Gulf of Mexico (Bright 1977). Three of these banks, the East Flower Garden Bank (EFG), the West Flower Garden Bank (WFG) and Stetson Bank (SB), make up the Flower Garden Banks National Marine Sanctuary (FGBNMS) and are the focus of this study. The Flower Garden Banks (FGB) are located on the outer continental shelf, approximately 175 km SSE of Galveston, Texas and are 21 km apart (EFG- 27°54.5'N, 93°36.0'W; WFG- 27°52.5'N, 93°49.0'W). SB is located approximately 112 km SSE of Galveston, Texas (28'09.

8'N, 94'17. 9'W). The banks are topographic expressions of seafloor uplift caused by underlying salt domes and occur as submerged islands of hard substratum surrounded by vast expanses of terrigenous continental shelf sediments (Bright 1977). All three banks support tropical fauna, but only the two FGB support coral reefs. Historical fish research at these areas include Boland *et al.* (1983), Bright and Pequegnat (1974), Bright *et al.* (1974), and Dennis and Bright (1988). A more complete description of the study area is given in Pattengill (1998).

Data Collection

The fish assemblages of the EFG, WFG and SB were visually censused during six cruises: September/October 1994, May/June 1995, September/October 1995, May/June 1996, August/ September 1996, and May/June 1997. Two non-destructive visual survey methods were used, the Stationary Diver Technique (SDT) (Bohnsack and Bannerot 1986) and the Roving Diver Technique (RDT) (Schmitt and Sullivan 1996). A survey team of six divers experienced in reef fish identification and assumed to provide equitable results conducted each method. Field identifications were based on Stokes (1980), Robins *et al.* (1986), and Humann and DeLoach (1994).

The SDT method used in this study was modified from Bohnsack and Bannerot (1986). The method required a diver to remain in the middle of a randomly placed imaginary cylinder with a radius of 6.5 m and a height of approximately 4m. A 6.5m rope, laid on the bottom, was used to help the diver visualize the cylinder radius. During an initial five-minute period, the diver recorded all fish species seen in the cylinder. After the initial five-minute period, the stationary diver counted the individual fishes within the cylinder, working from the bottom to the top of the species list, making one complete rotation for each species. The only species enumerated during the initial period were those unlikely to remain in the cylinder (Bohnsack *et al.* 1987). The cylinder sites were randomly chosen using random compass headings and random numbers of kicks, and were assumed to be similar to the areas of the bank not sampled.

The RDT (Schmitt *et al.* 1993; Schmitt and Sullivan 1996) was a roving survey that did not restrict the diver to a transect or particular area of the reef. The roving diver had free swimming range throughout a dive site and recorded every observed species. Therefore, the number of habitats and species that could be censused was higher, and information on the large suite of reef-associated fishes, including some rare and cryptic species was obtained. Dive times varied (though generally were between 30 and 45 minutes), depending upon the depth and corresponding dive safety limits. At the conclusion of the dive, the diver assigned each species to one of four log scale relative abundance categories according to the number of individuals seen during the dive (Single [1], Few [2-10], Many [11-100], and Abundant [>100]). Both the SDT and RDT methods surveyed visually identifiable, diurnally active, non-cryptic species that were located on, within, or above the reef structure.

These banks are relatively deep, and survey time was limited. Analyses on preliminary FGB and SB survey data were done to determine adequate sample size. These analyses included a plot of cumulative species recorded versus sample size, sample size optimization analysis (Bros and Cowell

1987), and statistical power analysis (Eckblad 1991; Peterman 1990). The results were considered in light of field-time logistics to determine a realistic but useable survey design. To acquire an adequate number of samples, the field survey design required a minimum of two days at each bank, one day for each method. The research team consisted of six divers, who conducted four SCUBA dives each day during daylight hours. This reduced biases due to diurnal temporal variation. The resulting surveys for each method were treated as replicates. The actual number of surveys for each sample varied due to weather and other factors.

Field survey time was often shared with a volunteer monitoring program, the Reef Environmental Education Foundation (REEF). REEF is a non-profit organization that educates and trains volunteer sport divers to collect fish census data. Participating volunteers use the RDT to generate surveys that are scanned into a publicly-accessible database.

Data Analysis

The fish assemblages were described using species composition and species abundance, calculated based on the data from all six census times pooled. Species abundance was estimated using the proportional abundance of each species using the SDT data. Species composition and abundance were also used to compare the fish assemblages of the three banks. Two measures of comparison, Jaccard's Coefficient (J) and Czekanowski's proportional similarity index (C_{ij}), were calculated for the assemblages of the three banks. Jaccard's Coefficient (J) (Ludwig and Reynolds 1988), a measure of percent overlap in the species recorded during SDT surveys at two areas, was calculated as:

$$J = C / A + B$$

where A and B were the number of species seen at bank i and bank j, respectively, and C was the number of species seen in common at both banks. Czekanowski's proportional similarity index (C_{ij}) (Schoener 1968) is a measure of similarity in the proportional species composition. It was calculated as:

$$C_{ij} = 1 - 0.5 \Sigma (|P_{is} - P_{js}|)$$

where C_{ij} is the proportional similarity between bank i and j and P_{is} and P_{js} are the proportion of species s at bank i and j, respectively. C_{ij} was calculated from a sub-set of the SDT data. In order to minimize the effect of including rare species in the calculation of C_{ij} (Grossman *et al.* 1982; Rahel *et al.* 1984), only species that were recorded in 20% or more of surveys from at least one bank were included in this sub-set. In addition, the sub-set excluded six schooling planktivores: blue chromis (*Chromis cyanea*), brown chromis (*Chromis multilineata*), creole wrasse (*Clepticus parrae*), creolefish (*Paranthias furcifer*), bonnetmouth (*Emmelichthyops atlanticus*) and boga (*Inermia vittata*). These species were present in high numbers above the banks, but their presence in SDT cylinders was inconsistent. When present, their large numbers under-emphasized the proportional abundance of other species.

The persistence in species presence and species abundance was calculated for each bank, and was calculated as variability over the six census times. Variability in species presence was estimated using Jaccard's Coefficient, where J was calculated for all pairs of census times (1 vs. 2, 1 vs. 3, 2 vs. 3, etc.). The variability in species abundance was estimated using the Coefficient of Variation (CV). CV was calculated for each species as:

$$CV = \text{standard deviation} / \text{mean abundance}$$

where a standardized abundance, average number of individuals per SDT survey, was used and CV was calculated over the six census times.

RESULTS

A total of 789 visual fish surveys were completed during this study (Table 2B.1). A cumulative species list generated from this study is given in Table 2B.2. The species richness at SB and the FGB (EFG and WFG combined) were similar but the species composition was not the same (143- SB; 145- FGB; and 177- total, with 111 sighted at all three banks). Of the species seen at each bank, only about half were documented during all six survey trips (61- EFG, 56- WFG and 52- SB), indicating a pattern of many rare species and a few common ones. Some of the most abundant species at all three banks were reef butterflyfish (*Chaetodon sedentarius*), Spanish hogfish (*Bodianus rufus*), bluehead wrasse (*Thalassoma bifasciatum*), brown chromis (*Chromis multilineata*), bicolor damselfish (*Stegastes partitus*), creolefish (*Paranthias furcifer*), and sharpnose puffer (*Canthigaster rostrata*). Species that were in high abundance at the FGB but present in relatively low numbers at SB were the Creole wrasse (*Clepticus parrae*), blue chromis (*Chromis cyan*ea), threespot damselfish (*Stegastes planifrons*) and queen parrotfish (*Scarus vetula*). Those that were abundant at SB but recorded in low numbers at the FGB were the seaweed blenny (*Parablennius marmoreus*), juvenile cocoa damselfish (*Stegastes variabilis*) and rock hind (*Epinephelus adscensionis*).

Table 2B.1. Survey effort. Number of stationary (SDT) and roving (RDT) visual fish surveys conducted during each cruise to the EFG, WFG and SB.

	EFG		**WFG**		**SB**	
Cruise	**Stationary**	**Roving**	**Stationary**	**Roving**	**Stationary**	**Roving**
Late summer 1994	24	12	21	18	21	20
Early summer 1995	14	23	18	23	15	20
Late summer 1995	31	26	26	24	25	29
Early summer 1996	17	20	16	22	20	21
Late summer 1996	26	30	24	28	22	16
Early summer 1997	26	21	26	21	22	21
Total survey effort	**138**	**132**	**131**	**136**	**125**	**127**

Table 2B.2. Cumulative species list. Compiled from three years of semi-annual surveys at the Flower Garden Banks National Marine Sanctuary. Species seen during Roving (RDT) and Stationary (SDT), as well as those sighted during other dives are listed. Surveys were conducted in depths of 22-32 m. Species seen at the surface (sfc) and those seen at night (ngt) are indicated. New documented records for the FGB or SB are indicated with an asterisk (*) in the right-most column.

SPECIES	COMMON NAME	EFG	WFG	SB	FGB	FGBNMS
Acanthuridae	**Surgonfishes**					
Acanthurus bahianus	Ocean Surgeonfish	x	x	x	x	x
Acanthurus chirurgus	Doctorfish	x	x	x	x	x
Acanthurus coeruleus	Blue Tang	x	x	x	x	x
Antennariidae	Frogfishes					
Histrio histrio	Sargassumfish	sfc			x	x
Apogonidae	**Cardinalfishes**					
Apogon affinis	Bigtooth Cardinalfish			x		0
Apogon maculatus	Flamefish	x	x	x	x	x
Apogon pseudomaculatus	Two-Spot Cardinalfish			x		0
Apogon quadrisquamatus	Sawcheek Cardinalfish			x		0
Aulostomidae	**Trumpetfishes**					
Aulostomus maculatus	Trumpetfish	x	x	x	x	x
Balistidae	**Triggerfishes**					
Balistes capriscus	Gray Triggerfish			x		x
Balistes vetula	Queen Tiggerfish	x	x	x	x	x
Canthidermis sufflamen	Ocean Triggerfish	x	x	x	x	x
Canthidemis maculata	Rough Triggerfish			sfc		0
Melichthys niger	Black Durgon	x	x	x	x	x
Blenniidae	**Combtooth Blennies**					
Hypleurochilus bermudensis	Barred Blenny			x		x
Ophioblennius atlanticus	Redlip Blenny	x	x	x	x	x
Parablennius marmoreus	Seaweed Blenny	x	x	x	x	x
Bothidae	**Lefteye Flounders**					
Bothus lunatus	Peacock Flounder			x		0
Bothus ocellatus	Eyed Flounder	x	x		x	*
Congridae	**Conger**					
Coner oceanicus	Conger Eel	ngt			x	*
Lobotidae	**Tripletail**					
Lobotes surinamensis	Tripletail	sfc			x	*
Carangidae	**Jacks**					
Alectis ciliaris	African Pompano		x	x	x	x
Caranx bartholomaei	Yellow Jack	x	x	x	x	x
Caranx crysos	Blue Runner	x	x	x	x	x

Table 2B.2 (continued)

SPECIES	COMMON NAME	EFG	WFG	SB	FGB	FGBNMS
Caranx hippos	Cravalle Jack	x	x	x	x	x
Caranx latus	Horse-Eye Jack	x	x	x	x	x
Caranx lugubris	Black Jack	x	x	x	x	x
Caranx ruber	Bar Jack	x	x	x	x	x
Elagatis bipinnulata	Rainbow Runner	x	x	x	x	x
Selene vomer	Lookdown			x		x
Seriola dumerili	Greater Amberjack	x	x	x	x	x
Seriola rivoliana	Almaco Jack	x	x	x	x	x
Decapterus macarellus	Mackerel Scad		x		x	*
Decapterus punctatus	Round Scad	x	x		x	*
Selar crumenophthalmus	Bigeye Scad	x			x	*
Trachurus lathami	Rough Scad	x	x		x	x
Carcharhinidae	**Requeim Sharks**					
Carcharhinus brevipinna	Spinner Shark	x			x	*
Carcharhinus falciformis	Silky Shark	x			x	x
Carcharhinus plumbeus	Sandbar Shark			x		x
Chaetondontidae	**Butterflyfishes**					
Chaetodon aculeatus	Longsnout Butterfly	x	x	x	x	x
Chaetodon ocellatus	Spotfin Butterfly	x	x	x	x	x
Chaetodon sedentarius	Reef Butterfly	x	x	x	x	x
Chaetodon striatus	Banded Butterfly	x	x		x	x
Cirrhitidae	**Hawkfishes**					
Amblycirrhitus pinos	Redspotted Hawkfish	x	x	x	x	x
Clinidae	**Clinids**					
Emblemaria pandionis	Sailfin Blenny	x	x	x	x	x
Dasyatidae	**Stingrays**					
Dasyatis americana	Southern Stingray	x	x	x	x	x
Diadontidae	**Spiny Puffers**					
Chilomycterus antillarum	Web Burrfish			x		0
Chilomycterus schoepfi	Striped Burrfish			x		0
Diodon holocanthus	Balloonfish	x	x		x	x
Diodon hystrix	Porcupinefish	x	x	x	x	x
Echeneididae	**Remoras**					
Hemiramphus balao	Balao	sfc			sfc	x
Echeneis naucrates	Sharksucker	x	x	x	x	x
Remora remora	Remora	x	x	x	x	*
Ephippidae	**Spadefishes**					
Chaetodipterus faber	Atlantic Spadefish			x		0
Exocoetidae	**Flyingfish**					
Cypselurus melanurus	Atlantic Flyingfish		sfc		x	x

Table 2B.2 (continued)

SPECIES	COMMON NAME	EFG	WFG	SB	FGB	FGBNMS
Gobiidae	**Gobies**					
Coryphopterus eidolon	Pallid Goby	x			x	*
Coryphopterus glaucofraenum	Bridled Goby	x	x		x	*
Coryphopterus punctipectophorus	Spotted Goby			x		0
Gobiosoma oceanops	Neon Goby	x	x	x	x	x
Gnatholepis thompsoni	Goldspot Goby	x	x	x	x	x
Ioglossus calliuris	Blue Goby			x		x
Priolepis hipoliti	Rusty Goby			x		x
Risor ruber	Tusked Goby	x	x		x	x
Haemulidae	**Grunts**					
Anisotremus surinamensis	Black Margate		x		x	*
Haemulon macrostomum	Spanish Grunt			x		0
Haemulon melanurum	Cottonwick	x	x	x	x	x
Holocentridae	**Squirrelfishes**					
Holocentrus adscensionis	Squirrelfish	x	x	x	x	x
Holocentrus bullisi	Deepwater Squirrelfish			x		0
Holocentrus coruscum	Reef Squirrelfish	ngt			x	*
Holocentrus marianus	Longjaw Squirrelfish			x		x
Holocentrus rufus	Longspine Squirrelfish	x	x	x	x	x
Holocentrus vexillarius	Dusky Squirrelfish	x			x	x
Myripristis jacobus	Blackbar Soldierfish	x	x	x	x	x
Inermiidae	**Bonnetmouths**					
Emmelichthyops atlanticus	Bonnetmouth	x	x		x	*
Inermia vittata	Boga	x			x	*
Kyphosidae	**Chubs**					
Kyphosus sectatrix/incisor	Bermuda/Yellow Chub	x	x	x	x	x
Labridae	**Wrassess**					
Bodianus pulchellus	Spotfin Hogfish	x	x	x	x	x
Bodianus rufus	Spanish Hogfish	x	x	x	x	x
Clepticus parrae	Creole Wrasse	x	x	x	x	x
Halichoeres bathyphilus	Greenband Wrasse	x			x	*
Halichoeres bivittatus	Slippery Dick	x	x	x	x	x
Halichoeres cyanocephalus	Yellowcheek Wrasse	x			x	*
Halichoeres garnoti	Yellowhead Wrasse	x	x	x	x	x
Halichoeres maculipinna	Clown Wrasse	x	x	x	x	x
Halichoeres radiatus	Puddingwife	x	x	x	x	x
Hemipteronotus splendens	Green Razorfish	x	x		x	*
Thalassoma bifasciatum	Bluehead Wrasse	x	x	x	x	x

Table 2B.2 (continued)

SPECIES	COMMON NAME	EFG	WFG	SB	FGB	FGBNMS
Lutjanidae	**Snappers**					
Lutjanus buccanella	Blackfin Snapper			x		x
Lutjanus cyanopterus	Cubera Snapper		x		x	*
Lutjanus griseus	Grey Snapper	x	x	x	x	x
Lutjanus jocu	Dog Snapper	x	x	x	x	x
Ocyurus chrysurus	Yellowtail Snapper	x	x	x	x	x
Rhomboplites aurorubens	Vermillion Snapper			x		x
Matacanthidae	**Tilefishes**					
Malacanthus plumieri	Sand Tilefish	x	x	x	x	x
Mobulidae	**Mantas**					
Manta birostris	Atlantic Manta	x	x	x	x	x
Mobula hypostoma	Lesser Devil Ray	x	x	x	x	*
Mobula teripicanna	Sickle-fin Devil Ray		x		x	*
Monacanthidae	**Filefishes**					
Aluterus monocerus	Unicorn Filefish			x		0
Aluterus scriptus	Scrawled Filefish	x	x	x	x	x
Cantherhines macrocerus	Whitespotted Filefish	x	x	x	x	x
Cantherhines pullus	Orangespotted Filefish	x	x	x	x	x
Mullidae	**Goatfishes**					
Mulloidichthys martinicus	Yellow Goatfish	x	x	x	x	x
Pseudupeneus maculatus	Spotted Goatfish	x	x	x	x	x
Muranidae	**Morays**					
Echelycore nigricans	Viper Moray			x		x
Gymnothorax miliaris	Goldentail Moray	x	x	x	x	*
Gymnothorax moringa	Spotted Moray	x	x	x	x	x
Gymnothorax vicinus	Purplemouth Moray	x	x	x	x	*
Myliobatidae	**Eagle Rays**					
Aetobatus narinari	Spotted Eagle Ray	x	x	x	x	x
Opistognathidae	**Jawfishes**					
Opistognathus aurifrons	Yellowheaded Jawfish	x	x	x	x	x
Orectolobidae	**Nurse Sharks**					
Ginglymostoma cirratum	Nurse Shark	x	x	x	x	x
Ostraciontidae	**Boxfishes**					
Lactophrys bicaudalis	Spotted Trunkfish	x	x	x	x	*
Lactophrys polygonia	Honeycomb Cowfish	x	x	x	x	*
Lactophrys quadricornis	Scrawled Cowfish	x	x	x	x	x
Lactophrys triqueter	Smooth Trunkfish	x	x	x	x	x
Lactophrys triqueter	Golden Smooth Trunk	x	x	x	x	*
Pomacanthidae	**Angelfishes**					
Centropyge argi	Cherubfish	x	x	x	x	x

Table 2B.2 (continued)

SPECIES	COMMON NAME	EFG	WFG	SB	FGB	FGBNMS
Holacanthus bermudensis	Blue Angelfish	x	x	x	x	x
Holacanthus ciliaris	Queen Angelfish	x	x	x	x	x
Holacanthus tricolor	Rock Beauty	x	x	x	x	x
Pomacanthus paru	French Angelfish	x	x	x	x	x
Pomacentridae	**Damselfishes**					
Abudefduf saxatilis	Sergeant Major	x	x	x	x	x
Chromis cyanea	Blue Chromis	x	x	x	x	x
Chromis enchrysura	Yellowtail Reefish	x	x	x	x	x
Chromis insolata	Sunshinefish	x	x	x	x	x
Chromis multilineata	Brown Chromis	x	x	x	x	x
Chromis scotti	Purple Reefish	x	x	x	x	x
Microspathodon chrysurus	Yellowtail Damselfish	x	x	x	x	x
Stegastes fuscus	Dusky Damselfish	x	x	x	x	*
Stegastes partitus	Bicolor Damsel	x	x	x	x	x
Stegastes planifrons	Threespot damselfish	x	x	x	x	x
Stegastes variabilis	Cocoa Damselfish	x	x	x	x	x
Priacanthidae	**Bigeyes**					
Priacanthus cruentatus	Glasseye Snapper	x	x		x	x
Rachycentridae	**Cobia**					
Rachycentron canadum	Cobia			x		0
Rhincondontidae	**Whale Shark**					
Rhincodon typus	Whale Shark		x	x	x	x
Scaridae	**Parrotfishes**					
Scarus coelestinus	Midnight Parrotfish	x			x	*
Scarus croicensis	Striped Parrotfish	x	x		x	x
Scarus taeniopterus	Princess Parrotfish	x	x	x	x	x
Scarus vetula	Queen Parrotfish	x	x	x	x	x
Sparisoma atomarium	Greenblotch Parrotfish	x	x	x	x	*
Sparisoma aurofrenatum	Redband Parrotfish	x	x	x	x	x
Sparisoma viride	Stoplight Parrotfish	x	x	x	x	x
Sciaenidae	**Drums**					
Equetus acuminatus	Highhat		x	x	x	x
Equetus lanceolatus	Jacknife fish	x		x	x	x
Equetus punctatus	Spotted Drum	x	x	x	x	x
Equetus umbrosus	Cubbyu			x		x
Scombridae	**Mackerels**					
Acanthocybium solandri	Wahoo			x		0
Euthynnus alletteratus	Little Tuny	x	x	x	x	x
Scomberomorus cavalla	King Mackerel			x		x

Table 2B.2 (continued)

SPECIES	COMMON NAME	EFG	WFG	SB	FGB	FGBNMS
Scorpionidae	**Scorpionfishes**					
Scorpaenodes caribbaeus	Reef Scorpionfish			x		x
Scorpaena plumieri	Spotted Scorpionfish		x	x	x	x
Serranidae	**Sea Basses**					
Epinephelus cruentatus	Graysbe	x	x	x	x	x
Epinephelus fulvus	Coney	x	x	x	x	x
Epinephelus adscensionis	Rock Hind	x	x	x	x	x
Epinephelus guttatus	Red Hind	x	x	x	x	x
Epinephelus inermis	Marbled Grouper	x		x	x	x
Epinephelus morio	Red Grouper			x		0
Liopropoma eukrines	Wrasse Bass	x		x	x	x
Liopropoma rubre	Peppermint Bass	x	x		x	x
Mycteroperca bonaci	Black Grouper	x	x	x	x	x
Serranus phoebe	Tattler Bass			x		x
Mycteroperca interstitialis	Yellowmouth Grouper	x	x	x	x	x
Mycteroperca phenax	Scamp	x		x	x	x
Mycteroperca venenosa	Yellowfin Grouper	x	x	x	x	x
Mycteroperca rubra	Comb Grouper			x		x
Mycteroperca tigris	Tiger Grouper	x	x		x	x
Paranthias furcifer	Creole Fish	x	x	x	x	x
Serranus annularis	Orangeback Bass			x		x
Serranus tigrinus	Harlequin Bass			x		0
Sparidae	**Porgies**					
Calamus nodosus	Knobbed Porgy	x	x	x	x	x
Sphyraenidae	**Barracudas**					
Sphyraena barracuda	Great Barracuda	x	x	x	x	x
Sphyrnidae	**Hammerheads**					
Sphyrna lewini	Scalloped Hammerhead	x	x	x	x	x
Syngnathidae	**Pipefishes**					
Sygnathus pelagicus	Sargassum Pipefish	sfc			x	*
Synodotidae	**Lizzardfishes**					
Synodus intermedius	Sand Diver	x			x	x
Synodus saurus	Bluestriped Lizzardfish	x	x	x	x	*
Synodus synodus	Red Lizzardfish	x	x	x	x	x
Tetradontidae	**Puffers**					
Canthigaster rostrata	Sharpnose Puffer	x	x	x	x	x
Sphoeroides spengleri	Bandtail Puffer	x	x	x	x	x
	TOTALS	**141**	**130**	**148**	**150**	**182**

During the course of this study, 45 species were documented for the first time at the FGB and/or SB (Table 2B.2). It was assumed that most of these species were not new residents to the banks but rather were not previously documented due to survey methodology and effort (pers. comm. S. Gittings, G. Dennis). A few species, however, including the honeycomb cowfish (*Lactophrys polygonia*), sergeant major (*Abudefduf saxatilis*) and yellowtail snapper (*Ocyurus chrysurus*) have established populations since the work of Dennis and Bright in the early 1980s or may currently be establishing populations. In addition, chance recruitment events at the FGB and SB have led to the existence of one to a few individuals of species not usually seen at the banks, including midnight parrotfish (*Scarus coelestinus*), harlequin bass (*Serranus tigrinis*) and black margate (*Anisotremus surinamensis*). A unique gold color phase of the smooth trunkfish (*Lactophrys triqueter*) was also documented during the course of this study (Pattengill, *submitted*).

Jaccard values indicated highest similarity in species composition between the EFG and WFG, and that the WFG was slightly more similar to SB than was the EFG (Table 2B.3). A similar trend was seen when species abundance was used in the comparison (Table 2B.3).

The CV results indicated low temporal variability in the abundance of many species over the six time periods (Figure 2B.1). Approximately half of the species at each bank had a CV value of less than 1.0. Based on the results of all 155 species, an average (SD) CV of 1.31 (0.79), 1.30 (0.81), and 1.41 (0.73) was calculated for the EFG, WFG, and SB, respectively.

During the course of this study 1,222 RDT surveys were completed by REEF participants, representing approximately 800 survey hours. These data, along with the research team's SDT data were entered into a database available on the Internet at *http://www.reef.org*. The utility of the non-expert data were compared with SDT data collected by the research team, and those results are presented in Pattengill and Semmens (*in press*).

Table 2B.3. Similarity analyses. Values in the top of the matrix are Jaccard coefficient values (J), comparing the species present at the EFG, WFG and SB, based on RDT data. Values in the bottom of the matrix are proportional similarity values (Cij), comparing the species abundance of the EFG, WFG and SB. The Cij values were calculated using SDT abundance data for the top 53 species excluding the schooling planktivores. The similarity values are based on all surveys conducted during the study.

Bank	EFG	WFG	SB
EFG	x	0.85	0.63
WFG	0.86	x	0.64
SB	0.39	0.41	x

DISCUSSION

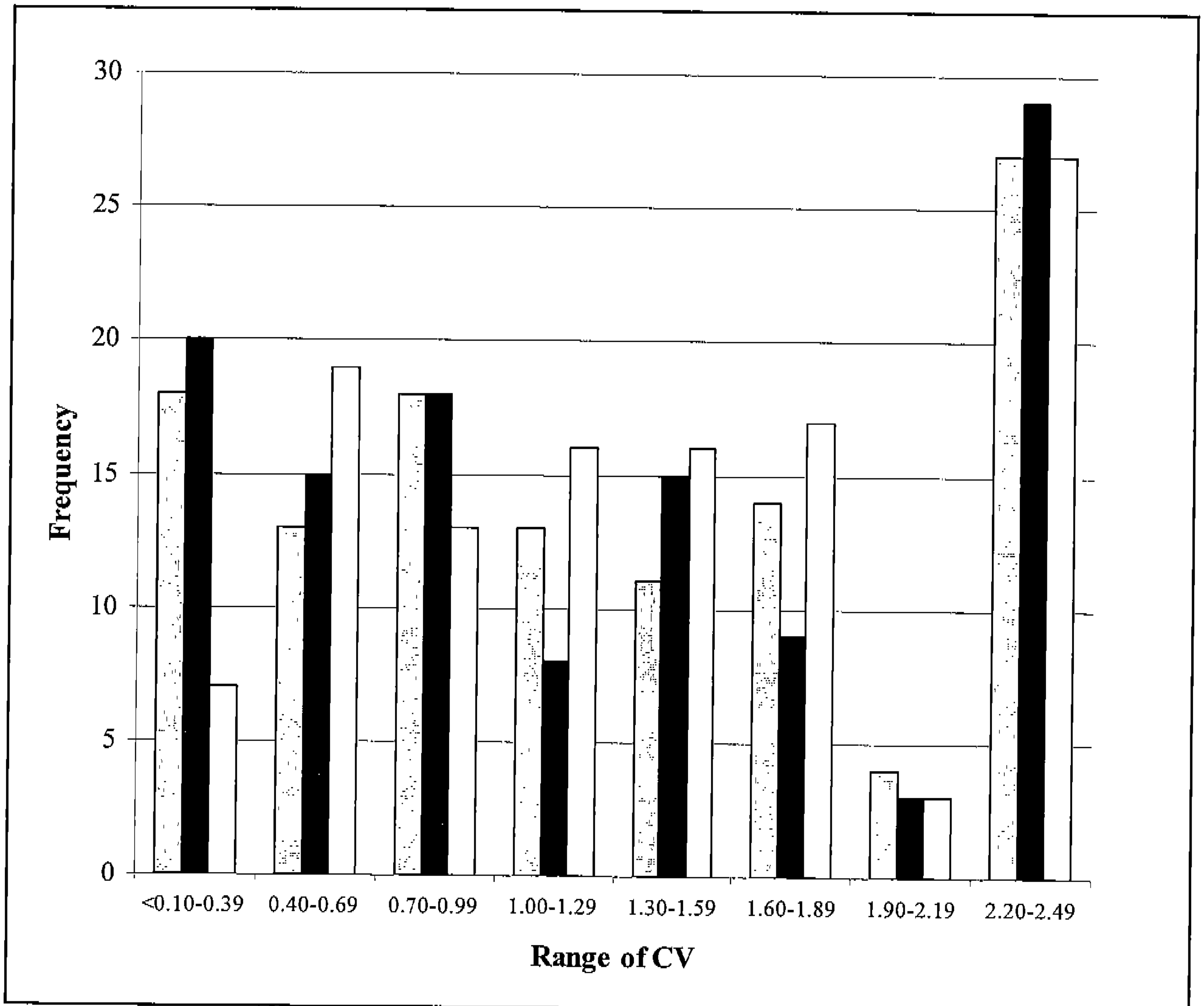

Figure 2B.1. The number of species in each Coefficient of Variation (CV) range. EFG is represented by the light colored bars, WFG by the dark bars, and SB by the medium bars. CV was calculated for all species over the six census times, using SDT abundance.

This study provides the most comprehensive set of information to date on the diurnal fish assemblages in the high diversity upper zone (18m - 32m) of the FGBNMS. The fish assemblages of the FGB and SB consisted of many rare species and few abundant ones, as is the case in most tropical systems. As expected, species richness at the three banks was limited compared with other areas in the tropical western Atlantic. Dennis and Bright (1998) cite three major factors that limit the number of reef fishes occurring in the northwestern Gulf of Mexico: limited habitat diversity, limited habitat area, and distance from source populations. Recruitment success to the FGB and SB apparently varies among species. The ability of fish larvae to recruit to the banks depends upon recruitment variability and post-recruitment factors. Recruitment variability is influenced by the amount of time fishes spend as planktonic larvae, the amount of local larval retention, hydrographic patterns of the Gulf, and reproductive activities at the FGB, SB and, probably more importantly, at distant source areas. Water transport from reef tracts on the Yucatan shelf and off Tampico, Mexico, into the vicinity of the northwest Gulf of Mexico requires approximately 4 to 9 weeks and rarely takes less than three weeks (Kirwan *et al.* 1984; Kelly, pers. comm. as cited in Bright *et al.* 1991). Therefore, unless local retention is occurring, species that cannot survive as larvae longer than three weeks should be unable to recruit to the northwest Gulf. However, the 4,000+ oil and gas platforms in the Gulf of Mexico may act as "stepping stones" for dispersal. In fact, the recent appearance of yellowtail snapper (*Ocyurus chrysurus*) at the FGB in 1997 most likely is a result of this species "hopping" along the platforms in the eastern side of the Gulf, as reported by recreational fishermen.

This persistence study is one of few conducted on a larger, continuous reef system and in the tropical western Atlantic region. During the three years of this study, the abundance of many species exhibited relatively high persistence. While it is clear that the bipartite life cycle of fishes and the associated recruitment variability affects the fish assemblages at these isolated areas, as evident by the chance recruits, post-recruitment factors including available food and habitat influence the resulting FGB and SB systems. Pre and post-recruitment factors interact to maintain relatively stable assemblages. The low inter-annual variability in physical conditions (S. Gittings, pers. com.) most likely enhances the stability. The size of the area studied and the minimal anthropogenic pressure impacting the fish assemblages are likely major contributing factors to the documented stability. Finally, the species pool available to the FGB and SB is a sub-set of the relatively small tropical western Atlantic set of species (compared with the Indo-West Pacific), and this undoubtedly leads to lower levels of natural variability.

In all analyses, the fish assemblages of the EFG and WFG were more similar to each other than either was to the SB assemblage. This result was expected due to the similarity in habitat between the two FGB. Several characteristics distinguish SB from the EFG or WFG. The benthic cover and habitat structure of SB is very different from that found at the FGB. In addition, SB has the greatest annual temperature range and the lowest winter temperatures among the three banks. Though the EFG and WFG were more similar to each other than to SB, in all analyses the WFG was consistently more similar to SB than was the EFG. An obvious similarity between the WFG and SB is the smaller size of shallow habitat area when compared with the EFG. Considering that these banks are essentially islands surrounded by much deeper water, the size element of the island biogeography theory (MacArthur and Wilson 1967) could be an important factor shaping the fish assemblages of these isolated features (Pattengill *et al.* 1997). A comparison among the average number of species and the average number of individual fishes documented per SDT survey supports this idea, with the smallest being at SB and the largest at the EFG.

The accuracy and reliability of non-expert data needs to be considered before adoption into a monitoring program. Data presented in Pattengill and Semmens (*in press*) demonstrate that, given similar sample size, experts had higher accuracy, but the increased sample effort of non-experts provided data with comparable power. As the REEF program continues to grow, care must be taken in evaluating the utility of these data. The economy of effort and the large volume of data collected are this program's greatest advantages. The standardized census method, applied over a wide geographic range, will provide a consistency in the data collection effort not often available. The collection of fish sighting information by volunteer sport divers enables the Flower Garden Banks National Marine Sanctuary to more effectively monitor and protect its resources.

Visual survey methods are routinely used for gathering data on reef fish communities and, because they are non-extractive, such methods are ideal for marine parks or long-term, repetitive sampling. Selection of a census method for a long-term monitoring program requires repeatability, effective use of time, and the provision of valid data that are comparable to studies in other areas. The two methods employed in this study provide complementary information. The RDT allows a more complete search than other methods, yielding a more comprehensive species list, while the SDT provides more quantitative information on a sub-set of species. Results of Spearman correlation analysis between RDT and SDT abundance ranks were high (0.86, Pattengill 1998), indicating the RDT abundance estimates for many species are not as crude as one might assume. For the very rare species and those that are transient or patchy, frequency of sighting might be a more appropriate measure in monitoring change.

This fish database provides the FGBNMS management with knowledge of the existing conditions. Without this basic information, evaluating impact, whether natural or anthropogenic, and documenting change is difficult. An understanding of the level of natural variation in the system, especially in its current, relatively undisturbed, state, will enhance the ability to evaluate change when detected.

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SHARKS AND RAYS OF STETSON AND THE FLOWER GARDEN BANKS

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INTRODUCTION

Stetson and the Flower Garden Banks are part of a large array of topographic highs rising up from the continental shelf of the northwestern Gulf of Mexico (Rezak *et al.* 1985). Topographic highs are defined as natural or artificial features rising up from the sea floor that provide significant vertical and structural relief in an otherwise level and homogeneous landscape. These features function as important habitat for a plethora of marine organisms by serving as suitable substrate within the photic zone for sessile organisms, which in turn support higher trophic assemblages. These communities consist largely of resident species; however, many wide-ranging species occur periodically, interacting with resident species. What wide-ranging species utilize topographic highs, and more importantly, how topographic highs function as habitat to wide-ranging species is virtually unexplored, particularly elasmobranchs (sharks, skates and rays).

Biological surveys conducted at Stetson and the Flower Garden Banks report 16 elasmobranch species (Table 2B.4). However, most records are anecdotal or incomplete, and in some cases, suspicious. Few specimens or photographs are available to confirm identifications of the reported species, and in most cases, no effort was made to characterize their abundance, size, sex, or habitat use.

As a result of coastal habitat loss and heavy fishing pressure, many shark populations in the western Atlantic and Gulf of Mexico are considered by scientists and resource managers to be overexploited (NMFS 1998). Of the shark species found in Table 2B.4, six are listed as overfished in a report to Congress (NMFS 1998). Rays and skates are currently not monitored by the National Marine Fisheries Service, so their population status is unknown, yet both groups are exploited in the western North Atlantic Ocean.

Recent declines in the abundance of certain wide-ranging elasmobranchs have stimulated research on habitat associations and life history strategies of some species. Fisheries biologists have focused on the utilization of nearshore waters as nursery areas by sharks (e.g. Gruber *et al.* 1988, Morrissey & Gruber 1993a, 1993b, Holland et al. 1993); however, similar investigations around topographic highs on the mid- and outer-continental shelf have not been conducted. Further, little is known regarding seasonal habitat areas, such as adult winter and summer feeding areas of many wide-ranging elasmobranchs.

Stetson and the Flower Garden Banks, together with their immediate waters, comprise the Flower Garden Banks National Marine Sanctuary (FGBNMS). A primary objective of resource managers is to conserve natural living resources (e.g., populations, species, communities) that are anthropogenically exploited or affected by managing human activities. Because the FGBNMS is used by thousands of recreational divers each year and fished by commercial and recreational fishermen, sanctuary personnel are challenged to manage activities for multiple use with an ecosystem perspective. Meanwhile, fisheries biologists and managers are responsible for conserving fish populations that include sharks, skates, and rays, particularly those populations exploited by humans. Information regarding elasmobranch habitat use of the FGBNMS is, therefore, useful to divers, fishers, biologists, and resource managers.

The objectives of this paper are (a) to summarize the taxonomic diversity of elasmobranchs associated with Stetson and the Flower Garden Banks, and (b) to assess the habitat use of these sites by select elasmobranch species.

Table 2B.4. Elasmobranchs reported at mid-shelf (MSB) and the Flower Garden Banks (FGB) in the scientific literature. Stetson Bank is classified as a mid-shelf bank, whereas FGB are classified as outer-shelf banks. National Marine Fisheries Service considers species denoted with an asterisk (*) as being overfished, in their annual report to Congress (1998).

Species	FGB	MSB	Platform	References Cited
*Ginglymostoma cirratum**	2, 3, 4, 5	2, 4, 5		1. Bright & Cashman, 1974
*Rhincodon typus**	4	5		2. Sonnier, Teerling & Hoese, 1976
Isurus oxyrinchus	3			3. Boland, Gallaway, Baker & Lewbel, 1983
Mustelus canis	3			4. Dennis & Bright, 1988
*Carcharhinus falciformis**	1, 3, 4	4, 5	3	5. Rezak, Bright & McGrail, 1985
*Carcharhinus leucas**	3, 4	5		
*Galeocerdo cuvieri**	3, 4	5		
Rhizoprionodon terraenovae	1, 5	4, 5		
*Sphyrna lewini**	3, 4, 5	4		
Squatina dumeril	4, 5			
Pristis sp.	4, 5			
Raja olseni	3			
Dasyatis americana	2, 3, 4, 5	2, 4, 5	2	
Aetobatis narinari	3, 4, 5			
Rhinoptera bonasus	3			
Manta birostris	1, 3, 4, 5			

STUDY SITES

Stetson Bank is a mid-shelf bedrock bank (Rezak 1983) composed primarily of soft claystone (Neumann 1958). The bank is located 174 km south-southwest of Sabine Pass at 28°10.0′N and 094°′17.′W. The bank occupies approximately 4 ha, with a base depth of 48 m and crests at roughly 20 m (Bright & DuBois 1974). Bank margins are defined by areas of high relief with outcropping structures standing 4.5 m above the surrounding bottom. These structures are sometimes separated by small "canyon-like" passages. Total relief for Stetson Bank is calculated at 29 m.

The Flower Garden Banks consist of two bedrock banks with carbonate caps occurring near the continental shelf edge, approximately 198 km due south of Sabine Pass on the Texas - Louisiana border. Each bank is the product of upward migrating salt diapirs that in turn supports the northernmost coral reef communities on the North American continental plate. These banks are similar in origin, general structure, and sediment distribution, but differ in details of structure, physiography and sedimentology (Rezak 1983).

The East Flower Garden Bank is at 27°54′32″N latitude and 93°36′W longitude. The bank is pear-shaped and covers an area of about 67 km². Slopes are steep on the east and south sides, but gentle to the west and north. The shallowest depths of the bank are about 20 m, whereas surrounding water depths are about 100 m to the west and north and about 120 m on the east and south sides. Total relief on the bank is about 116 m (Rezak 1983).

The West Flower Garden Bank is 12 km west of the East Flower Garden Bank at latitude 27°52′27″N, longitude 93°48′47″W, and covers about 137 km². The bank is oval-shaped and oriented in a northeast-southwest direction. The crest of the bank lies at a depth of approximately 20 m. Surrounding water depths vary from 100 m to the north, to 150 m to the south. Total relief on the bank is approximately 130 m (Rezak 1983).

SAMPLING & ANALYSIS

Random *in situ* surveys of elasmobranchs using SCUBA were conducted opportunistically at the study sites. Surveys were typically limited to depths of 37 m; however, some surveys were conducted to depths of 62 m. Observations made from surface platforms (boats or offshore platforms) of elasmobranchs near the sea surface were also documented. These were compiled with records of underwater observations into a comprehensive catalogue and classified as one of three observation types: underwater, surface, or aerial.

Biological and ecological data gathered for each record included the animals' identification to the lowest taxonomic group possible, estimated size and sex, relative abundance, habitat area, date, time of day, location, and notes regarding behavior observed. Sizes were reported in 3-ft increments and later converted to their approximate metric group (i.e., 1-2 m, 2-3 m, etc.). Shark size was reported as the estimated total length (TL), while batoid size was reported as the estimated "wing-span" or disc width (DW) of the animal. Sex was determined by the presence or absence of claspers, and reported as male, female, both sexes present, or undetermined. Relative abundance was reported as the number of conspecifics observed for each record reported.

Species identifications were confirmed from photographic, videographic documentation or specimens provided by Texas Parks & Wildlife Department biologists, commercial fishermen, and recreational divers. Records of elasmobranchs were pooled by site and month. Months were grouped into the following seasons: Winter 1 (December - January), Winter 2 (February - March), Spring (April-May), Summer 1 (June - July), Summer 2 (August - September), and Autumn (October - November).

Many scientists and lay people participated in elasmobranch surveys on various undocumented cruises to the study sites; therefore, the overall sampling effort was unmeasurable. However, to gain some perspective regarding the scope of sampling entails examining the principal effort I made to survey elasmobranchs. I made personal excursions to study sites with the intention of visiting each study site at least once during each pooled season. From July 1992 through April 1998, I spent 21 days at Stetson Bank and 172 days at the Flower Garden Banks. While it was possible to visit the Flower Garden Banks at least once during each season, I was unable to visit Stetson Bank during the Winter 1 season.

TAXONOMIC DIVERSITY

Fourteen species of elasmobranchs were positively identified from surveys conducted in this study. These species represent three orders (2 shark & 1 batoid), seven families (4 shark & 3 batoid), and nine genera (5 shark & 4 batoid) (Table 2B.5). One species (*Mobula tarapacana*) is a new record for the Gulf of Mexico (Childs 1997), and three species (*Carcharhinus perezi, Dasyatis centroura*, and *Mobula hypostoma*) are rare records for the northwestern Gulf of Mexico. These species are predicted to occur in the region (Walls 1975, Robins *et al.* 1986, Hoese & Moore 1977, McEachran & Fechhelm 1998); however, these are among the first records confirming their presence. Six species (*Carcharhinus obscurus, C. perezi, Carcharhinus plumbeus, D. centroura, M. hypostoma* and *M. tarapacana*) are new records to the banks and reefs of the northwestern Gulf of Mexico. Five unconfirmed species (*Carcharhinus brevipinna, Carcharhinus limbatis, Negaprion brevirostris, Sphyrna mokarran*, and *Sphyrna tiburo*) are reported from surveys at these sites that are suspect, and not discussed further herein.

SEASONAL HABITAT USE AND SELECT SPECIES ACCOUNTS

Table 2B.5 summarizes the seasonal occurrence of juvenile and adult elasmobranch species at Stetson and the Flower Garden Banks from records gathered during this study . Many sharks are known to segregate spatially and temporally by size and sex, utilizing different bathymetric or geographic areas (Springer 1940, 1967). Habitat areas are characterized as adult winter and summer feeding areas, mating areas, and nursery areas (Castro 1987, 1993). Nursery areas may be further differentiated as primary and secondary nursery areas (Bass 1978, Simpfendorfer & Milward 1993).

Table 2B.5. Seasonal occurrence of juvenile (J) and adult (A) elasmobranch species reported in this studyare shown in the upper section of the table. The presence of both juveniles and adults are denoted by JA. Seasonal distributions of elasmobranchs at Stetson (ST) and the Flower Garden Banks (FGB) are portrayed in the lower section of the table. Black blocks represent confirmed reports of the species, while grey blocks represent unconfirmed reports.

Elasmobranch Habitat Use by Life History Stage

Species	Common name	Winter 1 Dec-Jan	Winter 2 Feb-Mar	Spring Apr-May	Summer 1 Jun-Jul	Summer 2 Aug-Sep	Autumn Oct-Nov
Ginglymostoma cirratum	nurse shark	A	A	A	A	A	A
Rhincodon typus	whale shark				JA	JA	JA
Galeocerdo cuvieri	tiger shark	A	A				
Carcharhinus falciformis	silky shark	J	J	J	J	J	J
Carcharhinus obscurus	dusky shark				J	J	J
Carcharhinus perezi	Caribbean reef shark	J	J	J	J	J	J
Carcharhinus plumbeus	sandbar shark	A	A	A	A	A	A
Sphyma lewini	scalloped hammerhead	A	A	A	A	A	J
Dasyatis americana	southern stingray		A	A	A	A	A
Dasyatis centroura	roughtail stingray					A	
Aetobatis narinari	spotted eagle ray	A	A	A	A	A	A
Mobula hypostoma	lesser devil ray			A	A		
Mobula tarapacana	sicklefin devil ray					A	
Manta birostris	manta ray	J	J	J	JA	JA	JA

Elasmobranch Habitat Use by Shelf Position

Species	Common Name	Winter 1 Dec-Jan	Winter 2 Feb-Mar	Spring Apr-May	Summer 1 Jun-Jul	Summer 2 Aug-Sep	Autumn Oct-Nov
Ginglymostoma cirratum	nurse shark	BOTH	BOTH	BOTH	BOTH	BOTH	BOTH
Rhincodon typus	whale shark				BOTH	BOTH	BOTH
Galeocerdo cuvieri	tiger shark	FGB	FGB				
Carcharhinus falciformis	silky shark	FGB	FGB	FGB	FGB	FGB	FGB
Carcharhinus obscurus	dusky shark				FGB	FGB	FGB
Carcharhinus perezi	Caribbean reef shark	FGB	FGB	FGB	FGB	FGB	FGB
Carcharhinus plumbeus	sandbar shark		FGB	ST	ST	ST	ST
Sphyma lewini	scalloped hammerhead	FGB	BOTH	FGB	FGB	FGB	BOTH
Dasyatis americana	southern stingray		FGB	ST	BOTH	FGB	FGB
Dasyatis centroura	roughtail stingray					ST	
Aetobatis narinari	spotted eagle ray	FGB	FGB	ST	BOTH	BOTH	FGB
Mobula hypostoma	lesser devil ray			FGB	FGB	ST	
Mobula tarapacana	sicklefin devil ray					FGB	
Manta birostris	manta ray	FGB	FGB	FGB	FGB	BOTH	BOTH

Primary nursery areas are areas where adult female sharks deposit their offspring, whereas secondary nursery areas are areas where juveniles are found before becoming reproductively active and joining the adult groups. Juveniles are thought to move seasonally; thus, secondary nursery areas may be grouped as winter or summer.

Ginglymostoma cirratum: Adult nurse sharks were observed in all seasons except the Winter 1 period when trips to the study sites were rare. Observations of nurse sharks were rare during the winter and spring months, while common during the summer months. Whereas this species is not known to be wide-ranging, it is likely these sites function as year-round habitat for nurse sharks. Based upon infrequent observations during the winter, nurse sharks presumably inhabit deeper regions of the banks during the winter months, yet are residents of these features.

Rhincodon typus: Whale sharks were reported in the summer and autumn periods at Stetson and the Flower Garden Banks when both juvenile and adult sharks were observed. These pelagic planktivores are wide-ranging, and observations at the study sites are primarily of solitary animals. However, in two different years, observations were made of aggregations of up to 50 animals in the waters near the Flower Garden Banks after the annual mass coral spawning event in late summer. Based upon the data available, it appears that whale sharks utilize a broad area which includes the study sites as summer feeding habitat.

Galeocerdo cuvieri: Tiger sharks were observed at the Flower Garden Banks during winter months, and all sightings were adult animals. During this period, it is common to observe more than one animal in a single dive along the escarpment of a bank. An anecdotal account was reported in July of an adult tiger shark caught with hook and line at the Flower Garden Banks by recreational fishermen. It is likely this species occurs in the area throughout the year, although not in the abundance observed in the winter months. Based upon records gathered in this study, the Flower Garden Banks function as winter feeding habitat to adult tiger sharks.

C. obscurus and *C. perezi*: The Flower Garden Banks function as secondary nursery habitat to two carcharhinid species, the dusky and Caribbean reef sharks. Juveniles of these two species have been observed primarily on dives conducted during the summer and autumn periods, and specimens of each species were collected from the Flower Garden Banks. Additional juvenile carcharhinid sharks were observed during the winter periods at these banks and are best identified as either of these species.

C. plumbeus: Adult sandbar sharks were observed at the Flower Garden Banks during the Winter 2 period, however not during warmer months of the year. This species was, however, observed at Stetson Bank during summer months. Due to difficulties in sampling Stetson Bank during the winter periods, data should not be interpreted to indicate movement between mid-shelf banks such as Stetson, and outer shelf banks such as the Flower Garden Banks, although this is a reasonable hypothesis. At present, it is fair to state that sandbar sharks associate with topographic highs, and that the Flower Garden Banks function as adult winter feeding habitat while Stetson serves as adult summer feeding habitat.

Sphyrna lewini: Scalloped hammerheads were abundant in surveys conducted at the Flower Garden Banks during the Winter 2 period. Eight robust adult males of this species were documented at the East Flower Garden Bank in early December, the earliest record of the winter. Observations of this species basking at the surface during the Winter 2 period are estimated at over 200 adults at each Flower Garden Bank. Scalloped hammerheads depart the Flower Garden Banks in late March to early April as water temperatures rise. This species was observed at Stetson Bank during the Winter 2 season; however, few individuals were observed, indicating that this site is not visited by the same abundance of hammerheads as the Flower Garden Banks. Scalloped hammerheads were observed rarely at all sites during the spring, summer and autumn seasons. Data clearly indicates that the Flower Garden Banks function as adult winter feeding habitat for male scalloped hammerheads.

D. centroura: Small aggregations of three adult roughtail stingrays were infrequently observed at Stetson Bank and another mid-shelf bank (Sonnier Bank) during the summer season. Little is known regarding this species, and it is rarely reported in the northwestern Gulf of Mexico. It is possible that this species visits mid-shelf banks such as Stetson and Sonnier during the summer months as it migrates over the continental shelf. The migratory pattern of this species in the Gulf of Mexico is poorly known.

Aetobatis narinari: Spotted eagle rays occur in large aggregations during the winter seasons and appear to coincide with the scalloped hammerhead migrations. Spotted eagle rays were observed in early December when adult hammerheads were also observed. All reported spotted eagle rays are approximately 2 m in width, indicating adults. They have been observed swimming in polarized schools estimated at 200 individuals per school. These aggregations occur at the Flower Garden Banks during the Winter 1 & 2 seasons and depart approximately the same time as the scalloped hammerhead sharks. Solitary individuals are periodically observed at all study sites during spring, summer, and autumn seasons; however, they are rare based on records collected during these seasons. The Flower Garden Banks function as adult winter feeding habitat for spotted eagle rays.

Manta birostris: Manta rays are common to these banks and are typically juveniles, although adults are sometimes observed during the summer months. From data collected, it is accurate to state that the Flower Garden Banks function as nursery habitat for manta rays in the region; however, their nursery area may include more than the topographic highs surveyed.

M. hypostoma: Adult lesser devil rays were regularly observed at the Flower Garden Banks during the Spring and Summer 1 seasons in aggregations of up to 22 individuals. Members of both sexes were documented, often swimming in pairs. The animals appear to migrate from the Flower Garden Banks in July, and a few individuals have been documented at Stetson Bank in the Summer 2 season. It appears that this species visits the Flower Garden Banks as part of its annual migratory pattern; however at this time, I am not certain how these banks function as habitat to the species. It is possible that these animals mate at these banks, based upon the aggregations and pairing observed; however, mating behavior has yet to be observed.

M. tarapacana: Several rare observations of sicklefin devil rays have been made at the Flower Garden Banks during the Summer 2 period, although not reported in the same year. These records occur in close timing with the annual mass spawning of corals at the Flower Garden Banks. All devil rays are pelagic planktivores and thought to be wide-ranging. Previously, this species was reported to occur off the coast of Venezuela in the western North Atlantic, although thought to occur further north (Notarbartolo-di-Sciara & Hillyer 1989). Little is known of this species distribution in the western Atlantic, and how this species uses the Flower Garden Banks can be surmised at best as opportunistic summer feeding habitat as corals spawn en masse.

CONCLUSIONS

Topographic highs in the northwestern Gulf of Mexico, such as Stetson and the Flower Garden Banks, are utilized as habitat by a number of wide-ranging elasmobranchs. For some sharks and rays (tiger, sandbar, and scalloped hammerhead sharks, and spotted eagle rays), the topographic highs function as adult winter feeding habitat. During the summer, these features serve as adult feeding habitat to whale sharks and three species of devil rays. The Flower Garden Banks function as nursery habitat for dusky sharks, Caribbean reef sharks, and manta rays. These sites also support several resident species that include nurse sharks, Caribbean reef sharks, and manta rays. The Flower Garden Banks may also function as a mating area for lesser devil rays, although data supporting this hypothesis is weak.

Because these features serve as important habitat to some wide-ranging elasmobranch species and some of these species are considered overfished by NMFS (e.g., dusky and sandbar sharks), natural resource biologists and managers should integrate this information into management plans designed to conserve elasmobranch populations and ecological assemblages associated with topographic high ecosystems.

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FISH COMMUNITY STRUCTURE: MISSISSIPPI/ALABAMA PINNACLE TREND

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INTRODUCTION

An extensive, high profile, deep reef tract is located on the Mississippi-Alabama outer continental shelf. This tract, referred to as "The Pinnacles," is one of a number of drowned fossil reef complexes arising at wide intervals along the shelf edge of the northern Gulf of Mexico along the "40-fathom" contour. Although shallow reef fish faunas in the Gulf of Mexico have been reasonably well studied, deep reef faunas have not. Thus, community structure and trophic biology for demersal fishes of The Pinnacles remains poorly known, as do the physical parameters controlling faunal composition and species dominance. Currently, it is difficult to draw inferences about the potential vulnerability of The Pinnacles fauna to human activities on the outer shelf.

The Pinnacles reefs are not actively accreting since rapid light attenuation below 65 m, together with mid-winter temperatures dipping below 18° c, restricts reef-building corals and algae to sporadic small colonies. However, these fossil reefs do support a lush fauna of sessile soft corals, black corals, crinoids and sponges—together forming living habitat for a well-developed fish fauna. These deep reefs are important as reef fish havens and replenishment zones; i.e., a source of re-population of more heavily impacted inshore reefs. The Pinnacles probably also serve as important spawning and/or feeding grounds for key species targeted by sport and commercial fisheries. This area is potentially vulnerable to the effects of offshore oil development in addition to continuous fishing pressure.

Our overall research goal is to define demersal fish faunal composition, quantitative community structure, relative abundance, species dominance, habitat affinities, and trophic structure. Simultaneously, we will collect physical data about the benthic habitat and water column to define mechanisms underlying community structure on The Pinnacles. Our study focuses specifically on numerically dominant resident fishes to define those components dominating food web interactions.

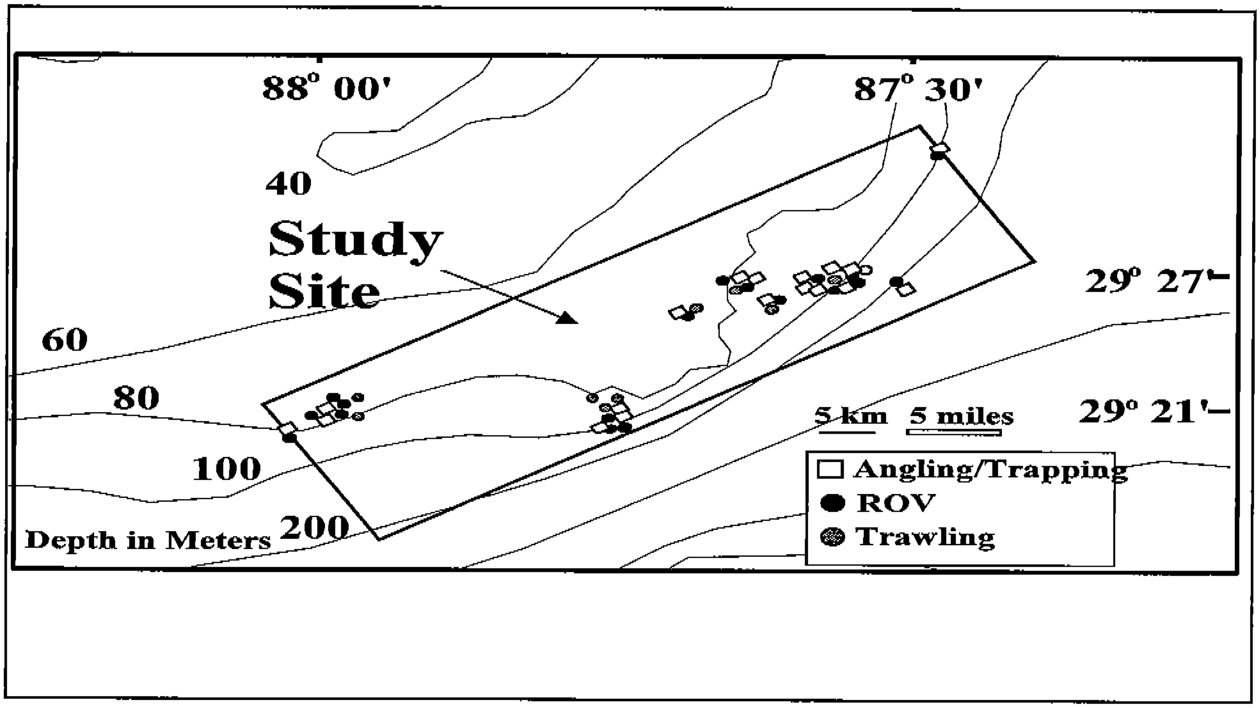

Figure 2B.2. U.S. Geological Survey, BRD station sites occupied during RV Suncoaster Cruise FCSC 97-01, Pinnacles reef tract, Mississippi-Alabama Outer Continental Shelf.

Objectives of this investigation are: (1) to determine taxonomic composition, diversity, and origins of The Pinnacles fish fauna; (2) to define quantitative community structure; (3) To define characteristic reef biotopes; and (4) to define species food habits, trophic guilds, and the overall food web. This report addresses the first three objectives. A companion report by one of us (Weaver) addresses the fourth objective.

METHODS

Study Sites. The Pinnacles complex, including out study sites (Figure 2B.2), comprises two linear series of topographic features that parallel the coastline, 60-80 n. mi. off Mobile Bay. Base depths of the two tracts are 85 and 110 m, respectively. Reefs are steep-sided and either flat-topped, spire-topped, or ragged topped. They fall into three basic categories of relief: low (< 1m), medium (1-5m), and high (> 5m); and vary from a few meters to a few hundred meters across. We targeted large reefs in each of the relief categories, since large reefs tend to provide maximum habitat heterogeneity and fish diversity.

In August 1997, we engaged in an initial BRD OCS-Program that sponsored 12-day ROV reconnaissance and sampling cruise on RV Suncoaster. A 4-day BRD fish sampling cruise followed in October 1998 aboard RV Tommy Munro. Additional study specimens were collected incidentally during MMS-sponsored cruises undertaken by Continental Shelf Associates (CSA). To quantitatively define community structure during the 1997 cruise, we employed an ROV equipped with a high resolution video camera to accomplish timed transects. Videotape analysis was used to identify and enumerate species and to resolve characteristic biotopes. Trapping, angling, and off-reef trawling were used during BRD cruises to obtain specimens for ID validation and for stomach content analysis. Sampling during CSA cruises was accomplished via angling. Sampling methods, including micro-hook angling were effective for planktivores, microvores, and macrovores.

RESULTS

During the 1997 and 1998 BRD cruises, 118 separate sampling stations were occupied, spanning the East-West extent of the Mississippi-Alabama pinnacles complex (Figure 2B.2). Individual reefs were sampled at high intensity for one flat-top pinnacle Figure 2B.3. The fauna and biotopes were documented via nearly 50 hours of videotape, enabling a rough first-order analysis of faunal composition, sources of contribution to the fauna, comparative community structure within and among pinnacles reefs and an empirical classification of dominant reef-fish biotopes. Over 2,400 fish specimens were collected, representing 150 species, 74 of which are characteristic reef-fish or reef-associated species. Of these, ca. 700 reef fish specimens have been analyzed for stomach contents.

Resident Caribbean reef fishes are the major component of The Pinnacles fauna. Prominent taxa include 15 species of serranids, 3 wrasses, 3 pomacanthids, 3 chaetodontids, 3 sparids, 3 scorpaenids, 3 holocentrids, 2 priacanthids, one apogonid, one pomacentrid, and 4 muraenids. A definitive species list will await verified identifications for preserved specimens and validation of ROV records.

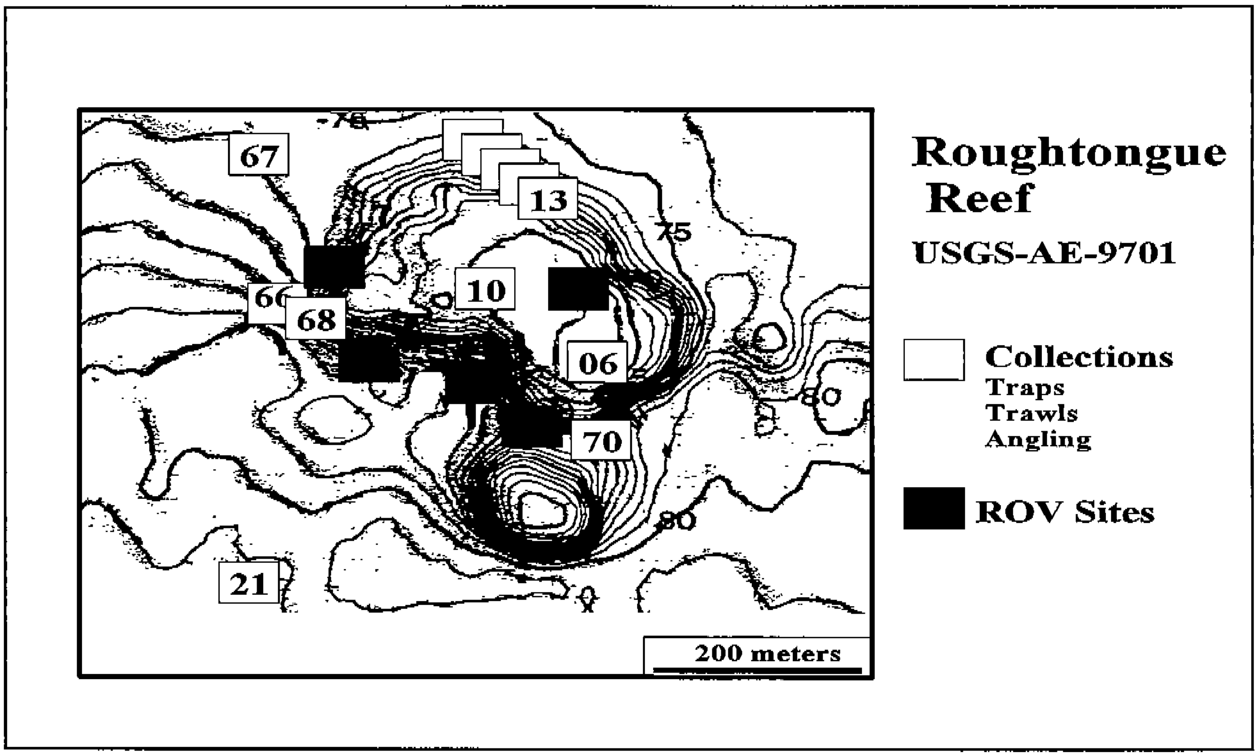

Figure 2B.3. Sampling intensity for one large flat-topped pinnacle study site targeted during BRD RV Suncoaster Cruise FCSC 97-01.

Fundamentally, however, The Pinnacles support a diverse and abundant tropical reef-fish fauna that is surprisingly rich, given the latitude and depth, episodic turbidity events from the Mississippi plume, and the sediment resuspension effects of major storms. Planktivores comprise the dominant faunal component. Coralivores and herbivores such as scarids and acanthurids are understandably absent, given the absence of hermatypic corals and their algal symbionts as a food base. Other taxa, such as balistids and haemulids are very poorly represented on these ahermatypic reefs. Thus, the fauna might aptly be termed a winnowed Caribbean reef fish fauna, dependent upon a planktonic food base (versus benthic algal food base as on shallow coral reefs).

A second potentially very important component includes a small number of abundant mobile, schooling, hemi-pelagic, predators including the scombrid *Euthynnus alletteratus*, three species of the genus *Seriola*, and the small scad *Trachurus lathami*. These mobile predators/foragers may play a major role in structuring fish communities on The Pinnacles reefs. A third component includes shelf species, associated with reef-top flats, and/or the circum-reef talus apron, including ogcocephalids, malacanthids, and serranids of the genera *Centropristis* and *Serranus*. Such species may use the reef primarily as a shelter base from which feeding forays can be launched onto adjacent soft substrate. A fourth faunal component includes fishes from the adjacent upper continental slope, which impinge on deep reefs, foraging heavily on the reef-top biotope. Included are the codlet *Bregmaceros*, an abundant planktivore, along with the boarfish *Antigonia*, and unidentified myctophids.

Rounding out The Pinnacles fauna, quite surprisingly, are a small group of demersal species—more typically considered residents of soft substrate habitats on the inner shelf and estuary. Included here are the sciaenids *Cynoscion arenarius*, *Leiostomus xanthurus*, and *Micropogonias undulatus*. These species were observed by ROV, feeding in large numbers right on the reef surface at night, and were captured both by angling and baited trap.

Videotape quantification plus food habits data indicate that key trophic guilds on The Pinnacles reefs include the dominant reef-top planktivore guild, a reef-base micro-benthivore guild, an epifaunal cropper guild, a demersal macrovore guild, and a pelagic macrovore guild. The food web appears to be dominated by interaction between the planktivore guild (primarily anthiine species) and two macrovore guilds (a demersal snapper-grouper-moray guild, and a pelagic amberjack-little tuna guild). Characteristic members of the planktivore guild include the damselfish *Chromis enchrysurus*, and two small streamer-basses, *Hemanthias vivanus* and *Pronotogrammus martinicensis*. The diet of the last species is typical for the guild, predominantly copepods and larval forms of other taxa.

DISCUSSION

Our deep reef community structure results parallel those of Thresher and Colin (1986)[1], who reported that planktivorous anthiines dominated the fauna at 80-100 meters at Enewetak Atoll, and that

[1] Thresher, R. E. and P. L. Colin. 1986. Trophic structure, diversity, and abundance of fishes of the deep reef (30-300 m) at Enewetak, Marshall Islands. Bulletin of Marine Science 38(1):253-272.

Table 2B.6. Relative abundance (%) of fishes at reefs of varying topographic profile from BRD Cruise FCSC 97-01, August 1997. Data derive from ROV videotape analyses. Parameter = total number of individuals per species divided by total number of fishes of all species x 100 for a single target reef site representing each category.

Species	**Common Name**	**Percent by Reef Profile Type**		
		Low (<1m)	**Medium (1-5m)**	**High (>5m)**
Pronotogrammus martinicensis	Roughtongue bass	0	86	45
Hemanthius vivivanus	Red barbier	0	-	36
Chromis enchrysurus	Yellowtail reeffish	0	-	10
Pristigenys alta	Short bigeye	13	-	1
Labridae spp.	Wrasses	40	-	1
Serranus phoebe	Tattler	40	3	3
Other taxa		7	11	4
TOTAL		100%	100%	100%

piscivores ranked second in importance. However, community structure on deep offshore reefs in the Gulf of Mexico is much more complicated than this simplistic analogy suggests. Preliminary data applied to a between-reef comparison reveals that high and medium profile pinnacles are dominated by the planktivore guild, whereas the micro-benthivore guild predominates on low profile reefs (Table 2B.6).

Indeed, the area, steepness, rugosity, current complexity, and extent of live cover of individual pinnacles are all important modifiers of species composition and faunal dominance. We propose seven empirically-defined key reef biotopes for The Pinnacles: reef top (flat), reef crest (rim), reef slope (wall), reef base, fore-reef patches, circum-reef talus flat, circum-reef sand flat. Thus, within-reef faunal differentiation takes place on a finer spatial scale. For example, on the reef crest biotope, *P. martinicensis* predominates among a suite of three key planktivores (Figure 2B.4, upper left). In contrast, the immediately adjacent reef top biotope is characterized by a suite of two planktivorous anthiines + one micro-benthivore, with *H. vivanus* dominating (Figure 2B.4, upper right). On the circum-reef talus apron biotopes, gobiids, labrids, and priacanthids together dominant the fauna (Figure 2B.4, lower right).

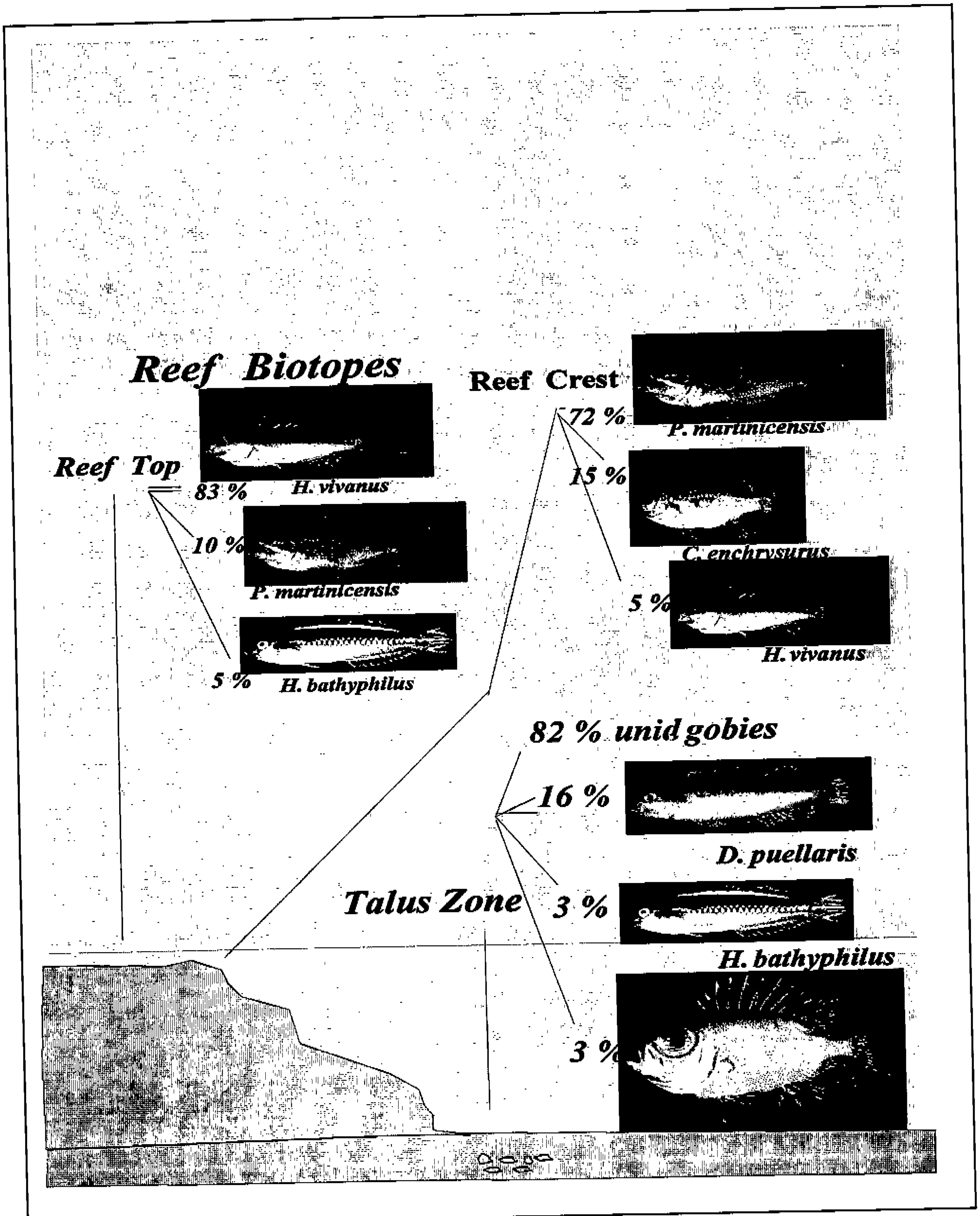

Figure 2B.4. Simplistic first-order scheme of community structure among dominant fishes on three characteristic Pinnacles biotopes.

The emerging knowledge of the deep reef fish community structure and diversity provides the baseline with which to index the health, productivity, and stability of The Pinnacles ecosystem. Many short-term phenomena are elusive, and difficult to detect and measure; many major events are equally difficult to assess. Demersal fish communities integrate both, and respond on a time scale relevant to human interests.

In striking contrast to resilient sessile invertebrates, fishes respond to deteriorating conditions by moving away. In contrast to the poorly described benthic invertebrate fauna, the fish fauna is completely known taxonomically and readily assessed in terms of taxonomic diversity and species dominance. Thus, changes in species richness, abundance, dominance rank order, modal size, size frequency distribution, and biomass can be precisely determined to assess the health and stability of the deep reef ecosystem. Analysis of food habits of fishes will further reveal the major energy pathways controlling community structure and identify areas of vulnerability to human activities on the outer shelf.

We would urge that important corollary studies be undertaken to define the static physical and dynamic watermass processes that drive community structure on Pinnacles reefs. It can readily be hypothesized that pinnacles of some critical minimum relief interrupt laminar currents creating local turbulence. Such local turbulence is of critical importance to planktivorous fishes. Coupling high-resolution 3-D topographic mapping of individual study pinnacles with 3-D acoustic Doppler current profiling, together with simultaneously coordinated, biotope specific, ROV video-transecting of fish communities, would provide the physical-hydrological context with which to resolve the local distribution and abundance of the plankton/planktivore food base that determines community structure on deep reefs.

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TROPHIC SUBSIDIES IN THE TWILIGHT ZONE: FOOD WEB STRUCTURE OF DEEP REEF FISHES ALONG THE MISSISSIPPI- ALABAMA OUTER CONTINENTAL SHELF

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ABSTRACT

Food web structure of fishes was examined in the deep reef community along the Mississippi-Alabama outer continental shelf. Fish communities on high-profile topographic features are numerically dominated by roughtongue bass, *Pronotogrammus martinicensis*, and red barbier, *Hemanthias vivanus*. Stomach content analysis reveals that calanoid copepods, mollusk/crustacean larvae and pelagic tunicates dominate the diet of both species, and that these fishes in turn serve as prey for large reef predators. Seasonal shifts in the diet of planktivores were also evident. Fish eggs and fish larvae constitute a greater portion of stomach contents in Feb/March samples, and indicate trophic links to pelagic, soft-bottom, and possibly nearshore primary production (via spawning aggregations of large, migrating species). Dietary shifts in predatory fishes reveal that pelagic plankton (including colonial salps) and planktivorous reef fishes form the primary trophic pathways throughout the year for common fishes in the deep reef community.

INTRODUCTION

Feeding habits and food web structure of reef fishes occurring along the Mississippi-Alabama outer continental shelf were surveyed. Trophic pathways are important to develop an understanding of the ecological framework in the reef fish community. Analysis of food web structure will identify the relative importance of resident reef fishes in the diet of large predatory fishes, predator-prey relationships among fishes and invertebrates, and the role of fishes in supplying nutrients to the benthic invertebrate community.

Detailed studies of the food habits of deep reef fishes have not been reported in the literature, and few reports of diets of shallow reef fishes in the Gulf of Mexico are available (e.g. Nelson and Bortone 1996, Weaver 1996). The reef fish, invertebrate, and plant assemblage varies dramatically with depth, limiting comparisons among shallow and deep reef communities. To identify food habits of deep reef fishes, developing food web models from the literature would therefore yield an inaccurate, simplistic view. Diets of marine fishes are known to vary dramatically with body size, environment, and season, and collection of fishes provides the only method to develop a detailed description of trophic pathways in the deep reef environment.

MATERIALS AND METHODS

Fishes were collected by hook-and-line angling during four research cruises from August 1997 to October 1998. A variety of artificial and natural baits were used to sample fishes over a wide range of body sizes. Specimens were placed on ice and frozen or immediately preserved in 10% buffered formalin. Fishes were dissected in the laboratory and stomach contents were removed, sorted, and prey items were identified to the lowest possible taxon. Numerical abundance of each prey taxon was calculated to estimate relative importance in the diet of each species. Diets of the common reef fishes were incorporated into a working food web model following the methods of Winemiller (1990) to identify the dominant trophic pathways among the reef fish community (Figure 2B.5).

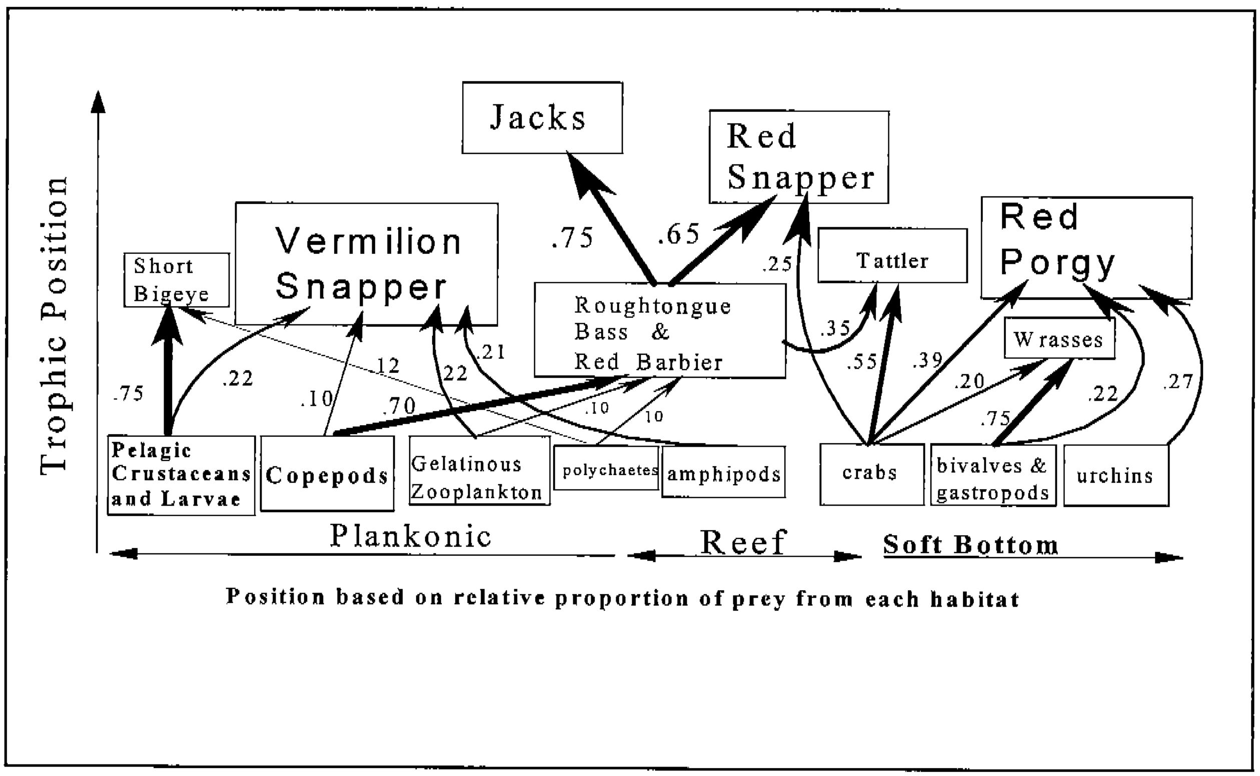

Figure 2B.5. Preliminary food web model for the deep reef fish community, based on methods proposed by Winemiller (1990), indicating primary trophic pathways identified from samples taken during our August 1997 cruise.

Table 2B.7. Prey items identified in stomach contents of specimens collected from the Mississippi-Alabama outer continental shelf. The number of specimens examined that contained prey is indicated. "X" indicates presence of prey groups in stomach contents, while "L" indicates presence of planktonic larval forms for each prey group, such as gastropod veligers and shrimp zoeae.

Taxa	**Bryozoans**	**Anthozoans**	**Polychaetes**	**Gastropods**	**Bivalves**	**Cephalopods**	**Crabs**	**Shrimps**	**Amphipods**	**Copepods**	**Echinoderms**	**Urochordates**	**Fish Eggs / Larvae**	**Fishes**
Batrachoididae-toadfishes														
Opsanus pardus (5)				X			X				X			X
Carangidae-jacks														
Seriola dumerili (4)														X
Seriola fasciata (1)						X								X
Seriola rivoliana (1)														X
Holocentridae-squirrelfishes														
Holocentrus adscensionis (3)							L	X						X
Neoniphon marianus (2)			X				L	L					X	X
Serranidae-sea basses														
Centropristis ocyurus (6)				X			X	L	X		X			
Hemanthias vivants(50)			X	L	L		L	L	X	X		X	X	X
Pronotogrammus martinicensis (131)			X	L	L	X	L	L		X				
Serranus phoebe (44)						X	X	X	X		X		X	X
Priacanthidae-bigeyes														
Priacanthus arenatus (15)						X	X/L	X/L					X	X
Pristigenys alta (8)			X	L		X	L	X/L					X	
Apogonidae-cardinalfishes														
Apogon pseudomaculatus (4)							X/L	L						
Malacanthidae-tilefishes														
Caulolatilus chrysops (2)			X		X		X				X			
Malacanthus plumieri (7)				X	X		X				X			X
Lutjanidae-snappers														
Lutjanus campechanus (26)						X	X	X						X
Rhomboplites aurorubens (74)			X	L		X	L	X/L	X	X		X	X	X
Sparidae-porgies														
Pagrus pagrus (30)			X	X	X		X				X			X
Sciaenidae-drums														
Pareques umbrosus (3)			X	X			X	X/L						
Pareques iwamotoi (1)				X			X				X			
Chaetodontidae-butterflyfishes														
Chaetodon aya (1)							L		X					
C. sedentarius (3)	X							L						
Pomacentridae-angelfishes														
Holacanthus bermudensis (2)	X	X									X			
Labridae-wrasses														
Bodianus pulchellus (3)				X	X		X				X			X
Decodon puellaris (2)			X	X	X		X							
Halichoeres bathyphilus (10)			X	X	X	X	X/L	L			X			X
Pomacentridae-damselfishes														
Chromis enchrysurus (4)			X				L	X/L		X				

Table 2B.8. Feeding guilds of deep reef fishes along the Mississippi-Alabama outer continental shelf. Determination of feeding guild is based on stomach contents identified in this study, or from food habits given by Randall (1967).

Feeding Guild: Characteristic Prey Type

1. Microzooplanktivore–copepods, ostracods, larvaceans, gastropod veligers, crustacean larvae.
2. Macrozooplanktivore–hyperiid amphipods, shrimp zoeae, stomatopod zoeae, crab megalopae, fish larvae, salps, squids.
3. Piscivores–fishes and squids.
4. Benthic Generalized Carnivores–a variety of mobile prey that may include fishes, crabs, shrimps, and gastropods.
5. Benthic Carnivores–primarily infauna/epifauna including crabs, bivalves, gastropods, brittle stars, sea urchins, polychaetes.
6. Epibenthic Browsers/Grazers–hydrozoans, bryozoans, soft corals, sponges.

Feeding Guild: Reef Fish Taxa

1. Microzooplanktivores–*Chromis enchrysura, Hemanthias vivanus, Paranthias furcifer, Pronotogrammus martinicensis, Selar crumenophthalmus, Trachurus lathami.*
2. Macrozooplanktivores–*Apogon psuedomaculatus, Chaetodon aya, Priacanthus arenatus, Pristigenys alta, Rhomboplites aurorubens.*
3. Piscivores–*Aulostomus maculatus, Fistularia petimba, Lutjanus campechanus, Mycteroperca microlepis, M. phenax, Seriola dumerili, S. fasciata, S. rivoliana.*
4. Benthic Generalized Carnivores–*Bodianus pulchellus, Centropristis ocyurus, Corniger spinosus, Epinephelus flavolimbatus, Epinephelus nigritus, Epinephelus niveatus, Gymnothorax* spp., *Holocentrus adscensionus, Liopropoma eukrines, Ophichthus puncticeps, Muraena* spp., *Opsanus pardus, Malacanthus plumieri, Neoniphon marianus, Pontinus rathbuni, Rypticus maculatus, Scorpaena dispar, Serranus phoebe.*
5. Benthic Carnivores–*Balistes capriscus, Calamus leucosteus, C. nodosus, Caulolatilus chrysops, Decodon puellaris, Halichoeres bathyphilus, Pagrus pagrus, Pareques iwamotoi, P. umbrosus.*
6. Epibenthic Browsers/Grazers–*Chaetodon sedentarius, Holacanthus bermudensis, Parablennius marmoreus.*

RESULTS

Over 950 individuals of were examined for food habits, with ~500 containing prey items. Dietary patterns of the most common reef fish taxa are presented in this report (Table 2B.7). Feeding guilds were then identified based on stomach contents (Table 2B.8). The numerically dominant species on high profile reefs, *P. martinicensis* and *H. vivanus*, have diets dominated by calanoid copepods, gastropod larvae and a variety of other pelagic plankton. Benthic feeders include the tattler, *Serrranus phoebe* and the greenband wrasse, *Halichoeres bathyphilus.* Epibenthic browsers include the bank butterflyfish, *Chaetodon sedentarius*, and the blue angelfish, *Holacanthus bermudensis*. Seasonal shifts in the diet of the dominant reef fish taxa were evident. The diets of *H. martinicensis* include a higher proportion of fish eggs and pelagic tunicates during the early spring. Stomach contents of *S. phoebe* in the spring collection were 100% small anthiine fishes. Diets of vermilion and red snapper in spring samples were dominated by pelagic tunicates, including colonial pyrosomes.

CONCLUSIONS

Planktivorous anthiine fishes (*P. martinicensis* and *H. vivanus*) numerically dominate the deep reef fish community, although resident fishes in this community occupy a variety of feeding guilds. *P. martinicensis* and *H. vivanus* in turn become prey for a variety of reef predators, and newly settled juveniles and young of the year anthiines appear to be an important seasonal component of the diet for a number of larger reef fishes. A seasonal shift in the diet is evident for planktivores and larger predatory species. Fish eggs, fish larvae, and pelagic tunicates increase in importance in the diet of planktivores, and *L. campechanus* exhibited a diet dominated by colonial pelagic tunicates in winter months. Trophic pathways among the deep reef community indicate primary links to the pelagic community, and eggs and larvae of soft-bottom fishes, a variety of invertebrates, and spawning aggregations of migratory species (such as *M. microlepis*). Ongoing analysis of food web structure for the deep reef community will further identify pathways of energy flow and trophic links between hard-bottom reef, soft-bottom and pelagic ecosystems.

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STATUS OF THE GULF OF MEXICO RED SNAPPER STOCK: ANOTHER PERSPECTIVE

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INTRODUCTION

The red snapper *Lutjanus campechanus* stock in the western Gulf of Mexico was recognized by the Gulf of Mexico Fisheries Management Council (GMFMC) as being severely overfished more than a decade ago. The GMFMC implemented management measures beginning in the mid 1980s (Goodyear 1995). The initial action set a 12-in size limit for the recreational fishery while still allowing the retention of five undersized fish per fisher. The GMFMC took more restrictive actions in 1990: the size limit was increased to 13 in; a recreational bag limit of seven fish was imposed; quotas were established for the commercial fisheries; and, an emerging nearshore longline fishery, which was taking significant numbers of large red snapper, was prohibited. Also in 1990, the offshore shrimp fishery began widespread compliance with the Turtle Excluder Device (TED) regulations that had been implemented to protect sea turtles. These devices may have caused an associated reduction in shrimp catch (Renaud *et al.* 1993) and fish catch, including red snapper (LGL Ecological Research Associates, Inc. 1997).

These and continued management actions appear to benefit the affected fish stocks. For example, the recruit index (CPUE of age 1 red snapper in summer, Goodyear 1995, Schrippa and Legault 1997) has steadily increased since the mid 1980s. As of 1996 (the 1995 year class), recruitment approached a level last seen in the 1970s and early 1980s (Schrippa and Legault 1997). One exception occurred in 1990, and reflected exceptional abundance of the 1989 year class (Goodyear 1995, Schrippa and Legault 1997). When the annual commercial quotas were first set in the range of 2- to 3-million lbs in the mid-1980s, they were not filled. In recent years, Total Allowable Catch (TAC) has been set at 9.12 million lbs. The commercial allocation (4.65 million lbs) has been reached within a matter of weeks, and the fishery subsequently closed. Frequently the recreational allocation (4.47 million lbs) has been exceeded in these same years, but closures have not occurred because of the time required to estimate recreational landings. In 1997, the National Marine Fisheries Service (NMFS), for the first time ever, closed the recreational fishery before the end of the year. In 1998, the fishery was closed at the end of September. Estimates of stock level by year and age (Schrippa and Legault 1997) has shown substantial increases in recent years, especially the portion of the stock ≥14 years of age. Age 14, assuming an instantaneous natural mortality rate of 0.10, is the age when red snapper reach maximum reproductive potential (Goodyear 1995).

Despite the apparent positive effects of management actions, the unweighted transitional Spawning Potential Ratio (SPR, Goodyear 1993, 1995) used to index the status of the stock has remained lower (1-10%, depending on the assumptions used in the estimate) than the 20% overfishing threshold adopted by the GMFMC. Further, the GMFMC has recently raised the target SPR value to 26 to 27% which supposedly reflects Maximum Sustained Yield (MSY).

The low levels of SPR has caused NMFS and the GMFMC to continue to take draconian management measures in order to raise SPR to 26% by the year 2032. We believe that this management target is not appropriate for red snapper for reasons outlined below.

METHODS AND RESULTS

Stock status at present and in the future is based upon projections from an assessment model. There are three basic steps in the assessment:

- Estimates of fishing mortalities for the directed fisheries (on age-2+ fish) and the number of fish by age are made using sequential population analysis (SPA) with an extension of the ADAPT methodology under three assumed natural mortality rates.
- A simple cohort analysis, which accepted the number of age-2 fish from step (1), assumed natural mortality rates for juveniles and shrimp bycatch estimates, produces fishing mortality estimates for the age-0 and age-1 fish as well as estimates of the number of age-0 fish (recruits).

- A stock assessment simulation model (LSIM, described by Goodyear 1989) uses estimates from steps (1) and (2) to provide transitional spawning potential ratio (SPR) estimates for the 1984-94 historical record. Assessment of management alternatives for the future (1999 onward) uses the same model but projected recruits are estimated with an assumed Beverton and Holt stock-recruitment (S-R) function.

The assessment procedure implies a simple life history. A recruit is defined to be an age-0 fish that can be captured by shrimp trawls. The sole population control (i.e., density dependence) occurs in the egg to recruit life-stage. All age classes are assumed to exhibit density independent mortalities and fecundity. As outlined below we have reservations regarding the population estimates of age-2+ fish, the natural mortality and bycatch estimates of juveniles and the stock-recruit relationship being used to make future projections of SPR. We take particular exception to the underlying assumption that red snapper has average resilience to fishing pressure as compared to other stocks of finfish. It is clearly among the most resilient of finfishes.

Results of Habitat Suitability Index (HSI) modeling in combination with estimates of red snapper residing at platforms and natural habitats yields an estimate of 8 million age-2 red snapper at the beginning of 1992. This compares to the stock assessment model estimate of 4 million. Our estimates of bycatch and the age composition of the bycatch suggests bycatch and the age 1 fraction of that catch has been grossly overestimated by NMFS. Bycatch estimates similar to ours have been obtained by independent researchers. Conditional survival from the shrimp fishery is indicated from these results to be more than doubled.

The available stock recruitment data confirm that red snapper is among the most resistant of all finfishes to fishing pressure. The SPR associated with the extinction level of fishing for the "average" finfish is 20%. In comparison the same value for red snapper is about 0.5%. Based on a Beverton-Holt stock-recruit function, red snapper stock size at an SPR of 26% would be on the order of *2 billion* pounds. This is acknowledged by the managers to be in the ridiculous range. It is likely that density-dependent population controls occur at life stages other than for the eggs to recruit stage and that a Ricker stock-recruit function would therefore be more reasonable. Using a Ricker function with the available S-R data suggests that SPR_{MSY} would be 2.8% and that stock size at this level would be on the order of 310 million pounds. These levels would be obtained in the near future with no bycatch reduction and a total allowable catch of 9.12 million pounds.

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Dr. Benny J. Gallaway has worked at LGL Ecological Research Associates, Inc. for the past 23 years and serves as President and Senior Marine Ecologist for the firm. Dr. Gallaway received his Ph.D. from Texas A&M University and has in excess of 40 publications in the peer-reviewed literature. He also serves as a Visiting Professor with the graduate faculty of the Department of Wildlife and Fisheries Sciences, Texas A&M University.

SESSION 2C

NITROGEN OXIDES (NO_X) IMPACTS AND CONTROLS IN CENTRAL PLANNING AREA

Co-Chairs: Ms. Terry Scholten and Mr. Jedd Sondergard

Date: December 8, 1998

Presentation	Author/Affiliation
The Need for NOx Controls in the Central Planning Area	Ms. Terry Scholten Minerals Management Service Gulf of Mexico OCS Region
Strategies for Evaluating NOx Control Options for Future Outer Continental Shelf Development Projects	Ms. Terry Rooney BP Exploration & Oil, Inc. Houston, Texas Mr. John Alford Santa Fe International Corporation Dallas, Texas Mr. Christopher Arms Hunt Engine, Inc. Harvey, Louisiana
Study: The Operation and Maintenance of Catalytic Converters on Natural Gas Fired Compressor Engines	Mr. Ken DeJohn Mr. Ronnie Kamper BP Exploration
The Operation and Maintenance of Catalytic Converters at Mobile 916-A Platform	Mr. Frank Piccolo Spirit Energy
Industry Perspective on the Need for NOx Controls	Mr. Brian E. Shannon Principal Environmental Scientist ARCO Technology & Operational Support

THE NEED FOR NOx CONTROLS IN THE CENTRAL PLANNING AREA

Ms. Terry Scholten
Minerals Management Service
Gulf of Mexico OCS Region

ABSTRACT

The Offshore and Coastal Dispersion (OCD) model was used to estimate the cumulative onshore impact from Outer Continental Shelf (OCS) sources located in the Central Planning Area (CPA) of the Gulf of Mexico. The results indicate that the significance level for nitrogen dioxide (NO_2) established by the Minerals Management Service (MMS) is exceeded along a portion of the Louisiana coastline. By MMS regulations, if a significance level is exceeded, then best available control technology (BACT) is required. Several options are available for resolving this issue.

INTRODUCTION

The significance level for NO_2 is defined in 30 CFR 250.303(e) and 30 CFR 250.304© as an onshore concentration from OCS sources that equals or exceeds 1 microgram per cubic meter ($\mu g/m^3$). In 30 CFR 250.303(j) and 30 CFR 250.304(f) the significance levels are applied to facilities "either individually or in combination with other facilities in the area."

The OCD model was used to develop estimates of the cumulative projected impacts from future lease sales. The results of that modeling (MMS 1997) showed a maximum impact of approximately six times the significance level. This raised the question of whether the actual emissions from OCS sources were affecting Louisiana's coastline in concentrations above 1 $\mu g/m^3$.

METHOD

To determine if current actual OCS emissions affecting the Louisiana coastline were above 1 $\mu g/m^3$, several modeling runs were made. Because no current emission inventory was available, extrapolations were made using the 1993 inventory collected for the Gulf of Mexico Air Quality Study (Systems Applications International *et al.* 1995). This inventory is typically called the MOAD or MMS OCS Activity Database (Steiner *et al.* 1994).

The OCD model was used for this work because the results will be used for a regulatory application, and OCD is the only dispersion model approved by MMS for this regulatory purpose.

The modeling domain was separated into seven areas to keep the transport distances typically down to less than 50 km. The seven individual runs for each year were then combined to generate composite figures (Figures 2C.1–2C.3). All three years of meteorological data, 1989, 1990 and 1991, produced similar results.

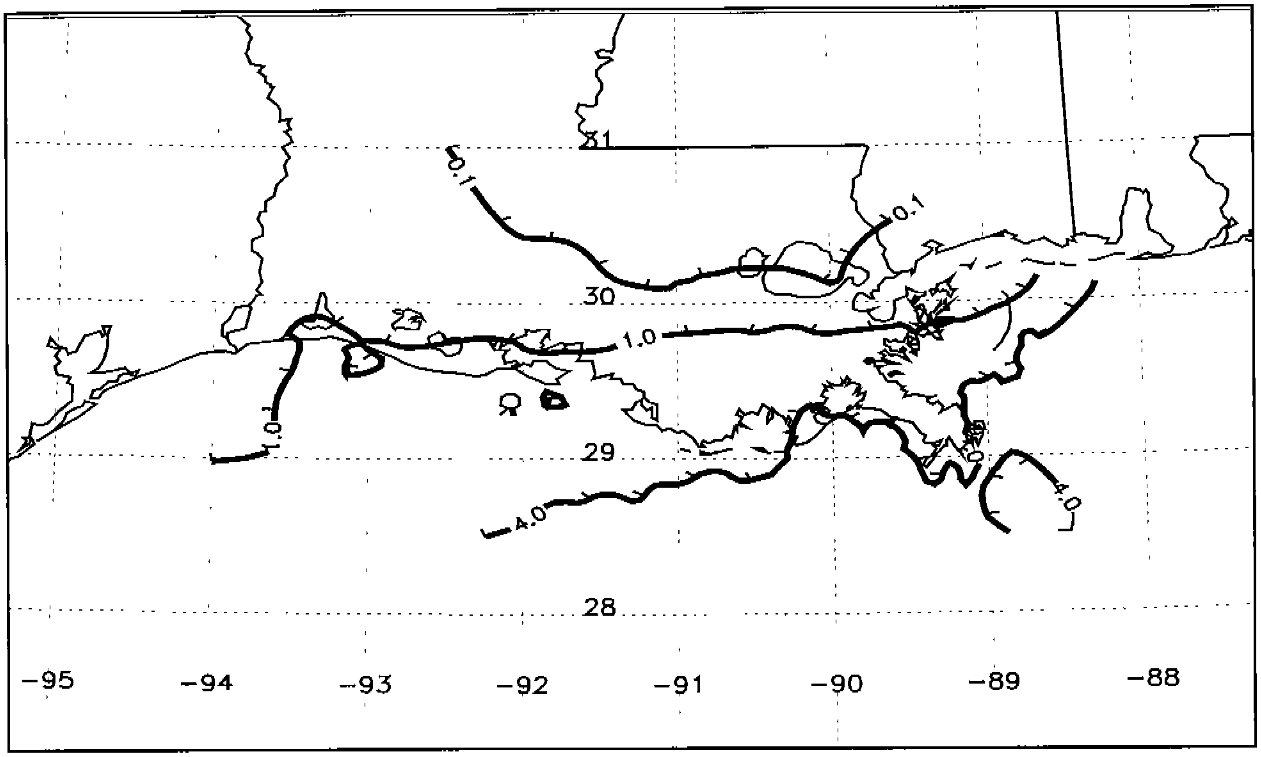

Figure 2C.1. 1989 Composite modeling results in micrograms per cubic meter

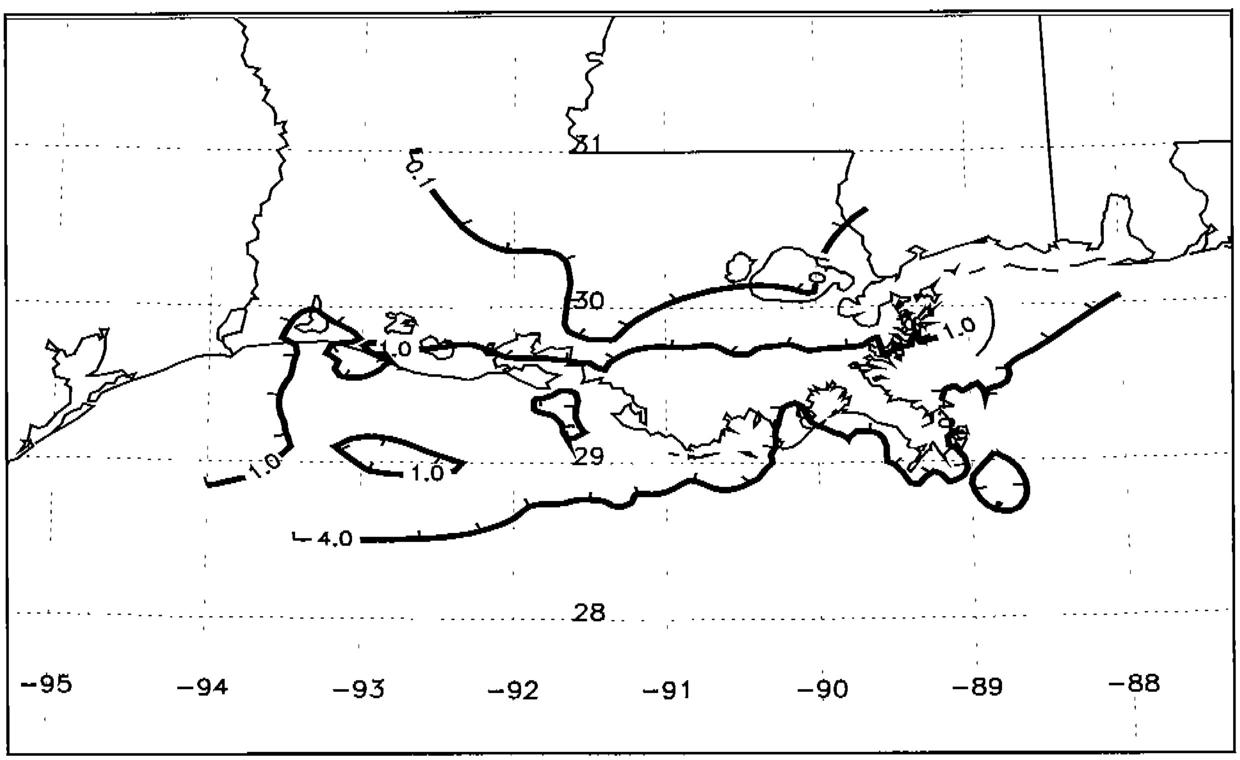

Figure 2C.2. 1990 Composite modeling results in micrograms per cubic meter.

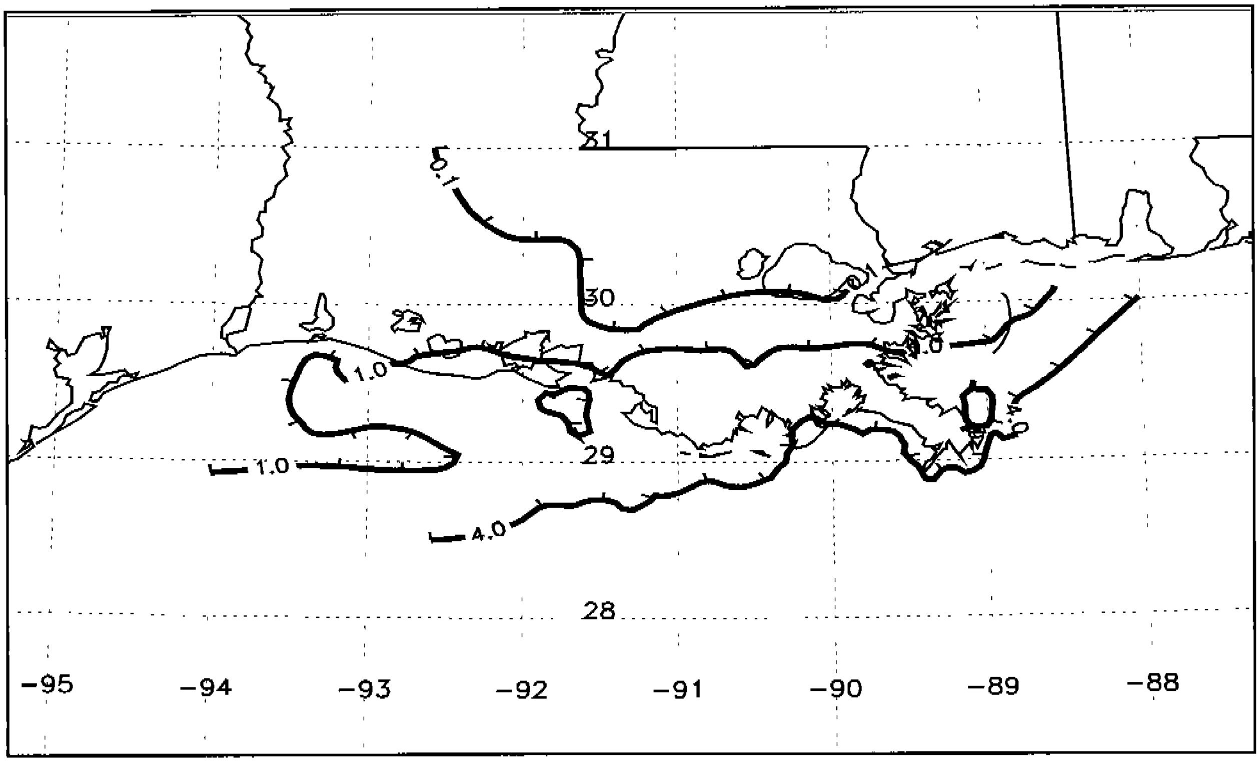

Figure 2C.3. 1991 Composite modeling results in micrograms per cubic meter.

The MOAD equipment inventory used included only platform equipment and did not include any drilling, construction, or transportation emissions. Additionally, OCS activities increased, in the CPA, between 1993 and 1997, when this work was started. Because of these two factors, the MOAD equipment inventory is expected to under-represent the emissions for the 1997 to 1998 time frame. It should be noted however, that modeling with just the MOAD equipment inventory still results in onshore impacts in excess of 1 $\mu g/m^3$. The composites (fig 1-3) were generated from modeling runs using 1.4 times the MOAD equipment inventory. It is assumed that increasing the inventory by 40 percent is a better approximation of the actual emissions than just using the inventory with no compensation.

CONCLUSION AND DISCUSSION

All modeling scenarios performed for the cumulative analyses resulted in onshore concentrations above 1 $\mu g/m^3$ along portions of the Louisiana coastline. The onshore impacts ranged from below 0.1 $\mu g/m^3$, in portions of Cameron parish, Louisiana and Baldwin county, Alabama, to greater than 4 $\mu g/m^3$, in portions of Lafourche, Jefferson and Plaquemines parishes of Louisiana.

Since the significance level is apparently exceeded, the regulations require installation of BACT to reduce the onshore impact. Emission controls are costly. In this case, there is a regulatory requirement for the controls, but there doesn't appear to be a corresponding environmental need for the controls. The National Ambient Air Quality Standard for NO_2 is 100 $\mu g/m^3$. All of the areas affected by the OCS emissions are well within (LDEQ 1998 & EPA 1998) that standard.

Table 2C.1. Some options for handling the issue.

Alternative	Meets Current Regulatory Requirements	Cost to Industry	Cost to MMS	Reduces NOx	Comments
IMPOSE BACT					
1a) on all facilities	YES	MOD-HIGH	LOW	YES	Operators allowed to provide information to demonstrate that they are not significantly affecting onshore areas.
1b) on all new facilities	PARTIALLY	MOD	LOW	YES	Operators allowed to provide information to demonstrate that they are not significantly affecting onshore areas.
FURTHER STUDY					
2a) different model	NO	LOW-MOD	LOW-MOD	MAYBE/ FUTURE	May eliminate the need for controls. Requires MMS to approve additional dispersion model.
2b) new inventory	NO	MOD	MOD	MAYBE/ FUTURE	Unlikely to eliminate the need for BACT /needed for accuracy. Currently a 1999-2000 inventory is planned.
2c) by MMS	NO	NONE	MOD	MAYBE/ FUTURE	No funding is currently planned for this analysis. A NOx and O_3 study is planned for 2000-2002.
2d) by Industry	YES	MOD-HIGH	NONE	MAYBE/ FUTURE	Operators allowed to provide information to demonstrate that they are not significantly affecting onshore areas.
CHANGE REGS					
3a) cumulative	NO	NONE	LOW	NO	
3b) significance levels	NO	NONE	LOW	NO	
4) **NO ACTION**	NO	NONE	NONE	NO	

This leads to the question of whether the cost for the controls is justified. The MMS is preparing an environmental assessment to help in evaluating the different alternatives available for handling this issue. A matrix of the alternatives is shown in Table 2C.1.

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STRATEGIES FOR EVALUATING NOx CONTROL OPTIONS FOR FUTURE OUTER CONTINENTAL SHELF DEVELOPMENT PROJECTS

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OVERVIEW

Clean Air Act Amendments in 1990 mandated a comprehensive review of the impacts on onshore air quality from Outer Continental Shelf (OCS) operations under the jurisdiction of Minerals Management Service (MMS). As a result, a number of changes are occurring in the way emissions are quantified and new facilities permitted. Based on a facility's distance from shore, length of operation and development plans, MMS has the authority to require control technology be employed to reduce significant impact from new offshore operations on onshore air quality.

Offshore oil and gas drilling and producing facilities include space, weight and safety concerns not associated with land based operations. Temporary peaks in emissions rates can occur in the initial few years of a project while drilling operations are in progress. It is these peaks that are the most common cause of any potential short term significant impact. In instances where controls may be required, the operator and contract partners must select control options that achieve worthwhile emissions reductions within the technological, logistical and economic constraints of the project.

This analysis identifies a range of NOx reduction strategies for OCS drilling and production facilities located in the Gulf of Mexico, the most active OCS region. This paper represents an operator's perspective on achieving a balance among the many important factors to be considered when selecting a control strategy. Some of these factors are actual emissions reductions, relative costs, operating ease and dependability.

The heightened awareness of the necessity to regulate and operate "cleaner, cheaper, better" requires both operators and agencies to work together constructively. The control option selected should be the one that achieves the greatest reduction that are truly "significant" for the lowest cost.

OFFSHORE EXPLORATION AND PRODUCTION OPERATIONS

Oil and gas exploration and development from the Outer Continental Shelf (OCS) account for 24% of the natural gas and 14% of oil production in the United States. This translates into significant resources for the country and revenues for the Federal Government and coastal states. In 1994, the United States imported more than half of its petroleum needs. OCS leasing and production are one of the largest sources of funds for the federal government. In 1993 alone, production from over 3,800 offshore platforms provided $2.5 billion to the federal government and coastal states.[1]

In 1993, about 800 wells were drilled in the Gulf of Mexico OCS. Drilling is either exploratory or developmental. Exploration drilling is temporary, ranging from a few weeks for shallow depth wells to up to half a year for deep wells. If exploratory drilling discovers oil and gas reserves that can be economically developed, a platform will be built and installed within a few years. Development wells are drilled from the platform. Drilling from the platform can extend over a number of years depending on the number of wells needed to produce the field.

Production platforms range in size and complexity from single well structures to large, manned oil platforms with up to 60 wells. For the first few years following installation, a typical large platform houses both drilling and production equipment. When all wells are drilled and completed, the rig is removed and onboard production equipment is all that remains. Large platforms can be in place for 15 - 20 years.

BP Exploration installed its newest platform in 1,300 feet of water 25 miles off the Mississippi Delta. This platform will process oil and natural gas from 44 wells. For about 18 months, two drilling rigs will operate simultaneously, one on the platform and one floating rig, located over 4 miles away, above a subsea template. Oil and natural gas from these wells will be produced through the existing facility installed in 1994. It is this type of operation - a large new development with the potential for short term emissions peaks from drilling operations - that may require emissions reductions strategies not normally necessary.

OFFSHORE DEVELOPMENT EMISSION SOURCES

Drilling

The major emission sources from drilling operations are diesel-powered generators that provide power for the drilling equipment and ship's services. There are commonly three to four engines, each capable of generating 1,500 - 2,000 horsepower. Only one-half to two-thirds of that power is normally required, but specific operations like drilling the large volume surface hole and backup engine support make it essential that this amount of capacity be available.

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[1]Minerals Management Service. 1993. *Federal Offshore Statistics: 1993,* U.S. Department of the Interior, Minerals Management Service, Operations and Safely Management, Office of Statistics and Information, OCS Report MMS 94-0060.

Table 2C.2. Reduction options, effectiveness and costs.

Reduction Method	% Reduction*	Costs*
Conversion to Turbocharging	30 - 60%	$1,500,000
Convert roots to centrifugal blowers	20 - 30%	>$800,000
Increase compression ratio 18:1 with general engine overhaul	• Slight increase possible. • Offset by reduced fuel consumption	$260,000
Timing Retardation	15 - 40%	$10,000
Selective Catalytic Conversion - ammonia injection	80%	$1,000,000
Low emissions liquid fuel	50 - 65%	$1,800,000
Power Management with engine conditioning	1 5%	$260,000 includes engine overhaul

* based on 4 - 2200 HP MD engines operating for 2 years; does not factor in savings from possible reductions in fuel consumption; NOx emissions without controls - 506 tons per year - 4000 gpd fuel use

Most rigs operating in the Gulf were built over 10 years ago and do not have the latest control technologies. Most control options will require retrofitting the existing engine design. A retrofit conversion to an existing engine will be very expensive (see Table 2C.2) and less efficient in terms of NOx prevention than a new, low emissions engine. The rig will have to be taken out of service to perform the modification, losing those days, and associated revenues, to down time. Since offshore rigs are engineered to maximize the amount of work to be done in tie least amount of space, add-on equipment space and location demands will need to be closely evaluated for design feasibility.

Production

Production equipment usually uses natural gas produced onsite to power engines, generators, turbines, and other combustion equipment. Only emergency pumps and generators are fueled by diesel. Gas compressors, which transport natural gas through the pipeline to onshore, are the major source of long term platform NOx emissions. Turbines generate electricity to power the boilers and heaters on most larger platforms. While they produce large amounts of horsepower, the associated NOx levels will tend to be significantly lower than the compressor engines.

New production facilities incorporate emissions reduction technologies such as waste heat recovery and vapor recovery units. Waste heat cogeneration reduces fuel consumption and associated emissions while it eliminates the cost of another fuel source. Vapor recovery captures lighter hydrocarbons that would otherwise be lost to the atmosphere from low pressure sources. While only cost-effective on new structures, these examples represent improvements being seen on the newer and larger facilities making them more energy efficient than the older structures. Control technology can be more easily and economically incorporated into new installations than added on to those already in place.

Production facilities are moving into deeper and deeper waters to support new discoveries with the greatest potential for finding large hydrocarbon reserves. Current technology will allow facilities to be installed in water depths of 4,000' and more. The major challenge to installing deep water facilities is one of economics rather than technology. The same rigorous space, weight, and safety concerns which apply to conventional platforms are even more critical to deeper water projects as the costs are magnified.

CURRENT REGULATORY OVERSIGHT

Responsibility for managing oil and natural gas exploration and production from the OCS rests with the Minerals Management Service (MMS), an agency within the Department of Interior. The 1990 Clean Air Act Amendments directed the MMS to determine what, if any, significant impact OCS operations in the central and western Gulf of Mexico had on onshore ozone non-attainment areas. Preliminary photochemical modeling results from an August 1993 episode in Houston Texas documented that virtually no impact from OCS emissions was seen in onshore areas with high ozone concentrations.[2] From the results of this scientific study, MMS will determine if further action is needed to control OCS sources to reduce onshore ozone.

The study requirement was an opportunity for MMS to evaluate their regulatory process for managing air emissions in the Gulf. Those regulations are found in 3OCFR 250 Subpart C—Pollution Prevention and Control. As a result, MMS is implementing a series of regulatory reforms to standardize emissions factors, compile air emissions source data and recommend cost-effective emissions reductions from the OCS.

Emissions levels for offshore exploration and development operations are outlined in an Air Quality Review (AQR), a long-standing requirement for both exploration and development plans. The AOR is the format for calculating project specific emissions. Project details such as length of operations, horsepower, vessel support and anticipated well test volumes are input to a standardized spreadsheet. The AQR spreadsheet is designed to use AP-42 and other standard state and industry factors, along with project parameters, to calculate the operation's potential to emit.

Similar to onshore Prevention of Significant Deterioration (PSD) criteria, MMS is reviewing development projects with AQR emissions levels greater than 250 tons per year (in any year of operation) to determine if additional control technology is required. This threshold review is without regard to whether the facility is within existing allowable exemption levels. It includes even the temporary operations that will occur as part of the project, such as drilling operations. MMS

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[2]Yocke, Mark A., Steorts, William L., *et al.* Minerals Management Service, Photochemical, meteorological, and emissions modeling results of the Gulf of Mexico air quality study. Paper presented at 14th Information Transfer Meeting, Minerals Management Service, 15-17 November 1994, New Orleans, LA.

regulations define a source as temporary if it occurs for less than three years. Development projects that are close to shore, within 100 km, that have long term drilling operations, are the instances most likely to trigger the evaluation of NOx reduction strategies.

NOx REDUCTION OPTIONS

The first application of a NOx reduction strategy is at the time of the AQR spreadsheet calculations. Standard spreadsheet factors will calculate emissions based on continuous operations at maximum horsepower for all equipment. As mentioned earlier, drilling normally uses less than the maximum horsepower available onsite. Historic fuel consumption rates for rig engines, certified by the drilling contractor, should be the basis for the AQR emissions calculations, particularly for large, long-term projects. Neither drilling nor vessel support operations operate at maximum horsepower on a daily basis. Consequently, the project's potential to emit can be significantly over-estimated by including emissions that will never occur.

NOx is the pollutant with the greatest potential to exceed the 250 tons per year (tpy) limit. In combustion, available nitrogen combines with oxygen to form nitrogen oxides, primarily NO and N02. These two compounds are commonly referred to as NOx. NOx is a precursor to ozone and is a criteria pollutant within the Clean Air Act. Methods to reduce NOx emissions therefore must 1) prevent NOx from being formed or 2) remove the NOx from engine exhaust before its released to the atmosphere. Tables 2C.2 and 2C.3 summarize NOx control options for diesel engines. These tables list the range of predicted reductions, costs and other factors which can be advantages and disadvantages depending on the specifics of a particular project and rig.

Drilling - Diesel Engines

NOx reduction options for diesel engines are broken into four categories for this discussion: major engine combustion modifications, ignition timing retardation, new technology and power management.

Major engine combustion modifications include turbocharging and blower conversions and increasing the compression ratio. Each has its own set of factors to be evaluated for the specific project. Advantages include emissions reductions up to 60%, reduced fuel consumption and increased horsepower. Disadvantages are the high equipment costs and significant time required to convert. The time to retrofit can also be considered lost revenues since the rig may not be able to operate while the conversion is underway.

Timing retardation involves an engine adjustment up to 60. Peak combustion temperature and thermal NOx formation are reduced. This adjustment is the least cost -and perhaps the most cost effective option - with NOx reduction of 15 to 40% possible. Down time is avoided and it is applicable to all types of diesel engines. The range of reduction is very engine-specific. Fuel consumption will increase 2 to 4% because of decreased engine efficiency.

New technology development can also be found for small niche market of diesel-powered engines. The options discussed here, exhaust after treatment and low emissions liquid fuel may not be considered new technologies for some applications. Within the unique space, safety and logistical needs of the offshore operating environment, further evaluation of these options is required.

Exhaust after treatment, commonly referred to as catalytic converters, offer the greatest reductions, in the range of 80%. In the oxygen rich exhaust of a diesel, only selective catalytic reduction (5CR) will decrease NOx. 5CR adds not only the bulk and costs of the catalytic converter and reaction vessel, but also several significant operational concerns.

The rig layout will need to be evaluated to determine if it can satisfy the equipment space requirements for the reaction vessel and ammonia bulk tanks. The reaction vessel must be close enough to the engine exhaust to maintain temperatures between 720° to 875° for the reaction to occur.

Rig engines operate at variable loads so provisions must be made to allow ammonia injection rates to respond to these load changes. If ammonia injection and load rates are out of synchronization, the exhaust will be either over-treated, with an associated ammonia slip and potential odor, or under-treated with excess NOx resulting. The amount of aqueous ammonia will vary based on the predicted emissions of the engines. At a minimum, hundreds of gallons of aqueous ammonia must be onboard at all times. Provisions must be made to provide a continual supply of the liquid ammonia to the offshore location and to accommodate the vessel and rig space to store the bulk tanks. Safety concerns associated with lifting these extra loads onto boats and decks are important issues, in addition to cost considerations. Additional NOx emissions will result from the vessel support necessary to supply the large volume of aqueous ammonia to the offshore operation.

Low emissions liquid fuel was developed as a standby fuel for interruptible natural gas supplies in California. It is a virtual drop-in replacement for #2 diesel, the fuel used in all offshore platform and semisubmersible rigs. When burning this specialty fuel, diesel engine NOx emissions can be similar to those of natural gas combustion, according to the manufacturer. Actual emission reduction benefits from burning this fuel may vary considerably based on the type of engine and combustion temperature. Costs are a major disadvantage, running three times higher than #2 diesel. This is a significant cost burden when using thousands of gallons of fuel each day.

Power management is an effort to establish a closer relationship between the amount of power needed to perform the job versus the amount of power available under normal practice. It must be stressed that safety concerns take precedent and in no way should the concept of power management be interpreted as compromising the need for available standby power during critical operations.

The key to power management is to reduce all *unnecessary* loads allowing one engine instead of two, or two engines instead of three, to do the job. Unnecessary lighting, excess mud pump pressure, too many mud pumps and excessive tripping rates are the kinds of routine activities that offer the greatest potential to reduce horsepower. The demand for greater horsepower results in excess engines being on-line. Two engines each carrying 40% load waste 17% more fuel and emit 35% more NOx than a single engine carrying 80% load. Effective power management requires that each engine be operated in its optimum range. This will reduce overall NOx emissions and fuel consumption.

A feasibility review, involving key onsite rig personnel from both the operator and drilling contractor, in addition to engine specialists, will be the first step. Current rig operating standards and specific needs of the upcoming project will determine feasibility and set the criteria for critical operations that will require 100% spinning reserve. Once critical operations are defined, possible reduction opportunities will be defined based on current engine condition, associated fuel consumption and overall power needs.

Production

Production equipment is generally powered by natural gas. A range of control options exist to reduce NOx from turbines, reciprocating engines, flares and vents. In house research has provided a range of capital costs for retrofitting production equipment in the 2,000 HP range.

For natural gas fired turbines, selective catalytic reduction and water injection will provide 80% reductions for capital costs in the order of $1 - 2 million. Turbines emit much lower concentrations of NOx than other production equipment, so it is unlikely that controlling these sources will give the greatest reduction for the least cost. Natural gas engines can be retrofitted with non-selective catalytic converters and achieve 80% reductions with capital expenditures of up to $100,000 per engine. There will be annual costs for operation and maintenance, in addition to catalyst replacement every seven years. Routine, scheduled maintenance of the catalyst bed and a precise air-fuel ratio are necessary to achieve the desired reduction and extend the life of the catalyst. Engine modifications will produce similar reductions of 80%, for higher costs, about $150,000 to $750,000 per engine.

Short term peaks in NOx emissions tend to result from drilling operations, the focus of this report. Eliminating NOx impacts associated with these drilling peaks could involve installing controls on the permanent production equipment as the most cost effective approach.

Evaluating control options for production equipment involve the same issues as drilling engines do—determining the largest emissions and potential reductions. In the cases reviewed for this discussion, the largest NOx emissions resulted from operation of natural gas compressor engines. As with the previous discussion of diesel engine controls, a variety of site-specific factors control the feasibility and actual costs of retrofitting production equipment. Those factors include proximity to shore, platform space constraints, age and type of equipment and operating and maintenance schedules. A few other factors, such as economies of scale and variability in natural gas quality could affect the feasibility and costs of future retrofits.

Offsets

A final reduction strategy to be evaluated is the offset concept. Are there other facilities where NOx reductions can be achieved more easily and cheaply that will offset the amount of NOx that is considered to be significant from the new operations? This approach must be pursued cautiously but should be an available option for those times when reductions are required. Current MMS regulations address the use of emissions offsets to reduce impacts on onshore. A regulatory program must be developed to implement this approach.

FACTORS INFLUENCING CONTROL SELECTION

As listed in Table 2C.3 there are a host of advantages and disadvantages for each control option mentioned so far. There is no one method that can be prescribed across the board. Each operation must be evaluated based on its design parameters and limiting factors. A project's feasibility can be linked to rig availability, date of anticipated first production and a host of other scheduling concerns. As a result, the best control technology may not be readily apparent. To optimize the solution, set project objectives and develop a strategy that gives preference to the least-cost control that accomplishes the objectives.

Selection of the preferred alternative, or combination of a few, requires careful analysis. It's important to involve the drilling contractor and other equipment manufacturers in a review of emissions calculations and alternate control options. As with any new technology or equipment, the best solution to a problem is reached by understanding all the advantages and disadvantages of various options that may not be readily apparent.

After a careful review of predicted emissions levels is completed and the most accurate potential to emit has been determined, it is time to prioritize the control options based on project details and the factors listed in Table 2C.3. Each of these considerations will be of varying importance depending on the project's design parameters and its limiting factors. These advantages and disadvantages will aid in ranking the control options. As the list of options is reviewed the following questions must be asked:

- what percent reduction is possible?
- what is the track record for reliability in achieving reduction target?
- will the control be easy to operate and maintain?
- are there significant space/weight constraints?
- are there safety concerns with the equipment or process? how much down time is required to retrofit?
- are there long-term logistical support needs and costs?
- what are capital and O&M costs and is it a significant amount compared to the overall project costs?
- are there innovative ways to get the same reductions elsewhere?
- what are measuring and monitoring frequency and costs?
- is there an option that reduces long term emissions that may not have been considered because of regulations?
- will other solid or liquid wastes be generated when reducing the air emissions?

Table 2C.3. Reduction options, advantages disadvantages.

Reduction Method	Advantages	Disadvantages
Conversion to Turbocharging	• 6 - 12% decrease in fuel consumption • 40% increase in horsepower	• high costs • 40 days downtime to convert • should be done in shipyard • modification to peripheral equipment
Convert roots blowers to centrifugal blowers	• 4 - 8% decrease in fuel consumption • only engines modified	• high costs • 30 days downtime to convert
Increase compression ratio 18:1 with general engine overhaul	• 3-5% decrease in fuel consumption	• should be done along with blower conversion • may require special bearings
Timing Retardation	• low costs • no down time	• increase fuel consumption by 2 - 4% • increase engine wear rates
Selective Catalytic Conversion -ammonia injection	• significant reductions	• high costs • 10 -12 weeks delivery • size of reaction vessel • transport/handling of ammonia • ammonia slip from load changes • unproven technology offshore
Low emissions liquid fuel	• significant reductions • drop in replacement for #2 diesel • no down time for modifications	• high costs • market availability unknown • use to-date as standby fuel only
Power Management with engine conditioning	• cost savings from reduced fuel usage	• behavioral changes required

Once this exercise is worked through, the choices will become clearer. The hierarchy of options that develops can be ranked based on project needs. The rationale for a particular choice will be easy to communicate and support once this simplified cost-benefit analysis is performed.

An over-arching element for making this strategy successful is involvement with MMS as soon as possible. Their approval of the project is the litmus test that the controls selected do in fact achieve the balance between environmental protection and project feasibility. There is no substitute for formal and informal regulatory feedback throughout this evaluation period. Knowing the agency's minimum requirements and areas where flexibility exists provides the framework for designing a control plan that will meet the needs of the MMS and operator.

CONCLUSIONS

Evaluating NOx emissions in the OCS is becoming more commonplace. Before major changes are made in the way the offshore industry is regulated, MMS' current strategy should be allowed sufficient time to determine its effectiveness. That will result in actual impacts being defined by sound science, and the associated risks being understood, before additional regulatory burdens are unilaterally imposed. If the science concludes that significant risks exists, government and industry must form a partnership to identify the most cost-effective ways of obtaining the greatest reductions.

The stakes are high for both government and industry to work together to get it right. "Cleaner, cheaper, better" means *a/I* stakeholders charting a course for the best control option that is fit for purpose. The objectives are clear - continued exploration and development with cost-effective approaches to managing environmental risks.

Recent legislative initiatives are directing government agencies to assess all costs and benefits of available regulatory alternatives when deciding whether and how to regulate. Government should adopt the policy of using incentives, instead of disincentives, to direct the effort. Agencies must select those approaches that maximize net benefits.

Industry also has a responsibility to incorporate "cleaner, cheaper, better" into project designs. The need to evaluate NOx controls could happen at any time during a project, whether it be a new development or a platform that's been in place for years. For all future facilities, operators need to carefully weigh environmental impacts and controls during facility design to identify emissions and reduction technologies that are low cost and reliable. Controls designed into a new facility will be more economical than future retrofits. Production platforms are intended to be in place for decades. Regulatory changes should be anticipated. Are the emissions high enough that future regulatory changes could require a retrofit? If so, would it be cheaper to install the cleaner technology now? An effective pre-project assessment should preclude or minimize the to retrofit because reasonable control technologies are incorporated into the original design.

The reductions chosen should allow the operator to work within facility and project limitations. To reach that balance between maximum emission reduction and least cost control technology many variables must be identified, measured and prioritized.

Operators should pursue innovative approaches that involve the agencies as partners in the decision-making, to facilitate a full understanding of the operational factors that may limit or preclude choices.

An industry reputation for good performance will provide the cornerstone for the new. initiative to reform current command and control regulations. A clean environment and oil and gas development are not mutually exclusive. Voluntary application of commercially viable control technology demonstrates that environmental protection is an important factor in new facility design. Government's part must be to replace command and control regulations with regulations that focus on reducing significant risks.

STUDY: THE OPERATION AND MAINTENANCE OF CATALYTIC CONVERTERS ON NATURAL GAS FIRED COMPRESSOR ENGINES

Mr. Ken DeJohn
Mr. Ronnie Kamper
BP Exploration

VK-989 PLATFORM: BACKGROUND

- Production:
  - Platform rated for 69,000 BPD of oil and 80 MMSCFD of gas
  - Currently producing around 58,000 BPD of oil and 75 MMSCFD of gas
- Structure: fixed platform in 1,290 feet of water with 10 well subsea template 5 mile tie-back from 1,900 feet of water
- Wells: 27 wells on platform; 7 subsea wells
- Platform started up in October 1994
- Platform control system: pneumatic

COMPRESSORS

- Original compressors:
  - Two compressors rated for 15 MMSCFD of gas each
  - Started up in 4th quarter of 1994
  - Ariel recip compressors equipped with natural gas engines. Waukesha 9390 GSI rated for 1970 HP at 1200 RPM.
  - Added cat converters in 1st quarter of 1996
- New compressor
  - Turbine driven centrifugal rated for 35 MMSCFD added in 3rd quarter of 1998
  - Taurus 60 turbine equipped with Solonox

CATALYTIC CONVERTER RETROFIT

- BPX agreed to add catalytic converters to compressor engines when the DODC for Phase 2 subsea template was approved by MMS
- Catalytic converters added to 9390 engines in 1st quarter of 1996
- Catalytic converters should achieve NOX reduction to 2.0 gms/bhp/hr
- Weekly testing and monthly reporting to the MMS has been done since installation
- System included: (well over $100,000 installed)
  - Converters with platinum elements replaced silencers
  - Air/Fuel controller
  - Fuel control valve in fuel gas line
  - O2 sensors in exhaust lines

- High temp switches upstream and downstream of converters
- Measurement equipment for weekly readings/troubleshooting

PROBLEMS ENCOUNTERED WITH CATALYTIC CONVERTERS

- Process stability
  - Process gas fluctuations handled by adjusting engine speed and opening compressor recycle
  - Air/fuel control is always in conflict with engine speed controls
- Engine not set up for lean burn
  - To work properly, air/fuel ratio must be below that recommended by Waukesha for a GSI engine. GL engines are set up to run lean. Concerned with damage to GSI engine at lean ratio.
- Ignition controls
  - Existing Fairbanks 9000 Magneto Ignition system was changed out with a full electronic system (Altronic CPU95) ti better control and troubleshoot system. Tight ignition control is required to make systems work and prevent backfires. Change-out of ignition system was around $30,000 and was done in early 1997.
- Catalyst durability & design
  - Catalyst bed susceptible to high temperature
  - Catalyst bed susceptible to backfires
  - Backfire relief valve could possibly handle
  - Catalyst bed susceptible to settlement of bed material
  - Expensive to change out; cost of rebuild & platform shut-in

LESSONS LEARNED

- Catalytic converters cannot be easily retrofitted onto engines not set up for lean burn
- Control systems for catalytic converters are not well suited for applications with process fluctuations
- Reliability and durability of catalyst beds in question
- Tight engine control required
- Engines must be heavily loaded to achieve reduction
- Operations and maintenance of catalytic converters is labor intensive

THE OPERATION AND MAINTENANCE OF CATALYTIC CONVERTERS AT MOBILE 916-A PLATFORM

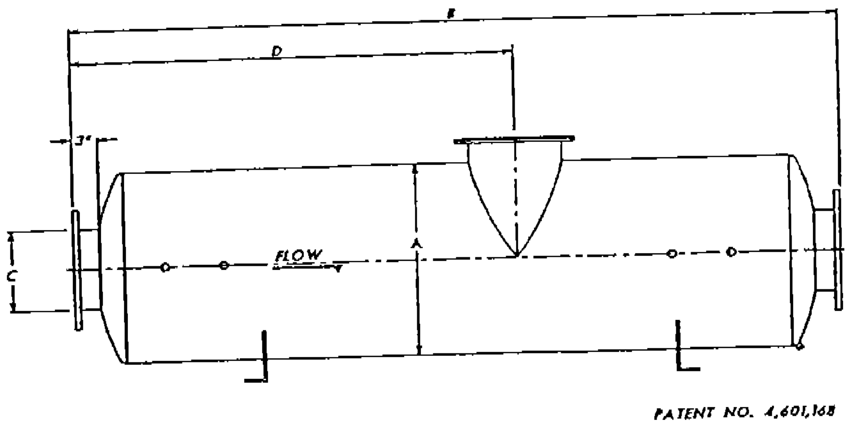
Mr. Frank Piccolo
Spirit Energy

SUMMARY

- NOx control by use of catalytic converters works
  - 95% reduction
  - 365 tons/yr. reduced NOx output
- Lessons learned
  - Do not run catalytic converter elements in series
  - Install delta psi gauge for monitoring elements
- Suggestions for improvement
  - Reduce testing and reporting to annually

Table 2C.4. Summary cost, Mobile 916 NOx control.

Up Front Costs		
Cost & installation of 3 catalytic converters		$115,000
Lessons learned		50,000
Emissions tester		15,000
	Total	$180,0000
Annual Operating Costs		
Cleaning		$ 8,000
Calibration gas		2,000
Maintenance		3,000
	Total	$ 13,000



True orientation of easy access catalyst portal is 45° near side or any position 360° around centerline

STANDARD:

Gas Sampling Coupling
Temperature Sensor Coupling
Drain Coupling
Support Brackets

STANDARD SPECIFICATIONS

MODEL	A	B	C	D	WEIGHT
DN/S - 503	8	36	3	20	130
DN/S - 1003	12	48	3	25	145
DN/S - 1754	14	59	4	35	175
DN/S - 2505	18	61	5	35	200
DN/S-3006 CP	20	69	6	41	220
DN/S - 3506	20	68	6	41	230
DN/S - 4008	22	79	8	48	420
DN/S - 4508	22	80	8	48	425
DN/S - 5008	22	80	8	48	425
DN/S - 57510	22	80	8	48	425
DN/S - 60010	24	85	8	48	525
DN/S - 65010	25	91	8	61	540
DN/S - 70010	26	96	10	61	600
DN/S - 75010	27	96	10	61	625
DN/S - 80010	27	96	10	61	625
DN/S - 85012	27	96	12	61	625
DN/S - 90012	28	102	12	67	780
DN/S - 100012	30	103	12	68	850
DN/S - 110012	30	111	12	74	865
DN/S - 115012	30	112	12	74	865
DN/S - 120014	32	113	14	76	875
DN/S - 125014	32	114	14	76	1025
DN/S - 135014	34	116	14	76	1025
DN/S - 145014	34	118	14	76	1025
DN/S - 155016	36	119	16	76	1075
DN/S - 160016	36	120	16	76	1075
DN/S - 175016	38	127	16	87	1125
DN/S - 185018	38	127	18	87	1125
DN/S - 195020	40	147	20	101	1250
DN/S - 200020	40	148	20	101	1250
DN/S - 220020	42	150	20	101	1275

OPTIONS:

Stack or elbow outlet
Side inlet / side outlet
Stack for compliance test w / 2-2" couplings

Stainless steel construction

DeNOx Silencer can be applied for oxidation service and selective catalytic reduction.

Dimensions subject to change without notice.

DeNOx Silencer Identification is generally by horsepower rating. The first digits in the model designation indicate HP. The following one or two digits is nozzle size. Design flexibility allows change in nozzle size to best fit piping design.

Figure 2C.4. DeNOx Silencer specifications.

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INDUSTRY PERSPECTIVE ON THE NEED FOR NOx CONTROLS

Mr. Brian E. Shannon
Principal Environmental Scientist
ARCO Technology & Operational Support

INTRODUCTION

These are the comments and perspectives of the Offshore Operators Committee (OOC) regarding the Minerals Management Service's (MMS - Gulf of Mexico Region) Notice of Intent to Prepare an Environmental Assessment (EA) for a Notice to Lessees (NTL) to reduce nitrogen oxides emissions in the Central Planning Area (CPA) of the Gulf of Mexico (63 *Federal Register* 43191 - 43192, 12 August 1998). These comments will also address the subject draft NTL entitled *Best Available Control Technology (Nitrogen Oxides).*

The OOC is an industry organization of some 100 member and associate member companies which collectively account for approximately 95% of Gulf of Mexico oil and gas production. These comments are made without prejudicing any individual member's right to have or express different views.

DISCUSSION

As stated in the *Federal Register* notice, "the proposed action to be analyzed in the EA is a NTL to require best available control technology (BACT) for NOx emissions on all facilities in the CPA" and further "the MMS requests interested parties to submit comments regarding any information or issues that should be addressed in the EA... ." The need for the proposed EA and the draft NTL is based upon MMS modeling runs using the Offshore Coastal Dispersion (OCD) Model to determine potential cumulative NO_2 and SO_2 impacts on onshore areas in the Final Environmental Impact Statement (FEIS) for Gulf of Mexico OCS Oil and Gas Lease Sales 169, 172, 175, 178, and 182 (OCS EIS/EA, MMS 97-0033). The Table on page IV-214, of the subject FEIS, shows only an exceedance (OCS program modeled without onshore contributions and no treatment of Prevention of Significant Deterioration (PSD) "baseline") of the Class I maximum allowable increase for NO_2 (annual average of 2.5 micrograms per cubic meter ($\mu g/m^3$) versus highest predicted contribution of

3.61 $\mu g/m^3$). All other averaging periods for NO_2 (Class II) and SO_2 (Class I and II) maximum allowable increases are significantly greater than the highest modeled contributions.

This is somewhat misleading since MMS regulations, 30 CFR Part 250.303(e) - new facilities and 30 CFR Part 250.304(c) - existing facilities, require the installation of BACT if the annual modeling significance value (1 $\mu g/m^3$) is exceeded (on a per facility analysis). The annual modeling significance level for NO_2, on a volume per volume concentration basis, is 0.532 parts per billion (ppb) and the SO_2 annual modeling significance level is equivalent to 0.382 ppb. These concentrations are extremely small and are below the lower detection limit of most air quality analyzers. It is also interesting to note that the Breton Aerometric Monitoring Program (BAMP) Technical Review Group (TRG), composed of air pollution professionals from both industry and government, does not believe that the annual NO_2 PSD increment has been consumed in the Class I Breton National Wilderness Area and have focused their research on the 3-hour and 24-hour increment for SO_2.

The OOC is concerned that MMS has used the annual modeling significance level of 1 $\mu g/m^3$ in an inappropriate manner. In the Environmental Protection Agency's (EPA's) PSD program, the modeling significance level is used to determine if a "*single*" facility's emissions, when modeled with a screening air dispersion model such as SCREEN3, need to be analyzed with a more refined model. Exceeding the modeling significance level does not require the application of BACT; it only requires the permit applicant to conduct an air dispersion analysis with a more refined model, i.e., ISCST3, ISCLT3, CALPUFF, etc..., with the inclusion of nearby (50 miles) emitting sources. The MMS has conducted the subject modeling on a "*cumulative*" basis, over a domain of 150 kilometers (km) or 93.2 miles, with the straight-line steady-state, hourly Gaussian OCD plume model. OCD is limited to dispersion conditions of inert pollutants that occur within 50 km (31.1 miles) of the source and are well approximated by steady-state meteorological conditions. At best, the use of OCD, over such a large domain with minimal surface meteorological data from one C-MAN buoy (42007) most likely an inappropriate surface site to use in the analysis as it is not representative of the entire CPA, and upper air data from the onshore National Weather Service's Slidell, Louisiana rawinsonde station, should be considered a screening analysis and should not result in the imposition of BACT.

We have asked MMS to provide us with a copy of the air dispersion modeling so that we could have a third party peer review conducted on the work; however, we were told that the work is considered "draft" and cannot be released outside of the MMS. We will only be allowed to comment on the modeling work performed for the proposed EA. In addition, when we discussed this modeling with appropriate MMS personnel to understand if any simulations had been done to better understand the cause of the impacts, we were told no analyses of any type, other than the cumulative assessment had been done. Consequently, imposition of any controls may well be a case of cost-ineffectiveness, as sources that have no impact onshore might be forced to implement controls under the proposal. Again, this assumes that the outcome of a significant impact should even be the trigger for BACT, with which we disagree.

The proposed BACT (NOx) NTL and EA are based on a "cumulative" projection of development for future OCS lease sales in the CPA. These projected air emissions may be significantly different from what will actually be installed as emission sources. Industry does not want to install NOx control equipment on existing facilities because of possible future emissions.

Because air dispersion modeling is key to understanding the impact of offshore exploration and production sources on onshore receptors, we recommend that MMS perform the EA modeling with the OCD Model and the non steady-state Lagrangian puff model, CALPUFF/CALMET. However, as part of the recommendation, we note the need to have a much more robust air quality and meteorological data base than the very minimal one that was used for the OCD modeling. We make this recommendation from the results of the Breton Aerometric Monitoring Program (BAMP) Phase I - Task 1 Final Report (*Recommendations For Air Quality Dispersion Models and Related Aerometric Data Sets in Support of the Breton Aerometric Monitoring Program (BAMP))* prepared by T. W. Tesche and Dennis E. McNally, Alpine Geophysics, LLC, 30 April 1998. Meteorological conditions are not steady-state in the vicinity of the Breton National Wilderness Area; therefore, the state-of-the-art CALPUFF/CALMET modeling system is more appropriate than OCD. The modeling work should make use of the aerometric data required by NTL No. 98 - 08, Meteorological Data Collection (Breton National Wildlife Refuge/Wilderness Area), 10 August 1998.

Operators within 100 km of the BNWA have been funding the BAMP to provide MMS with "scientifically peer reviewed" data and recommendations to later perform a PSD cumulative increment consumption analysis for the Federal Land Manager of the BNWA (if this is ultimately deemed necessary). This approach is far more rational than running a screening model, with suspect input variables, and then requiring BACT for NOx to be installed on all existing and proposed sources in the CPA because an extremely small modeling significance level has been exceeded. Operators need to know that the amount of capital and maintenance expense they will entail for BACT NOx controls will actually result in the improvement of onshore air quality. There are no NO_2 National Ambient Air Quality Standard (NAAQS, annual NO_2 100 $\mu g/m^3$ or 53.2 ppb) non-attainment areas along the Gulf coast. Nor does it appear that there are any problems with the increment being consumed for the Class II areas along the coast. The State agencies (LDEQ, MDEQ, and ADEM) have not expressed any concern with offshore petroleum production source impacts onshore. Further, available data from the state of Louisiana has shown that no coastal parishes in the CPA are non-attainment for the present 1-hour ozone standard, nor likely to become non-attainment for the new federal 8-hour ozone standard. One option for the EA is to find that, even with the questionable OCD modeling, that there are no real onshore air quality problems associated with offshore facilities. Thus, BACT should not be an option until there is a need.

From the preceding comments it should be clear that the OOC believes that the proposed BACT (NOx) NTL is premature until it can be demonstrated, with refined modeling, that there is a need to control NOx. Given that, the following comments will address the proposed NTL.

While it is understood that BACT as used by the MMS is not necessarily BACT as defined by the EPA, the flexible, case-by-case approach is very troublesome to the offshore exploration and production industry. While some of our member companies have in-house air pollution experts, the majority do not. These companies will have to rely on contractors to produce an analysis of the processes, systems, and techniques considered and proposed to achieve the required BACT (NOx) emissions reduction. Industry has historically requested a so-called "level playing field" in regulatory programs. The case-by-case approach has too much uncertainty in what the Regional Supervisor will approve as BACT (NOx). Should the need arise for the MMS to participate in the development of an onshore State Implementation Plan (SIP) for ozone non-attainment, how would the MMS be able to forecast the amount of offshore NOx reduction with such a flexible approach?

If an operator wishes to perform modeling to demonstrate that the contribution to the onshore ambient air concentration of NO_2 from a proposed or existing OCS facility, in combination with the contributions from existing facilities in the area, will not exceed the MMS modeling significance level, where will he get the needed emissions inventory and what radius of sources need to be included in the modeling? The operator should be able to use the CALPUFF/CALMET modeling system, rather than relying on OCD.

Because of the flexible approach, the time necessary for existing sources to develop their BACT analysis, get it approved on an individual basis, and installed by 1 January 2000 is not feasible. There are only a limited number of contractors, with the necessary expertise, available to perform the BACT analysis or develop an exception request by 1 July 1999.

The proposed NTL verifies the use of engine injection timing retardation of at least 3 degrees represents BACT for the control of the emission of NOx when using diesel engines. Engine retardation may not be appropriate in all cases due to decreased power, poorer fuel economy and throttle response, and increased emissions of volatile organic compounds (VOCs), particulate matter (PM_{10} and $PM_{2.5}$), and carbon monoxide (CO).

Although not expressly stated, we assume that the proposed NTL does not apply to mobile sources such as work boats, crew boats, MODU's, and drill ships under passage, etc...

We assume that the proposed NTL does not apply to emitting sources installed prior to 1980 and would request similar clarification.

CONCLUSION

The OOC believes that the provisions for determining whether the significance levels have been exceeded require that MMS separately determine if each new or existing "non-exempt" facility *individually* contributes to onshore ambient air concentrations above the significance level. In accordance with 30 CFR Part 250.303(j) and 30 CFR Part 250.304(f) if projected emissions from an "exempt" facility will, either individually or in combination with other facilities in the area, significantly affect the air quality on an onshore area, then the Regional Supervisor shall require the lessee to submit additional information to determine whether emission control measures are necessary. The MMS has conducted *cumulative* OCD modeling on "all" (not just with other facilities in the area) "exempt" facilities, in the CPA, and has concluded that NOx BACT needs to be applied to all existing and future facilities. OOC recommends that MMS perform the EA modeling with the OCD Model and the non steady-state Lagrangian puff model, CALPUFF/CALMET. This modeling should be conducted with more robust air emissions and meteorological data. We also suggest that numerous simulations should be done to better understand the cause of the modeled impacts before requiring all facilities in the CPA to apply NOx BACT.

Brian E. Shannon is presently employed by ARCO, in Plano, Texas, as a Principal Environmental Scientist. He has worked for ARCO for the past 19 years and serves as the first Chairman of the OOC's Gulf of Mexico Air Quality Subcommittee (OOC GMAQS). He is also presently the Project Manager of the OOC funded Breton Aerometric Monitoring Program (BAMP) and a former Technical Review Group member of the MMS's 1995 Gulf of Mexico Air Quality Study (GMAQS). Brian received his B.S. in physics in 1972 from the University of Minnesota and his M.S. in environmental science in 1980 from the Florida Institute of Technology.

SESSION 1D

DEEPWATER OPERATIONS

Chair: Mr. Jim Regg
Co-Chair: Ms. Deborah Cranswick

Date: December 9, 1998

Presentation	Author/Affiliation
Geological Controls and Variability in Pore Pressure in the Deepwater Gulf of Mexico	Dr. Michael A. Smith Minerals Management Service Gulf of Mexico OCS Region
DeepStar Project: Phase IV Overview	Dr. Paul R. Hays Texaco Inc.
Marine Board Lightering Study Document Not Submitted	Dr. E. G. (Skip) Ward Offshore Technology Research Center Texas A&M University
Deepwater Well Control: IADC/OOC Guidelines Document Not Submitted	Mr. Moe Plaisance Diamond Offshore Drilling
Deepwater Oil Spill Response Challenges Document Not Submitted	Mr. Dan Allen Chevron U.S.A.

GEOLOGICAL CONTROLS AND VARIABILITY IN PORE PRESSURE IN THE DEEPWATER GULF OF MEXICO

Dr. Michael A. Smith
Minerals Management Service
Gulf of Mexico OCS Region

INTRODUCTION

In all areas of the world, pressure-related drilling problems are the leading cause for abandoning a deepwater well before its targeted reservoir depths are reached or for expensive remedial changes to be required in the drilling and casing programs. This paper discusses geological controls and trends in the onset of geopressure in the deepwater Gulf of Mexico, shallow waterflow from overpressured sands in the tophole section, and other pressure-related problems unique to deep water. These topics are the subject of intense current interest with a number of joint industry projects and predictive models now available for MMS and company participation.

As exploration moves into deeper water in the Gulf of Mexico, pore-pressure prediction and the correct anticipation of overpressured sands becomes more and more critical to the effective evaluation of federal OCS lease blocks. The number of exploratory wells in more than 1,000 feet of water has increased by nearly a factor of three in the past five years (Figure 1D.1). Although 1999 may see a modest decline in deepwater activity, the number of wells in ultradeep water (more than 5,000 feet) will reach an all-time high.

In this study, we look at the occurrence of geopressure in about 80 wells in deep water from Viosca Knoll to Alaminos Canyon; most of them fairly recent wells drilled in more than 2,000 feet of water. We also analyze shallow waterflow encounters and trends in these areas. Finally, we discuss the MMS regulatory approach to geohazard mitigation and how we are working with offshore operators to contain the significant pressure-related hazards in deep water.

PORE-PRESSURE GRADIENTS

MMS geological reviews of exploration and development plans and applications for permit to drill on Gulf of Mexico OCS leases contain a discussion of possible abnormal pressure zones. Geopressure is the depth at which fluid pressure exceeds normal hydrostatic pressure (Fertl 1976; Dutta 1987). This onset of abnormal subsurface pressure is defined as the depth in the wellbore where pore pressures are equivalent to 12.5 pound per gallon (ppg) mud weights. Burial rates, geothermal gradients, compaction, and diagenetic reactions are the primary factors affecting the occurrence of geopressure (Law *et al.* 1998). In deepwater wells, the large seawater column causes greater depths to abnormal pressure, so depths below the mudline (bml) or seafloor were used in this study in place of vertical subsea depths. Geological factors controlling the deposition of turbidite systems, sequence stratigraphy, major faults, unconformities, and salt tectonics also affect pore

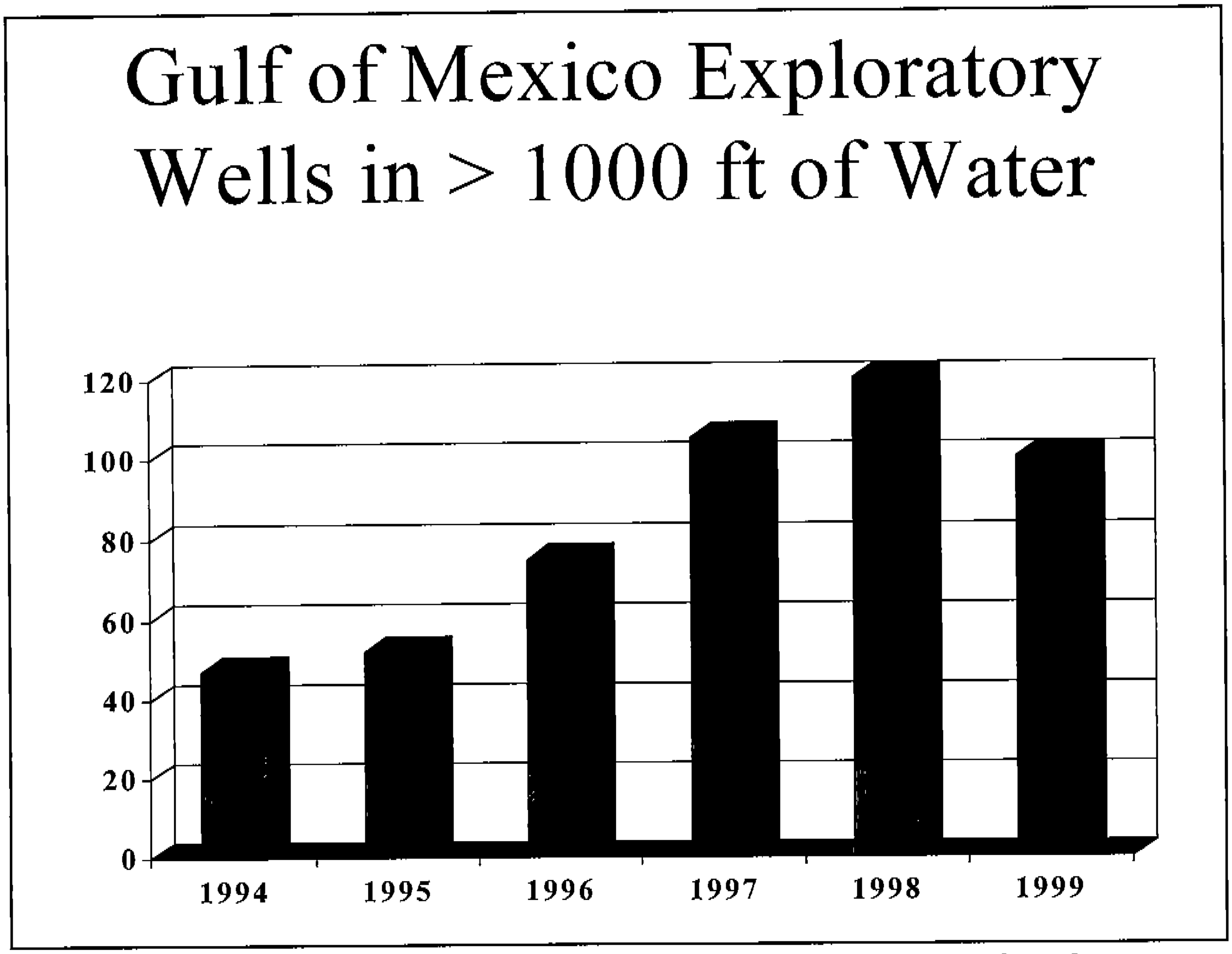

Figure 1D.1. Gulf of Mexico deepwater exploratory wells in more than 1000 feet of water.

pressure. In complexly faulted structures, formation pressures may be compartmentalized and vary between different sands.

We have analyzed predicted and actual pore pressures, sedimentation rates, and formation temperatures in the deepwater Gulf of Mexico and prepared trend maps of the occurrence of geopressures for this province. The wells in this study are located in four deepwater sections that include from east to west Viosca Knoll, Mississippi Canyon, and Atwater Valley; Green Canyon; Garden Banks; and East Breaks and Alaminos Canyon. The upper slope (less than 1,000 meters of water) in Mississippi Canyon has a thicker Pliocene section with a shallower top of geopressure, an average of 6,522 feet bml, than the deeper water parts of this area. In deeper water, the average top of geopressure occurs in the Miocene at 9,996 feet bml. In the younger Plio-Pleistocene section to the west in Green Canyon, Garden Banks, and East Breaks, the average top of geopressure occurs at 9,137 feet bml. However, in the deeper section in Green Canyon, Garden Banks, and Alaminos Canyon to the south and southeast, the top of geopressure occurs in the Miocene at an average depth of 12,389 feet bml. Throughout the deepwater Gulf of Mexico, it appears that older and more compacted strata have a deeper top of geopressure than occurs in younger strata.

The thermal gradient in Mississippi Canyon and Viosca Knoll is higher than that of deepwater areas to the west, generally more than 1.5 degree F/100 feet. In Garden Banks wells the thermal gradient averages about 1.0 degree F/100 feet and in Green Canyon the temperature gradient appears to increase from 0.8 to 1.3 degree F/100 feet to the southeast with greater water depths. These observations suggest that higher thermal gradients may correspond with a deeper top to geopressure. Below salt, formations can be overpressured due to an effective seal, and the top of subsalt geopressure generally occurs at greater depths and deeper in the stratigraphic section.

SHALLOW WATERFLOW SANDS

If shallow waterflow from an overpressured aquifer occurs above the first pressure-containing string, it can result in a shallow subsurface geohazard that will impact drilling and cementing practices as well as the setting depth and number of shallow casing points. This shallow hazard may even cause a change in surface location or the loss of a well. Shallow waterflow sands were deposited as continental slope/fan sequences during Upper Pleistocene progradation, the building out of prodelta sandy zones. Since 1984, shallow waterflow occurrences have been reported in about 60 Gulf of Mexico lease blocks covering 45 oil and gas fields or prospects. With a few exceptions, waterflow incidents occur at water depths exceeding 1,700 feet with an average occurrence in 2,830 feet of water. Waterflow problem sands typically occur from 950 to 2,000 feet but have been reported as deep as 3,500 feet below the seafloor. Individual channel-sand units display slumping zones or debris flows with a chaotic seismic character and, in some cases, tilted and rotated slump blocks. In the Mississippi Canyon and southern Viosca Knoll Areas, some of the shallowest channel sands can be identified as part of a particular distributary system such as the old Timbalier Channel, Southwest Pass Canyon, or Einstein levee/channel system. High sedimentation rates and an impermeable mud or clay seal from a condensed section are the main factors contributing to overpressures in shallow waterflow sands. These sands occur in a number of depositional subbasins that are generally bounded by salt ridges or walls. However, none of the occurrences are found over tabular salt sills that are 5,000 to 10,000 feet below the sea floor in some areas. This fact may suggest that communication with the deeper stratigraphic section contributes to abnormal pressures in shallow sands.

The integration of high-resolution multichannel and reprocessed conventional 2-D and 3-D seismic data for the tophole section, further refined by seismic facies analysis, can identify sand bodies with moderate or high shallow waterflow potential. In assessing shallow waterflow risk, information from surrounding wells and shallow borehole tests also provides important data for drilling program design. The MMS Notice to Lessees and Operators (NTL) on shallow geohazards in the Gulf of Mexico OCS, NTL 83-3, is currently undergoing extensive revisions (Stauffer *et al.* 1999). The updated NTL will accommodate the shifting focus of drilling into deeper water and the improved technology and data now available to mitigate deepwater geohazards such as shallow waterflow.

Mitigating approaches that have been used in the drilling of shallow water flow areas include drilling the shallow section as a pilot hole with MWD logging, downhole Pressure While Drilling logging, and monitoring and confirming shallow water flow occurrences with a ROV. Additional casing strings and quick-setting foam cements, borehole test to 3,000 to 5,000 feet bml before development drilling, and other geophysical and engineering techniques that are currently under development have also been employed. The loss of integrity, buckling, or collapse of shallow casing strings in development wells has caused serious economic loss in several cases. Establishing a database or catalog of known shallow water flow occurrences and the most effective methods for controlling them will greatly advance the partnership between the MMS and offshore operators in containing this critical deepwater hazard (Smith 1999).

OVERPRESSURED SANDS IN ULTRADEEP WATER

In the centroid concept, pore pressure in a reservoir sand at the crest of a high-relief overpressured structure can exceed pore pressure in the bounding shale. The top of a large structure near the seafloor may contain fluid pressures that are similar to the fracture gradient in adjacent shale (Traugott 1997). In water depths greater than 5,000 feet, the weight of a mile or more of a drilling mud column is added to hydrostatic pressure at the seafloor and extra casing strings may be required in shallow formations as pore pressures approach the fracture gradient. These unplanned additional casing strings may cause the target sands to be unreachable, or the limited wellbore size may be uneconomic. The marine riserless drilling joint industry project, where the riser carrying mud and cuttings back to the drilling rig is offset from the drillpipe, may overcome this problem and allow successful drilling of large, shallow structures by the next generation of drillships in water depths exceeding 10,000 feet. Other innovative casing and diverter systems are under development that may also contribute the new technologies required for successful exploration in the deepest Gulf of Mexico leases.

CONCLUSIONS

Many of the serious and costly drilling problems in deep water are related to the pore pressure/fracture gradient relationship. Other pressure-related hazards, such as shallow waterflow, require better predrill identification and quantification of overpressured problem sands. In many Gulf of Mexico frontier deepwater areas, a lack of offset wells requires better pressure models that incorporate all available geological data. Operations geologists and geophysicists in the MMS are working with deepwater operators to establish databases and methodologies that will improve industry's success in dealing with deepwater geohazards in the next millenium.

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DEEPSTAR PROJECT: PHASE IV OVERVIEW

Dr. Paul R. Hays
Texaco Inc.

INTRODUCTION

This summary reviews some highlights of DeepStar Phase IV work ongoing. Presently DeepStar has 22 participants with Unocal most recently joining us in August of 1998. Amerada Hess, among others, continues to show a strong interest. The participant roster give a good sense that although the project has a Gulf of Mexico (GOM) focus, much of the technology is generically applicable worldwide.

AGIP, British Gas, BHP, BP, Petrobras & Elf all have primary interest outside the GOM. However, in Phase IV of DeepStar, a significant part of our budget is focused on flow assurance issues that extend well beyond the Gulf of Mexico.

VENDOR PARTICIPATION

We continue to involve the vendor community in the program with about forty presently contributing and five to ten more likely to join before the end of Phase IV. These members of the vendor and contracting community seek to evolve their technology and expertise in closer contact with the oil industry. For a $5,000 fee per phase, these Contributors can attend most meetings and through in-kind or contributed studies advance their own technology and benefit the offshore oil community.

MISSION STATEMENT

DeepStar's Mission: "An Industry-Wide Cooperative Effort Focused on Identification and Development of Economically Viable, Low-Risk Methods to Produce Hydrocarbons from Deepwater Tracts in the Gulf of Mexico."

Although the project has a Gulf of Mexico focus whenever environmental criteria are involved, a large number of the project work products are applicable throughout the world. Exceptions are projects such as the Gulf of Mexico GOM focused Environmental Impact Statement for FPSO's and the GOM current monitoring program through the Yucatan Straight.

HISTORICAL BACKGROUND

The initial DeepStar studies concerned the feasibility of using extended reach sub-sea development tied back to a shallow water platform. Texaco thought the topics would be of interest to the industry as a whole, and the company also sought to recoup some of its costs by selling shares in a $550,000 project. Eleven companies, including the Minerals Management Service (MMS), participated in DeepStar Phase I.

Although DeepStar did start out focusing on a particular production scenario, extended reach sub-sea tie back to a shallow water platform, the program has diversified and broadened in scope. The technology being progressed is modular and many of the topics studied such as pipelines or flow assurance issues are directly applicable to any area in the world.

INCREASED EMPHASIS ON TESTING

In addition to expanding in scope, the DeepStar program has incorporated additional field scale testing.

We have brought a composite riser from conceptual study to near term field deployment of a 25-ft. composite riser pup joint. Currently negotiations are underway between ABB Vetco and an oil company that has expressed a strong interest in deploying this technology in a deepwater (~4,000 ft.) drilling application.

Underway since August 1996, the polyester mooring test has been a two-year test of a vertical mooring line composed of four manufacturers' ropes, deployed in 3,000 ft. water depth and instrumented for data retrieval. This system was removed November 1998, and plans are underway to perform extensive post-deployment analysis and testing to increase industry confidence in polyester mooring.

Field tests on a gas line owned by Kerr-Mcgee in Wyoming allowed us to verify a technique of removing hydrate plugs by depressurizing only one size of the plug.

In addition to these accomplishments, several projects in Phase IV involve either field scale deployments or laboratory testing of prototype scale equipment. As an example, we have initiated testing of an electrically heated pipeline configuration in a fjord offshore Norway. Large gate and ball valves for subsea manifolds will be tested in a laboratory setting to verify their efficacy. Also, we are conducting test engineering to develop procedures to drive conductor casing to 1,000 ft depth to help alleviate problems that arise when trying to set casing strings within a shallow water flow zone.

PHASE IV PROGRAM

We kicked off Phase IV in January 1998. Phase IV (actually the 5th phase of the program) is a 24-month program costing $500,000 per participant. Including money not expended in Phase III (which has been rolled over), the Phase IV budget for DeepStar is about $13,000,000, a record level.

Because participating fees are cumulative, each oil company participating will have spent about $1,000,000 on this program, for total cash expenditure on the order of $22 million since the program's inception. Yet our money has brought us far more than $22 million in R&D because we have leveraged our dollars by working with the vendor community and the federal government. In addition to the cash expenditure each company makes, it must be recognized that each oil company sending representatives to the meetings can readily expend man-hour costs equivalent to, or exceeding the participation fee. These in-kind costs, which result in the education of our personnel, provide one of the greatest values of participating in DeepStar.

The eight (8) major technological areas covered in Phase IV include

- Regulatory
- Flow Assurance ~ 3.85 MM
- Subsea - controls / pipelines / hardware
- Vessels / Mooring / Riser
- Drilling & Completion
- Project Administration
- Reservoir Engineering
- MetOcean

As the program has evolved, we have recognized that the development of subsea equipment although necessary, does not have the same show-stopping character as our inability to provide flow assurance over a long offset distance. The importance of this area is evidenced by the fact that ~3.85 MM, the largest chunk of the DeepStar budget, is devoted to this area of research. About 40 work programs have received funding approval from the senior advisors with an average value of $325,000.

REGULATORY COMMITTEE

The Regulatory committee's primary purpose is information exchange. This effort is one of the most important ongoing activities carried out by DeepStar. This forum gives DeepStar participants and the MMS a chance to discuss issues related to new development concepts that are departures from existing regulations. By holding discussions, we can better understand the issues that need to be addressed to ensure that new concepts are safe and fit for purpose. In addition, to being a forum to feed technical questions arising out of committee work, key Phase IV efforts include

- Targeting continuing discussion between regulatory authorities (Coast Guard/MMS) to sort out overlap of regulatory domain and point out where gaps still exist.

- Continuing to work with MMS to capture data from worldwide usage of FPS & FPSO's database and help the MMS become comfortable with use of FPSO's in GOM.

- Providing a forum for open industry discussion on these issues: for example the April 1997 forum jointly hosted by the MMS and DeepStar

FLOW ASSURANCE COMMITTEE

Goal: to gather the most extensive industry FA data set, to allow validation and improvement of FA predictive software packages, and to field qualify new FA monitoring, management and remediation technologies.

DeepStar had planned to conduct a series of four or five field tests, designed (1) to retrieve solids deposition and multiphase flow data, and (2) to field test new monitoring, management and remediation technologies.

FLOW ASSURANCE PROGRAM

The Flow Assurance Committee, working with its contractors, vendors and other Industry programs matured new hydrate and paraffin management technology to the point of performing full-scale field trials and demonstrations (the last step prior to commercial deployment). The primary Phase IV - 4,200 activities are focused on this field demonstration objective. Hydrate management trials are planned for both a multiphase black oil and for a condensate system (in a mist annular flow regime). Wax deposition trials are in a single-phase black oil system.

These trials and demonstrations were originally planned for existing producing fields. Unfortunately, suitable fields could not be found, either within Texaco or the DeepStar Participants, so the decision was made to demonstrate the technologies in a full-scale simulator. DeepStar partnered with the Department of Energy's Rocky Mountain Oilfield Test Center (in Casper, WY) to cost-share construction of this test facility. Construction of the facility was begun on a fast-track program in August 1998, but was halted in November 1998 when the actual facility costs exceeded budgeted funds. A recovery program is being developed to resume construction early summer 1999.

The core of the Phase IV Flow Assurance program was a series of field tests. The objective of the program was to retrieve sufficient multiphase flow and solids deposition data, to validate and improve current FA predictive tools. In addition, available management and remediation technologies were to be field qualified.

When the facility is finally constructed, instrumentation will be a key aspect of the program. We will utilize both novel and established instrumentation systems, including fiber optics and solids deposition monitors. As noted previously, the extensive and unique data recorded from this program will be used to validate and improve current FA predictive software.

We plan to field qualify available management and remediation technologies. These will include the latest chemical developments for wax and hydrate inhibition, and possibly other novel approaches.

We will field qualify optimum depressurizing techniques for hydrate re-mediation and test the suitability aggressive and multi-diameter pigs.

KEY FOCUS AREAS OF THE SUBSEA COMMITTEE

The stretch goal of the subsea committee is to provide subsea tieback technology in water depths to 10,000 ft.

In addition to chemical and mechanical strategies investigated by the Flow Assurance Committee, we plan to field qualify an electrically heated pipe system. If this system proves to be a practical solution, it would be able to keep the pipeline out of wax and hydrate formation conditions, and may also be an excellent remediation tool. This final section of the program will be conducted under the guidance of our subsea committee.

Other Areas to be studied include

- testing subsea manifold large gate and ball valves for 10,000 ft. operation in higher pressure ranges
- DeepStar Pipeline Pigging Systems - haven't designed systems for wax removal on a continuous basis
- GOM Pipeline Repair Alliance

ELECTRIC IMPEDANCE PIPELINE HEATING

This appears to be the most viable commercial alternative to date. A voltage drop is applied directly to a pipeline with an outer coating of insulation. This technology holds the promise of reaching beyond 15 – 20 miles.

VALVE CONCERNS

Problems with large bore high-pressure valves found on manifolds include

- long lead time
- not off-the-shelf
- reliability not fully established

PIPELINE REPAIR ALLIANCE

Recognizing that having equipment on hand for repair is unnecessarily expensive if each company does so separately, a CTR was organized to explore the possibility of warehousing a communal supply of emergency repair equipment.

VESSEL, MOORING, AND RISER COMMITTEE

The greatest effort has been focused on offshore testing of vertically loaded drag embedment anchors and components of a polyester mooring system.

TAUT LEG MOORING SYSTEM

As water depth increases, the spread of a conventional mooring system could traverse several blocks. Taut leg systems, consisting of vertically loaded anchor systems, with flotation buoys could help reduce the areal extent and cost of a deep water mooring system. Further substitution of polyester instead of conventional chain and wire rope mooring could reduce system component costs as well as reduce deck loads.

Several DeepStar members were able to participate in the deployment of the system offshore. The basic system involved in deployment consisted of the polyester line on a spool, with a helper tug and the buoy, which tethers the system inside the A-frame, used for deploying the buoy.

POLYESTER MOORING SYSTEM TEST

The test seeks to

- place steel taut leg mooring lines with lighter synthetic fibers
- install system in 3,000 ft. water depth in Gulf of Mexico and gather data for two years
- system instrumented to provide mooring line loads and buoy motions
- after 2 –3 year deployment, polyester line will undergo wear and chemical degradation testing

This test should improve the acceptability of polyester mooring components with their potential cost savings. As the system was removed in November 1998, the post-test analysis which includes both destructive and non-destructive testing is underway.

Other Phase IV programs carried out by the Vessel, Mooring and Riser committee include

- Deepwater Mooring and Riser Analytic Capabilities
- Mooring and Risers Beyond 6,000 ft. Water Depth
- Reliability Based Mooring Design Code
- API RP 2FPX "Planning, Designing and Constructing Floating Production Systems"

DEEPSTAR DRILLING COMMITTEE

The number one GOM deepwater drilling issue has been management and control of shallow water flows (SWF). There are often large artesian aquifers within the first few thousand feet below the mud line over the target reservoirs. The geological mechanism, which deposited the target hydrocarbon reservoir, is often the same mechanism, which in recent geological times created these aquifers. Therefore, many of the GOM deepwater areas have this potential problem.

When well conductor jetting-in operations encounter these aquifers, excessive artesian water flows may wash away the soils surrounding the conductor resulting in well loss and formation of a large sea floor crater. Other times, the aquifer is deeper where it may cause problems during 20" conductor string cementing operations. These are serious problems and DeepStar's drilling committee has worked extensively with the service industry in Phases IIA and III to develop techniques and products to manage these shallow water flow problems. In Phase IV we have put continued effort into engineering a test for driving conductor casing to a sufficient depth to obviate the need to set casing in the shallow water flow zone.

We are now wrapping up our effort to develop composite marine drilling riser with the National Institute of Standards and Technology Program led by Northrup Grumman. The riser has been tested at Vetco Gray in Houston. Some of the axial load cycles run to date include: 1) startup fixture test to 500 kips, 2) tension up through 1,500 kips design load, and 3) maximum tension of 1,850 kips. As testing has been successfully completed, the next step is to have an operator to agree to deploy this pup joint during drilling operations. Negotiations are underway. Separately, a second pup joint is being designed and tested to accommodate water depths to 10,000 ft.

Other CTR's pursued by the drilling committee include

- Bottom Driven Casing Test Installation Guidelines
- Ultra-Deepwater Wellhead and Riser Standards
- Well Control Software Refinements
- Validation of SSSV Practices
- Multi-Lateral Completion Reliability Forecasting

RESERVOIR ENGINEERING COMMITTEE

The entire production system is built to safely produce the reservoir. In the deepwater Gulf of Mexico, we are entering a new frontier with significantly different production characteristics from the experience of the Continental Shelf. The reservoir committee has studied available information and identified many of the variables impacting production system design. These include high rate wells, one to four producing zones, and an estimated 50% of these reservoirs that will require water injection.

Further work planned for DeepStar Phase 4 will investigate water injection aspects and the effectiveness of multi-lateral and horizontal wells. These are all techniques to increase the production rates and the total reserves recovered from each wellbore.

MET OCEAN COMMITTEE

This program is being conducted to make the first comprehensive measurements of current inflow into the Gulf of Mexico through the Yucatan Straight. This data gathering effort will be used to improve our Gulf of Mexico global current model with the ultimate goal of avoiding downtime during deepwater drilling operations. Field work will be done by a Mexican research institute

(CICESE). A budget of $850,000 has been awarded to Dynalysis of Princeton as the primary contractor. We hope to kick off the deployment effort in April 1999.

CONCLUSION

Prototype testing now forms a greater part of the DeepStar program. This trend is foreseen to continue as the Gulf of Mexico operators pick up the pace of deepwater development. For subsea technology, flow assurance is our first concern and a major effort to develop a major test facility at the DOE's RMOTC facility in Casper, Wyoming. Although with DeepStar's breadth and emphasis on technologies, the question the MMS needs to ask itself is "Why are we not actively participating in DeepStar?"

Paul Hays received an erector set at age 6, and his dad suggested he could become an "engineer." He received Ph.D. in theoretical and applied mechanics from the University of Illinois at Urbana, Illinois in May 1980. After a brief stint in the aerospace industry, he joined the oil industry in 1981. Early involvement with Deepwater focused on field development technology for 1,000 feet water depth offshore Norway with initial technical focus on deep-water production and drilling technology. He was involved with acquisition and development of technology to enable development with floating production systems. Technology development efforts evolved to Gulf of Mexico (GOM) focus with water depths to 2,200 feet.

In 1992, the DeepStar project began a program to develop technology to enable extended-reach subsea tie-back field development in GOM water depths ranging between 3,000 - 6,000 feet. Dr. Hays began work with DeepStar focusing on pipelines. As the program expanded in Phase II. He took on greater responsibility for production risers. In Phase IIA, Hays assumed additional responsibility for drilling and completions committee, and he took over responsibility for leading the overall DeepStar program at the kickoff of Phase III in February 1996. He proposed a $9 million Phase IV program that has grown to approximately $13 million with the addition of four new participants.

SESSION 1E

STUDIES REPORTS AND RESEARCH INITIATIVES

Co-Chairs: Dr. Pasquale Roscigno and Ms. Debra Vigil

Date: December 9, 1998

Presentation	Author/Affiliation
Long-Term Monitoring at the East and West Flower Garden Banks, 1996-1997	Dr. Quenton R. Dokken, Co-Principal Investigator Dr. John W. Tunnell, Jr., Co-Principal Investigator Center for Coastal Studies Texas A&M University-Corpus Christi Dr. Ian R. MacDonald, Co-Principal Investigator Mr. Carl R. Beaver Mr. Gregory S. Boland Mr. Derek K. Hagman Mr. Noe C. Barrera Geochemical Environmental Research Group Texas A&M University
The Interactions Between Neotropical Bird Migrants and OCS Platforms	Dr. Robert W. Russell Louisiana State University
Stability and Change in Gulf of Mexico Chemosynthetic Communities (CHEMO II)	Dr. Ian R. MacDonald Program Manager Geochemical and Environmental Research Group Texas A&M University
Shell Marine Habitat Program Document Not Submitted	Dr. Jerry Clark National Fish and Wildlife Foundation

LONG-TERM MONITORING AT THE EAST AND WEST FLOWER GARDEN BANKS, 1996-1997

Dr. Quenton R. Dokken, Co-Principal Investigator
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Mr. Carl R. Beaver
Mr. Gregory S. Boland
Mr. Derek K. Hagman
Mr. Noe C. Barrera
Geochemical Environmental Research Group
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This report (Dokken *et al.* 1999) was produced by the Texas A&M University-Corpus Christi Center for Coastal Studies and the Texas A&M University-College Station Geochemical and Environmental Research Group through contract to the Minerals Management Service and the National Oceanic Atmospheric Administration. This study represents an ongoing effort to understand the reef dynamics of the Flower Garden Banks coral reefs, and to protect this unique and valuable natural resource. Increased human activity (i.e. shipping, oil/gas exploration/production, recreational diving, fishing) in the vicinity of the Flower Garden Banks National Marine Sanctuary, makes research/monitoring efforts critical to preserving the long-term health and sustainability of the Flower Gardens Banks ecosystem.

The Flower Garden Banks comprise a unique coral reef ecosystem located approximately 200-km (110 nmi) southeast of Galveston, Texas, on the outer continental shelf of the northwestern Gulf of Mexico. Designated as a National Marine Sanctuary in 1992, the Flower Garden Banks represents the northernmost coral reef on the continental shelf of North America. The banks are topographic highs of bedrock displaced upward by the intrusion of two salt diapirs. The bedrock is capped with the calcium carbonate deposition of reef-building corals and calcareous algae. The living coral reef is comprised of 20 species of corals, and supports 120 species of fishes and more than 250 species of invertebrates.

This ecological monitoring effort is the continuation of monitoring efforts begun in 1989 and first reported in 1992. Study purposes are:

1. to provide relevant and timely environmental data to those charged with developing policies concerning oil and gas exploration and production in the vicinity of sensitive ecosystems,
2. to document long-term changes in reef-building coral and associated communities at the Flower Garden Banks caused by either impacts of petroleum exploration and production or other human impacts,

3. to document long-term natural variation in reef growth and associated communities on the Flower Garden Banks and,
4. to stimulate ancillary research efforts and coordinate monitoring activities with agencies and institutions conducting water quality assessments and other studies in the vicinity of the Flower Gardens in order to better evaluate causes of environmental change.

Photographic techniques (i.e., random transects, encrusting growth, repetitive quadrats, and video transects) were used to measure/assess the growth, diversity, percent cover, and incidence of bleaching and disease of scleractinian hermatypic corals at the Flower Garden Banks. Accretionary growth of corals was assessed using both direct measurement and sclerochronology methodology. Visual assessments of the population density of large-bodied fishes and sea urchins were made. Long-term temperature and insolation (light attenuation) were measured on the reef. The water column was sampled for contaminants using semi-permeable membrane devices (SPMD). Additionally, surveys of sea urchin populations, micromolluscan fauna, and habitats were conducted below the coral cap.

As in past studies, the *Montastraea annularis* complex (*M. annularis, M. franksi, M. faveolata*) was the dominant coral, providing 29.2% and 28.3% cover on the East and West Bank, respectively. *Diploria strigosa* was the second most common species of hermatypic coral with 13.1% and 10.0% cover on the East and West Bank, respectively. Total percent coral cover did not vary significantly between the East (54.4%) and West (49.8%) bank or between years. Analysis of species diversity and evenness showed no significant difference among studies, banks, or 1996 -1997.

In 1997, 45% of East Bank colonies and 67% of the West Bank colonies of *Montastraea cavernosa* showed substantial bleaching. Bleached colonies of *M. annularis* and *Millepora alcicornis* were also observed in 1997. This was believed to be a response to unusual water temperature fluctuations in 1997. Water temperatures ranged from 20.1 to 30.1 °C at the East Bank and 20.2 to 30.0 °C at the West Bank. Temperatures at the East Bank were lower than the seven year average for the period from mid-April through mid-June 1977. Another apparent deviation from the seven year average occurred from late July until mid-August 97 at the East Bank when daily temperatures were higher than average. Daily water temperatures at the West Bank were higher than average from early March thorough the first week of April and again from mid-June through early September 1997.

Mean accretionary growth at the East Bank was 5.7 mm/year and 7.3 mm/year at the West Bank. The encrusting growth rate was 3.7 and 4.0 mm/year at the East and West Bank, respectively. Average net encrusting growth rates were 0.06 and 0.14 cm/year at the East and West Bank, respectively.

Coral disease was minimal, occurring in 0.006% of the 3,700 coral colonies examined. *Diploria strigosa* and *Montastraea* spp. were the most commonly afflicted corals. The overall loss of coral cover due to disease was less than 0.03%.

Analysis of fish counts did not indicate any trends, but some significant differences did occur. Creole fish (*Paranthias furcifer*) were significantly more abundant in 1996 than 1997. Compared to 1991, density of all large bodied fish combined on the West Bank was significantly greater in 1996/1997, as was the density of the creole fish and creole wrasse (*Clepticus parrai*). 1996/1997 density of the queen parrotfish (*Scarus vetula*) was significantly greater on the East Bank than in 1991.

Water chemistry indicated the presence of polycyclic-aromatic hydrocarbons (PAH) at the West (273 ng/l) and East Banks (290 ng/l) from February to September 1997. From September 1996 to February 1997, 1,023 ng/l of PAH was recorded at the East Bank. The source of PAH was likely natural hydrocarbon seepage, condensate oil seepage, or combusted ship fuels. The reader is cautioned that: 1) the concentrations measured (ng/liter = parts per trillion) are infinitesimal, and 2) the application of the semi-permeable membrane devices to record these contaminants was done under less than ideal conditions. We advise against drawing conclusions from this information. Further study is warranted.

Pesticides and PCBs were also recorded. The amount of 4,4'-DDE (West Bank = 49.5 ng/l; East Bank = 43.5 ng/l) and 4,4'-DDT (West Bank = 23.6 ng/l; East Bank = 21.6 ng/l) were similar from the two sites collected from February to September 1997. The 4,4'-DDE (93.2 ng/l) and 4,4'-DDT (39.4 ng/l) were almost twice as high September 1996 to February 1997. The concentration of DDT relative to its derivative DDE suggests recently used DDT. The source and impact of these pesticides is not known. As with the application of semi-permeable devices to record PAH data, further study is warranted before drawing conclusions.

Other contaminants were detected, including:

- chlordane and its metabolites
- dieldrin
- hexachlorobenzene and its metabolites
- lindane
- PCB congeners

Analysis of attenuation coefficients (k) indicate that the water column at the Flower Garden Banks falls between the published values for the clearest coastal water (k=0.15) and the clearest oceanic waters (k=0.033). Analysis of trends in k values suggests that at least two attenuation regimes related to plankton blooms that reduce water column transmissivity. It appeared that blooms were periodically flushed by the infiltration of oceanic water.

Surveys and habitat characterizations of deep (30 to 50 m) reef zones further substantiate the biogenic zonation correlated to depths previously described. More investigation is required to describe the interactive dynamics of the coral cap with the deeper adjacent habitats.

Transect surveys of sea urchins, a primary herbivore, were conducted at each bank during both sampling periods. Based on the data, it was concluded that the sea urchin population continues to be depressed, and that it did not vary significantly between sampling years or banks. During the 1996 transect surveys one sea urchin was counted, and during the 1997 survey, three urchins were counted.

Micromolluscs from sand samples are currently being identified and counted. To date, 114 species representing 50 families have been identified, increasing by one-third the previously known invertebrate fauna of these reefs.

CONCLUSIONS

- The dominant corals of the Flower Garden coral reef ecosystem continue to grow at rates consistent with past measurements.
- The incidence of coral diseases is minimal and inconsequential at this time.
- The corals responded to elevated temperatures by exhibiting mild bleaching in 1997.
- Fish numbers showed limited variation, but no trends were apparent.
- Polycyclic-aromatic hydrocarbons and pesticides were present in the water column, but at minute levels (i.e. parts per trillion). Impact is not known.
- The sea urchin population continues to be depressed.
- The molluscan fauna has only been partially described in past studies, and it is likely that more intensive sampling of other groups of organisms would substantially increase the recorded biodiversity at the Flower Garden Banks.
- The strength of the monitoring strategy as has been applied since 1989 is that is provides a long-term database of repeatable measures of growth and condition of the scleractinian corals forming the habitats of the Flower Garden coral reefs.
- The weakness of the monitoring strategy as has been applied since 1989 is that it does not adequately assess the interactive dynamics of the Flower Garden coral reef ecosystem to describe the ecosystem dynamics. More measures need to be taken assess cause and effect relationships.

RECOMMENDATIONS

1. Eliminate growth spikes as a method for measuring accretionary growth. Use sclerochronology measurements to measure accretionary growth exclusively.
2. Continue and expand water chemistry analysis using SPMD technology. Record data no less than quarterly.
3. Expand water chemistry analysis to include nutrients (nitrogen and phosphorous) on a schedule no less than quarterly.
4. The protocol and technology applied to the measurement of light characteristics should be enhanced to allow diurnal collections, particularly during the late summer months before and after the annual spawning event.
5. Use random photographic transects outside the boundaries of the 100m^2 study sites to test the representativeness of the designated study sites.
6. Continue analysis of sea urchin population densities on a quarterly basis.
7. Add qualitative and quantitative analysis of macroalgae.
8. Add fish census (stationary visual and/or roving diver census) to suite of measurements.
9. Add seasonal photographic transects to assess temporal occurrences, such as disease and bleaching.

10. Continue and expand monitoring and studies of the biogenic zones below the coral cap. Trophic structure analysis should be undertaken to describe biological energy linkages between the biogenic zones.
11. Measure seasonal and annual current patterns around and above the Flower Garden Banks.
12. Develop and apply dynamic ecosystem models to research and management decision making.

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THE INTERACTIONS BETWEEN NEOTROPICAL BIRD MIGRANTS AND OCS PLATFORMS

Dr. Robert W. Russell
Louisiana State University

Each spring, approximately a billion landbirds migrate northward across the Gulf of Mexico, en route to breeding habitats from their wintering quarters in the tropics. Following a short breeding season in the north, most of these birds return southward across the Gulf, their numbers then augmented by offspring produced over the summer. From the standpoint of sheer numbers, these annual trans-Gulf migrations constitute one of the great wildlife events of the world. Nevertheless, basic aspects of the migrations remain poorly understood; indeed, until the 1950s, some scientists treated the very idea that birds routinely and "intentionally" migrate across the Gulf with skepticism.

Radar studies have indicated that the flight pathway of the majority of trans-Gulf migrants in spring is directed toward the coasts of east Texas and Louisiana—and thus over Gulf waters in which are located the majority of OCS platforms. Indeed, the ~4000 platforms located on the continental shelf of the northern Gulf of Mexico make up the largest artificial island system in the world. One of the most important components of birds' migration strategies is their use of local habitats for resting and refueling while en route. In light of the absence of natural islands or other terrestrial habitats during crossings of the Gulf of Mexico, it seems inevitable that the installation of 4,000 artificial islands in the northern Gulf must affect migrants in some fashion. Indeed, it may not be too fanciful to speculate that this recent availability of potential offshore stopover sites might even be affecting the evolution of bird migration strategies. However, to date, no systematic studies have examined the interaction between platforms and migrating birds.

To fill this informational void, an MMS-sponsored study of migrant-platform interactions began in spring 1998. The study is being carried out by personnel based at the LSU Museum of Natural

Science, and funded by MMS through a cooperative agreement with the LSU Coastal Marine Institute. Five major petroleum companies (Mobil, Exxon, BP, Phillips, and Texaco) are making platforms available to the study and are providing in-kind support. The goal of this research is to answer questions such as the following:

- How many individual migrating birds, and of which species, use platforms? How and when do they use platforms? How are the numbers of migrants using platforms related to migration traffic aloft?
- What proportion of migrating birds that stop on platforms depart successfully versus die there? Why do some birds die?
- What is the relationship between weather and trans-Gulf migration? In particular, how do local and synoptic conditions jointly determine the use of and survival on platforms by migrants?

To answer these questions, a team of five expert observers has been deployed to OCS platforms off the Louisiana coast during spring (15 March-15 May 1998) and fall (15 August-31 October 1998). Field methods are simple but powerful. The basic protocol consists of a time-designated census conducted by an observer while walking around the platform on a prescribed route, designed to provide a synoptic and comprehensive assessment of platform use by migrants. The platform census is repeated identically seven times throughout the day from pre-dawn to post-sunset, allowing us to determine when birds arrive and when they leave. When we detect a bird, we identify it to species and when possible age and sex; we record its location on the platform; we assess its likely body condition on a four-point scale based on behavioral cues such as alertness, vigor, and apparent thermal stress; and we note whether it is looking for food and whether or not it finds any.

The platform censuses are intended to provide information on platform use by migrants. Because not all incoming migrants land on platforms, it is important to obtain independent information on incoming migration traffic. Thus, in addition to the platform censuses, we conduct several surveys from a fixed point of the airspace over and around the platform. When we detect a bird in flight, we record its flight altitude, whether or not it approaches the platform, and its vanishing bearing (the direction toward which it departs). Throughout the day and between the other censuses, we conduct routine searches for dead birds. Any carcasses that are discovered are salvaged, labeled, frozen, and transported to the Museum for necropsy.

An important adjunct to the fieldwork on the platforms is the remote observation of migration over the Gulf using land-based radars. The National Weather Service recently completed the installation of a national network of modern Doppler radars, which replaced technology dating from the 1950s. The new radars (called NEXRAD) can ideally provide both large-scale distributional information as well as quantitative measures of the local abundance of bird migrants in the airspace. Currently there are 10 NEXRAD radars in operation at sites around the Gulf Coast, providing an observational network stretching from Brownsville to Key West.

Based on our first two field seasons, our preliminary conclusion is that the aggregate impact of platforms on migrating birds is neutral to moderately positive. In both spring and fall, platforms are exploited by large numbers of migrants for resting and refueling opportunities. During the spring, most of the mortality we observed was not caused by the platforms either directly or indirectly, and we documented unambiguous benefits to migrants in the form of successful feeding on the abundant insects that are transported offshore by wind. Many migrants that otherwise would likely have perished in the Gulf during severe spring weather were observed to take refuge on platforms, survive the severe weather, and then continue their migrations.

The situation is more complicated in the fall because the costs and benefits of platforms accrue differentially to different classes of migrants. For true trans-Gulf migrants, a minor adverse impact was evident in the form of small levels of mortality resulting from collisions with platforms, particularly during tropical storms. In addition to the true trans-Gulf migrants, we were surprised to discover an abundance of species that are shorter-distance migrants and do not winter to the south of the U.S. A variety of evidence indicates that these migrants "overshot" the coastline during the previous night's migration and inadvertently ended up over the Gulf. These birds reorient to the north at first light, and while attempting to make it back to shore, they often stop on platforms and feed heavily on the abundant moths that also ended up offshore inadvertently. Thus, for the "overshoot" migrants, which are ill equipped to deal with the rigors of overwater migration, platforms provide "steppingstones" back to the coast and probably enable many individuals to return to land successfully.

Although OCS platforms may be beneficial to some migrants, their most important impact may prove to be their tremendous value as research platforms for learning more about the ecology of trans-Gulf migration. Our understanding of trans-Gulf migration has already taken a quantum leap forward, but the first year of fieldwork has also raised a number of important questions. For example, the portion of the northern Gulf Coast on which migrants make landfall changes dramatically from day to day, often reflecting patterns of upper-level winds. This variation raises the question of whether different species use different trans-Gulf flight routes or whether migrants of all species opportunistically use whichever flight route is most efficient given current wind conditions. Another surprising discovery was the observation of large numbers of radar targets of unknown identity over the western part of the Gulf. Because of the relatively limited geographical configuration of our current platform layout, we are seeking to expand to ten platforms to provide a more comprehensive circum-Gulf perspective. If successful, this expansion of the platform network will allow us to "ground-truth" the radar observations across the northern Gulf and examine the possible existence and consequences of species-specific migration corridors.

STABILITY AND CHANGE IN GULF OF MEXICO CHEMOSYNTHETIC COMMUNITIES (CHEMO II)

Dr. Ian R. MacDonald
Program Manager
Geochemical and Environmental Research Group
Texas A&M University

INTRODUCTION

On the northern continental slope of the Gulf of Mexico, chemosynthetic communities are known to occur between longitudes 94° W and 88° W, at depths between the 400 and 2,200 m (MacDonald *et al.* 1996). These communities comprise dense and productive aggregations of benthic organisms that are dominated by chemosynthetic tube worms and mussels, but also include many benthic invertebrates and fish that are common throughout the Gulf slope (MacDonald *et al.* 1989). The chemosynthetic fauna is dependent upon methane and hydrogen sulfide dissolved in pore-fluid and very-near-bottom sea water. Methane supports mussels and hydrogen sulfide supports tube worms (Fisher 1990). The presence of these gases in the Gulf slope sediments is directly linked to migration of hydrocarbons from deep sub-surface reservoirs to the seafloor and the water column (Kennicutt *et al.* 1988). The greatest management concern is directed at communities with aggregations that extend over a large area and where the local high productivity supports a diverse assemblage of heterotrophic fauna.

Considerable progress was made in the understanding of chemosynthetic communities in the Gulf of Mexico during the early 1990s, particularly as a result of the MMS Program entitled "The Chemosynthetic Ecosystem Study" (CHEMO I). However, there remained many unanswered questions and many areas where qualified scientists and managers disagreed. The continuation of CHEMO was a new, 42-month program entitled "Stability and Change in Gulf of Mexico Chemosynthetic Communities" (CHEMO II). It was inaugurated at the beginning of the 1997 fiscal year and was designed to aid MMS in the scientifically sound management of seep communities. CHEMO II has now completed all of the scheduled field collections. The program principal investigators are close to completion of sample analysis and are preparing for a yearlong effort that will produce the program's final report.

This summary gives a brief overview of the CHEMO II program goals, study design, and participants. It describes progress during the past year, and it highlights the accomplishments of each program element.

PROGRAM OVERVIEW

The CHEMO II program includes community ecological, regional geological, microbial, and site-specific chemical and oceanographic studies. At the regional level, the program has been concerned with developing reliable methods for remote detection of significant chemosynthetic communities.

During the 1997 field season, side-scan sonar surveys of suspected chemosynthetic communities were carried out in two regional mega-sites (Figure 1E.1). During FY 1998, US Navy Submarine NR-1 was fitted with a laser line scan system and an X-Star Subbottom Profiler and was used to survey known and suspected communities to confirm interpretation of the sonar data.

The size and location of mega-sites were designed to optimize survey operations and provide significant regional coverage. Both areas encompass several types of geological formations. Both contain more than ten perennial sea surface slicks detected by remote sensing techniques. Additional survey data were collected at the Garden Banks (GB) 425 sampling site in support of the community-level studies. Characteristic of the mega-sites are summarized below:

1) Megasite 1 ("Shallow") - area 1214 km^2
   a) Boundaries - 91°35'W-91°10'W; 27°36'N-27°50'N
   b) Contains Green Canyon (GC) blocks 185, 233, and 234 sampling sites.
   d) Water depths range from 400-900 m

2) Megasite 2 ("Deep") - area 1214 km^2

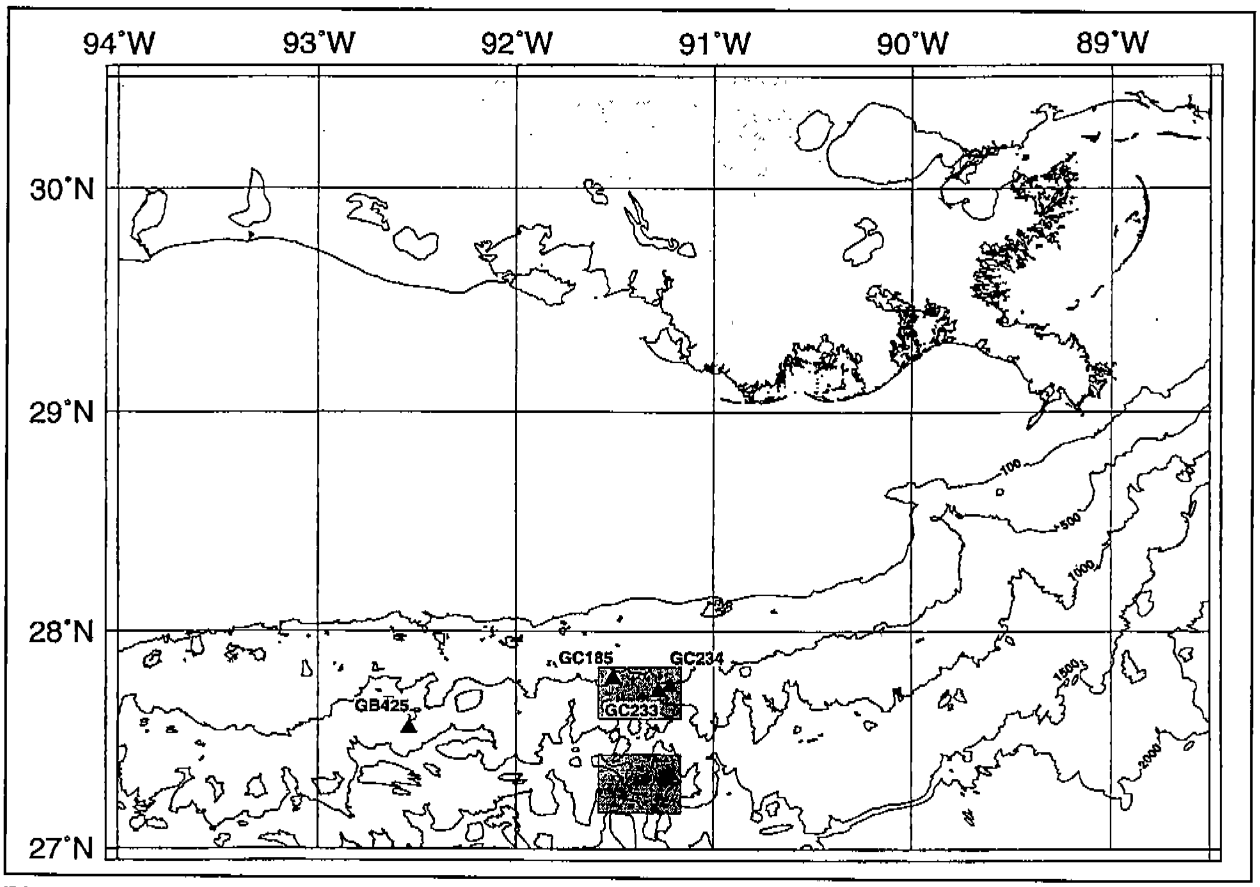

Figure 1E.1 Northern Gulf of Mexico showing study site locations for submersible operations (triangles) and mega-site areas for geophysical survey (shaded rectangles). Depth contours are in meters.

a) Boundaries - 91°35'W-91°10'W; 27°10'N-27°26'N
b) Contains northern Pygmy Basin; eastern Longhorn Basin; and most of Tiger Basin (intrasalt basins)
d) Water depths range from 950 to 1250 m

At the community level, efforts focus on the abiotic factors that control the distribution, abundance, and health of the major chemosynthetic and associated fauna. Investigations of the life history of these organisms are also included. Field work during 1998 has required the use of the manned submersible Johnson Sea-Link I. These submersibles were used to collect samples from a series of stations within each of four detailed study sites (Figure 1E.1). Characteristics of the sampling sites are summarized in Table 1E.1

Table 1E.1. Summary of principal community-level sampling sites and pertinent characteristics. (For locations, see Figure 1E.1.)

Sampling Site (abbreviation)	Latitude, Longitude	Depth (m)	Fauna present (by dominance)	Seepage properties
GC185 [Bush Hill (BH)]	27°46.9' N 91°30.4' W	550-580	tube worms heterotrophs mussels	high molecular weight hydrocarbons free methane to pentane gases
GC234 [Green Canyon (GC)]	27°44.1' N 91°15.3' W	525-560	tube worms heterotrophs mussels	high molecular weight hydrocarbons free methane to pentane gases
GC233 [Brine Pool (BP)]	27°43.4' N 91°16.8' W	640	mussels heterotrophs tube worms	brine free and dissolved methane gas
GB425 [Garden Banks (GB)]	27°33.2' N 92°32.4' W	600	mussels heterotrophs (?) tube worms	brine free and dissolved methane gas high molecular weight hydrocarbons

PROGRAM TEAM

Program objectives are being carried out by a multidisciplinary team of investigators. The principal investigators, their area of expertise, and the members of the Scientific Review Board are listed in Table 1E.2.

PROGRAM MILESTONES ACCOMPLISHED DURING FY 1998

The CHEMO II program moves into its third year, having successfully completed all of the scheduled fieldwork. Milestone accomplished during this period were as follows:

- The Interim Report has been accepted by the government and submitted in final form.

Table 1E.2. Program team and roles.

Texas A&M University Investigators
Geochemical and Environmental Research Group

Dr. Norman L. Guinasso, Jr. Physical Oceanography	Dr. Ian MacDonald Program Manager Imaging & GIS	Dr. Gary A. Wolff Data Management
Dr. Mahlon C. Kennicutt II Deputy Program Manager Environmental Chemistry	Dr. Roger Sassen Hydrocarbon Chemistry	

Department of Oceanography

Dr. John W. Morse Inorganic Chemistry	Dr. William Sager Geophysics

Principal Investigators Not at Texas A&M University

Dr. Samantha Joye University of Georgia Electrochemistry	Dr. Steven Macko University of Virginia Trophic Relationships	Dr. Douglas C. Nelson University of California, Davis Microbial Ecology
Dr. Robert Carney Louisiana State University Trophic Relationships	Dr. Paul Montagna The University of Texas at Austin Statistical Design	Dr. Eric Powell Rutgers University Histopathology and Community Health
Dr. Charles F. Fisher Pennsylvania State University Physiological Ecology	Dr. Kimberlyn Nelson Pennsylvania State University Molecular Ecology and Genetics	Dr. Steve Schaeffer Pennsylvania State University Molecular Ecology and Genetics

Scientific Review Board

Dr. James Barry Monterey Bay Aquarium Research Institute	Dr. Cindy Lee Van Dover University of Alaska	Dr. William W. Schroeder The University of Alabama

- The Annual Program Review and Cruise Planning Meeting was held in College Station during 13-15 March 1998.
- Submarine survey cruise 18-22 May 1998 (NR1-98). This opportunistic cruise aboard Navy Submarine NR1 deployed laser line-scan and high-resolution subbottom instruments for survey of the primary sites and suspected chemosynthetic communities identified during

TAMU^2-97 cruise. Mechanical failure by the NR1 curtailed the cruise after five days of operation, but much valuable data was collected during this time.

- Submersible sampling cruise 1-15 July 1998 (JSL-98). This cruise aboard R/V EDWIN LINK utilized the submersible Johnson Sea-Link I to collect samples from the four primary study sites. Sampling activities for the program expanded due to cooperative funding from the Naval Research Laboratory.

Progress descriptions by individual investigators detailed in the oral presentation indicate timely completion of contract obligations with few shortfalls and no problems which jeopardize the overall objectives of the program. If progress continues at the present rate, analysis of samples will be largely completed by the end of the first quarter of 1999.

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Ian R. MacDonald is an Associate Research Scientist at the Geochemical and Environmental Research Group of Texas A&M University. His primary research interest is the application of imaging and GIS techniques for marine ecology. He is the program manager for the Stability and Change in Gulf of Mexico Chemosynthetic Communities Program. MacDonald received a Ph.D. in oceanography in 1990 from Texas A&M University.

SESSION 1F

COASTAL STUDIES AND CHARACTERIZATION

Co-Chairs: Dr. Robert Rogers and Mr. Sam Holder

Date: December 9, 1998

Presentation	Author/Affiliation
Northeastern Gulf of Mexico Coastal and Marine Ecosystem Program: Coastal Characterization: An Overview and Update	Dr. James B. Johnston Mr. Lawrence R. Handley Mr. William R. Jones Mr. Steve Robb USGS, National Wetlands Research Center
Evaluation of Mitigation Activities Related to OCS Pipelines, Pipeline Canals, and Navigation Channels	Dr. Donald R. Cahoon USGS, National Wetlands Research Center Mr. John A. Bourgeois JCWS, National Wetlands Research Center
OCS Pipeline and Navigation Canal Habitat Change Study—Louisiana Document Not Submitted	Dr. James Johnston USGS, National Wetlands Research Center
Northeastern Gulf of Mexico Wetland and Seagrass Study Summary Document Not Submitted	Dr. James Johnston USGS, National Wetlands Research Center
Northeast Gulf of Mexico Habitat Mapping	Mr. Lawrence R. Handley USGS, National Wetlands Research Center
Development and Implementation of the Northeastern Gulf of Mexico Coastal Characterization and Data Information Management System and Data Transfer Computer Demonstration	Mr. William R. Jones Ms. Helena Schaefer USGS, National Wetlands Research Center

NORTHEASTERN GULF OF MEXICO COASTAL AND MARINE ECOSYSTEM PROGRAM: COASTAL CHARACTERIZATION: AN OVERVIEW AND UPDATE

Dr. James B. Johnston
Mr. Lawrence R. Handley
Mr. William R. Jones
Mr. Steve Robb
USGS, National Wetlands Research Center

INTRODUCTION

The U.S. Geological Surveys Biological Resources Division (BRD) mission is to provide leadership in gathering, analyzing, and disseminating biological information as support for sound management of the Nation's natural resources. Since becoming operational in October of 1996 through the transfer of programs from various bureaus within the Department of the Interior, the BRD, in cooperation with other Federal, State, and local partners, has begun research, inventory and monitoring, information sharing, and technology transfer. Through these activities, the BRD is fostering an understanding of biological systems and their benefits to society, and providing the essential scientific support and technical assistance required for management and policy decisions. The role of BRD's National Wetlands Research Center (NWRC) in Lafayette, Louisiana, with project offices in Baton Rouge, LA and Gulf Breeze, FL, is to provide leadership in research and development related to the Nation's natural resources for the Southeast. The research focuses on wetlands ecology, animal ecology, and the development and application of spatial analysis techniques for natural resource related studies.

Current geographic information system (GIS) technologies in use at NWRC are designed to provide natural resource managers with the on-line data and computerized techniques necessary to make informed decisions. Major GIS activities at NWRC include: compilation and analysis of digital databases for monitoring of natural resources; integration and transfer of databases with existing digital databases from various sources into a comprehensive GIS; and development of multifunctional decision support systems for natural resource managers using these data. NWRC is also an active participant in the National Information Infrastructure (NII), in particular the National Spatial Data Infrastructure (NSDI) and the National Biological Information Infrastructure (NBII), which will facilitate the dissemination of research results and other knowledge and information gained from these efforts. This summary and the three summaries that follow provides an overview and update of a four year study entitled, Northeastern Gulf of Mexico Coastal and Marine Ecosystem Program: Coastal Characterization.

OVERVIEW

The offshore oil and gas industry is developing oil and gas resources in the eastern Gulf of Mexico, a frontier area. The coastal area adjacent to the proposed development contains natural resources and socioeconomic infrastructures that may be affected by the proposed activities. During the mid 1970s to 1980s, available environmental and socioeconomic information pertaining to the Gulf of Mexico coastal habitats was synthesized for the Minerals Management Service in a series of Coastal Ecosystem Characterizations. The data bases for these characterizations are now 10 to 20 years old and are in need of being updated. For the proposed offshore oil and gas development to proceed in a timely manner, Federal, State, and local agency and private decision-makers need current information on coastal natural resource and processes and socioeconomic infrastructure upon which to base their decisions.

The Minerals Management Service (MMS), in response to the need for an integrated overview of coastal ecosystems, entered into a cooperative agreement with the, U.S. Geological Surveys National Wetlands Research Center (formally a part of the U.S. Fish and Wildlife Service) to prepare a series of Coastal Ecosystem Characterizations in areas of the Gulf of Mexico that might be effected by offshore oil and gas development. These characterizations compiled existing information and data by utilizing a holistic approach to identify functional relationships among natural processes and components of coastal ecosystems. The characterization approach is designed primarily to integrate environmental and socioeconomic data in a form useful for planning, impact assessment, and analysis, and to identify research needs. It is a tool that enables decision-makers to address problems including planning for urban and industrial developments, determining corridors for pipelines, siting of onshore and offshore facilities for OCS oil and gas activities and determining priorities for future research.

This Northeastern Gulf of Mexico (study) Coastal Characterization update includes the coastal areas of southeast Louisiana, Mississippi, Alabama, and the Florida panhandle and focuses on updating the data related to the previous characterizations of area. The existing characterizations (2), the Mississippi Delta Plain Region (southeastern Louisiana and Mississippi) and the Northeastern Gulf of Mexico Coast (Alabama and the Florida panhandle) are based on data that is now over 15 years old.

UPDATE

This update centers on the status of data collected for biological resources, socioeconomic features, and the data management aspects of efforts. Other papers in this session address wetlands, seagrasses, and live bottoms. Data searches in Mississippi, Alabama, and Florida are completed. The greatest number of datasets were in Florida. Over fifty were identified that have applicability to the Outer Continental Shelf oil and gas program. The Florida Game and Fresh Water Fish Commission and Florida Department of Environmental Protection were the leading contributors of data. For Mississippi, the Mississippi Automated Resource Information Service and Mississippi Department of Marine Resources supplied majority of data sets (20) with South Alabama Regional Planning Commission and the U.S. Fish and Wildlife Service for Alabama (12 datasets). NWRC is also completing Thematic Mapper (TM) satellite image backdrop for study area. For coastal erosion rates, there were no digital data so the updated (1989-1995) wetland maps and the 1979 and 1956 maps will be used to produce shoreline erosion data. Shellfish data was supplied by the National Oceanic and Atmospheric Administration Shellfish Program. By mid-1998, data set will be in a data dictionary housed on NWRCs Spatial Data and Metadata Server (*http://www.nwrc.gov/sdms*). The data will either be on the server or hot linked to agency who has data. Lastly, the wetlands and seagrass data will also be on server, as well as, live bottom report. Project is scheduled for completion in December 1998.

Dr. James B. Johnston serves as the Chief of Spatial (Habitat) Analysis at NWRC in Lafayette, Louisiana. Larry Handley serves as a Supervisory Geographer at NWRC. William Jones and Steve Robb are GIS Project Leaders at NWRCs Lafayette, Louisiana, and Gulf Breeze, Florida offices, respectively.

EVALUATION OF MITIGATION ACTIVITIES RELATED TO OCS PIPELINES, PIPELINE CANALS, AND NAVIGATION CHANNELS

Dr. Donald R. Cahoon
USGS, National Wetlands Research Center

Mr. John A. Bourgeois
JCWS, National Wetlands Research Center

The Minerals Management Service funded project "Coastal Wetland Impacts – OCS Canal Widening Rates and Effectiveness of OCS Pipeline Canal Mitigation" is entering its second year. This project's goal is to provide insights into improving the effectiveness of workable mitigation techniques and developing new mitigation techniques that can be used in regions where existing mitigation techniques have not been successful. This goal will be achieved from an assessment of (1) the types and severity of adverse impacts caused by OCS-related pipeline and canal projects and (2) the effectiveness of mitigation efforts to minimize or restore adverse impacts. Separate assessments will be conducted for the Western and Central Planning Areas of the Gulf of Mexico and for coastal barrier/beach dune and wetland habitats within each planning area, in order to compare habitat impacts/mitigation effectiveness in the different geomorphic settings typical of the northern Gulf of Mexico.

The primary tool for assessing impacts/mitigation effectiveness will be GIS analysis of historical aerial photography of select pipelines and navigation channels coupled with a literature review, interviews with agency and industry personnel, and ground-truthing. The project is coordinated through the Spatial Analysis and Wetlands Ecology Branches of the National Wetlands Research Center. The Gulf of Mexico study area has been divided into five (5) sampling subareas:

A. Western Planning Area Sampling Subareas
   1. Texas Barrier Islands
   2. Texas Chenier Plain

B. Central Planning Area Sampling Subareas
   1. Louisiana Chenier Plain
   2. Louisiana Deltaic Plain
   3. Mississippi/Alabama Coastal Plain

From each of these subareas, five (5) OCS pipelines and two (2) OCS navigation channels will be identified for detailed GIS analysis. For the selection of these pipelines and channels, several criteria must be taken into account. The first priority in the selection process is that the pipelines and navigation channels must be OCS related. Secondly, we are looking for pipelines that represent a variety of mitigation types and/or construction methods and that cross a variety of habitat types. Given this criteria, we can evaluate the effectiveness of the different mitigation types in relation to the typical geomorphic settings in the Gulf of Mexico.

METHODS AND RESULTS

Analysis of the typical rates of secondary impacts as well as the effectiveness of mitigation along OCS pipelines and navigation channels has occurred primarily through literature review, interviews, and permit acquisition. The information gathered to date has been in an attempt to make the best decision possible with regards to final selection of pipelines for GIS analysis. Impacts associated with OCS pipelines have come from review of literature and through interviews with agency personnel, private land owners and members of industry. The impacts of primary concern are the following:

Direct Impacts

- conversion of wetland habitat to open water and upland

Indirect Impacts

- changes in surface hydrology
- changes in groundwater hydrology
- changes in sedimentation patterns
- compacted marsh surface/flank subsidence
- erosion
- poor revegetation
- soil oxidation
- habitat degradation (esp. fisheries)
- acute disturbances during construction

We have acquired over 160 permits (section 10, section 404, CUP, ROW) representing over 75 pipelines in Louisiana alone. These permits provide most of the information on construction method as well as on the type of mitigation performed. The mitigation types most commonly found throughout the Gulf of Mexico are the following:

- backfilling
- bulkheads/plugs/etc.
- push-pull method
- directional drilling
- revegetation
- imported material
- double-ditching
- water control structures/marsh management

The analysis of the Mississippi/Alabama Coastal Plain will be completed easily, as these states have managed to avoid the majority of adverse impacts by consolidating pipeline landfalls into a very few corridors and by directionally drilling under the coastal wetlands. We have recently made the appropriate contacts with state officials in Texas and have initiated permit searches for that state. The majority of our effort has been spent in Louisiana, where we are ready to make final selection of pipelines pending some preliminary information from Texas so that we can be sure our analysis is representative of the habitats and mitigation types occurring throughout all subareas.

Dr. Donald R. Cahoon has worked for the past seven years as a Senior Research Ecologist at the U.S. Geological Survey, National Wetlands Research Center, in Lafayette, Louisiana. Over the past 16 years, he has worked in the wetland regulatory field and conducted research on wetland mitigation and restoration, and wetland sedimentation processes in coastal Louisiana as an employee of the Louisiana Department of Natural Resources, Louisiana State University, and USGS. Dr. Cahoon received his B. A. in botany from Drew University and his M.S. and Ph.D. in wetland plant ecology from the University of Maryland.

Mr. John A. Bourgeois has worked at the National Wetlands Research Center since September 1997 as a General Biologist II for Johnson Controls World Services. Prior to this, Mr. Bourgeois worked for the Louisiana Department of Natural Resources and the U.S. Forest Service. His primary interest lies in wetland restoration. He received a B.S. in biology from Tulane University and an M.S. in biology from the University of Southwestern Louisiana.

NORTHEAST GULF OF MEXICO HABITAT MAPPING

Mr. Larry Handley
USGS, National Wetlands Research Center

As part of the Northeast Gulf of Mexico Ecological Characterization Update, the National Wetlands Research Center (NWRC) was tasked with providing updated wetland and upland habitat maps at 1:24,000 scale for northeastern Gulf of Mexico to aid in the assessment of environmental impacts of permitting, construction of projects, and potential oil spills (Figure 1F.1). The National Wetlands Research Center and the National Wetlands Inventory had previously mapped coastal Mississippi for 1956 and 1978, coastal Alabama for 1956, 1978, and coastal Florida for 1956 and 1978 as parts of three ecological characterization projects of the early 1980's funded by the Minerals Management Service's forerunner, the Bureau of Land Management's Offshore Division. Coastal Alabama was mapped again using 1988 aerial photography as part of a project funded by the U.S. Fish and Wildlife Service, the Alabama Department of Economic and Community Affairs, and the EPA's Gulf of Mexico Program.

The Ecological Characterization Update targeted coastal areas along the northern Gulf of Mexico from the Chandeleur Islands of Louisiana to Cape San Blas, Florida. Color infrared aerial photography was acquired by NASA Ames Research Center at a scale of 1:65,000 for the area in February 1996. The NWRC has duplicated over 1,400 copies of these frames of photography, and, working with the University of Southwestern Louisiana' NASA Regional Application Center, has scanned the 189 frames of aerial photography for coastal Mississippi, 100 frames of the photography for

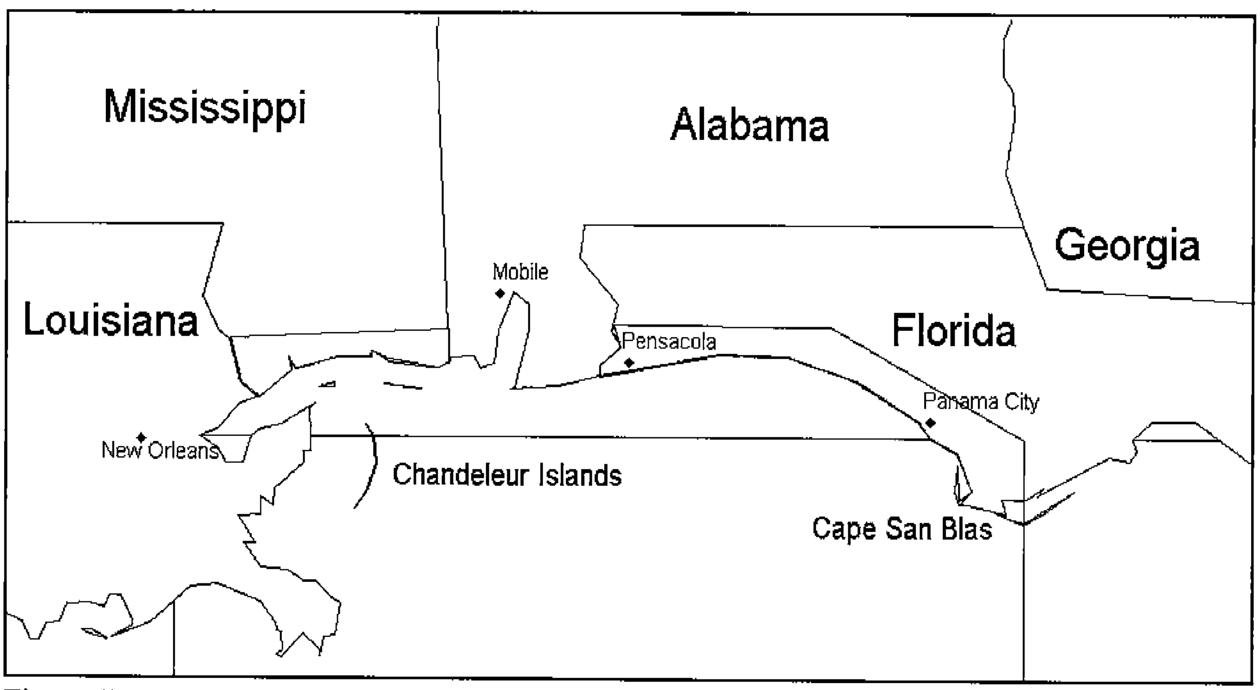

Figure 1F.1. Areas of 1996 Wetland Habitat Mapping Update.

coastal Alabama, and 160 frames for the Panhandle of Florida at 300 dots per inch and produced CD-ROMS for the Mississippi Department of Marine Resources and the U.S. Fish and Wildlife Service.

The original intent of the project was to map wetlands and uplands. However, the Minerals Management Service program was limited by the funding available and the cost of mapping. As a result, the 30 quads of coastal Alabama are not being mapped in this project; only wetlands are being mapped for the whole project area.

The wetland habitat database will eventually consist of 84 quads mapped at a scale of 1:24,000 covering the coastal habitats from Chandeleur Islands, Louisiana to Cape San Blas, Florida. The mapping protocol consists of data acquisition, stereoscopic photointerpretation, cartographic transfer, and digitization in accordance with nationally accepted mapping standards and conventions. Other important aspects of the project include the classification system, quality control, and peer review. Photointerpretation by NWRC and NWI has been completed for the project area, and draft maps have been produced. Groundtruthing for draft map review has been conducted for coastal Mississippi and Florida by NWRC and NWI personnel. Corrections have been made to the Florida Panhandle maps and they are being digitized with an expected completion by 1 January 1999. The Mississippi coastal draft maps are still being reviewed and corrected by NWI quality control and regional staff. Expected completion of the digital products for coastal Mississippi is 30 January 1999.

The mapping process follows standard operating procedures developed by the NWRC and the NWI. The photography is checked for quality, indexed, cut and prepped, and compiled by area (or estuary) into photo-packs. The photointerpretation phase consists of applying the classification system and the delineation of the habitats as they are viewed through a stereoscope. The information delineated on the photos is cartographically transferred to basemaps using a Zoom Transfer Scope. The base maps for the project are standard USGS 1:24,000 scale quadrangles. Work is checked throughout the process as part of quality control measures and cartographic integrity in accordance with nationally accepted map standards and conventions. The completed quads are tablet digitized. The digital data is maintained by quad (1:24,000) and available from NWRC in ArcInfo™ format.

The NWI classification system, *Classification of Wetlands and Deepwater Habitats of the United States*, Cowardin *et al.*, is being used to delineate the wetlands on the aerial photography. Review of the draft maps was performed with the assistance of the NWRC, NWI and staff from National Park Service-Gulf Islands National Seashore, U.S. Fish and Wildlife Service, Florida Department of Environmental Protection, and other state and federal field offices. Draft maps were distributed to staff of many public agencies, academia, and private individuals for peer review and comment.

The National Wetlands Research Center was originally tasked with mapping the distribution of seagrass habitat in the northern Gulf of Mexico as a result of a joint agreement with the Environmental Protection Agency (EPA). As part of the Environmental Monitoring and Assessment Program (EMAP), the mapping effort became an important baseline information component for a comprehensive estuarine resource assessment.

The original study targeted coastal areas along the Gulf of Mexico from Brownsville, Texas to Anclote Key, Florida. Following the initial aerial photographic data acquisition mission from Chandeleur Islands, Louisiana and points eastward along the gulf, EPA budget cuts and changes in project goals restricted the coverage to areas between Louisiana and Anclote Key, Florida. As a result, the available funding was not enough to include coastal Texas and Louisiana. Interests in seagrass maps and data the project would generate led to the Minerals Management Service and Florida Department of Environmental Protection to continue funding the mapping and digitizing. In addition, the project could not have been accomplished without the active participation of staff from a host of federal, state, and public entities, including the U.S. Fish and Wildlife Service, National Park Service, Dauphin Island Sea Lab, the National Marine Fisheries Service, and the Gulf Coast Research Lab.

Seagrass habitat communities are considered to be of significant ecological, environmental, and socioeconomical value. Urban development and natural impacts along the coast have produced changes in these habitats, underscoring the importance of comprehensive assessments and research. The seagrasses are distributed throughout a range of areas under a variety of ecological conditions. The habitats can be described as either continuous or patchy beds of varying species and densities. They are typically found in protected or low wave energy of relatively shallow waters, behind barrier islands, or estuaries with low turbidity. Seagrass beds are nursery habitat for a host of fish, microorganisms, and invertebrates. Seagrass is also an important food source for waterfowl. The Chandeleur Islands, located along a major migratory corridor for wintering duck populations, are characterized as having some of the most dense and productive seagrass beds remaining along the Gulf Coast. Seagrasses function as a water quality indicator since they show responses to pollutants, algal blooms, and other hydrologic events. Additionally, seagrasses reduce the erosion of valuable sediment by helping to stabilize substrates subject to tidal and/or wave energy. The most commonly found species of seagrasses present in the Northern Gulf of Mexico are *Halodule wrightii* (shoalgrass), *Thalassia testudinum* (turtlegrass), *Ruppia maritima* (widgeongrass), *Cymodocea filiformis* (manatee grass), and various macroalgae. The extent and distribution of seagrass habitats are critical for monitoring such a vital natural resource. Producing maps for different periods helps to understand trends and changes in estuarine ecosystems.

The seagrass habitat database consists of 149 quads mapped at a scale of 1:24,000 covering the coastal habitats from Chandeleur Islands, Louisiana to Anclote Key, Florida. The mapping protocol consists of data acquisition, stereoscopic photointerpretation, cartographic transfer, and digitization in accordance with nationally accepted mapping standards and conventions. Other important aspects of the protocol include the development of a classification system, quality control, and peer review. To date, final maps have been completed for Chandeleur Islands to St. Joseph Bay, Florida (Cape San Blas). Photointerpretation, map drafting, and groundtruthing are currently in progress for Apalachicola Bay through Anclote Keys, Florida. Digital data - ArcInfo™ format - is available for Chandeleur Islands through St. Andrew Bay, Florida.

The process begins with the acquisition of large scale aerial photography from which the seagrass habitats can be determined. Natural color emulsion, 1:24,000 scale, flown by NASA-Stennis in 1992 (June and November) is the primary data source. The photography is checked for quality, indexed, cut and prepped, and compiled by area (or estuary) into photo-packs. In most cases, only quads for areas where seagrass is detectable on the aerial photography have been mapped. The photointerpretation phase consists of development of a classification system and the delineation of the habitats as they are viewed through a stereoscope. The information delineated on the photos is cartographically transferred to basemaps using a Zoom Transfer Scope. Work is checked throughout the process as part of quality control measures and cartographic integrity in accordance with nationally accepted map standards and conventions. The completed quads are tablet digitized. The digital data is maintained by quad (1:24k) and available from NWRC in ArcInfo™ format.

The classification system was designed to indicate the presence of either continuous or patchy seagrass. In addition, the shoreline is delineated distinguishing land from either water or seagrass. Land can be defined as any upland, irregularly flooded habitat, or the extent of vegetated (non-seagrass) cover. There are two classes of open water: RIV (riverine, fresh water) and EST (estuarine or marine open water), and five classes of seagrass habitats. In the seagrass category, there are four classes of patchy habitat based on percent ground cover (grass patch versus bare ground), ranging from very sparse to dense: PSG1 (up to 10%—very sparse), PSG2 (15-40%—sparse), PSG3 (45-70%—moderate), and PSG4 (75-95%—dense); and one class of continuous seagrass habitat, CSG (95 to 100% cover). No seagrass density distinction was made in the continuous class. Macroalgae (ALG) was delineated only in those cases where field verification of seagrass habitat resulted in the identification of algae.

Groundtruthing was performed throughout the mapping process. It included the participation of field staff from National Park Service-Gulf Islands National Seashore, U.S. Fish and Wildlife Service, Dauphin Island Sea Lab consortium, Florida Department of Environmental Protection, and other state and federal field offices. Draft maps were distributed to project sponsors and to staff of many public agencies, academia, and private individuals for review. Any comments were evaluated and corrections made to the maps. Final maps were produced in August and September 1998. Digitizing was completed in October 1998. The digital data has been delivered to the Florida Department of Environmental Protection's Marine Research Institute for inclusion in the MMS sponsored Gulf-wide Information System, and is available through the data server at the National Wetlands Research Center.

DEVELOPMENT AND IMPLEMENTATION OF THE NORTHEASTERN GULF OF MEXICO COASTAL CHARACTERIZATION AND DATA INFORMATION MANAGEMENT SYSTEM AND DATA TRANSFER COMPUTER DEMONSTRATION

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In the 1980's, as oil and gas leasing was increasing, two characterization studies were conducted along the northeastern Gulf of Mexico and the Mississippi Deltaic Plain to identify natural resources and socioeconomic infrastructures that may be affected by proposed oil and gas activities. The studies involved the collection, creation, and organization of data sets that identify sensitive areas that could be threatened in the event of a catastrophic occurrence. The National Wetlands Research Center is updating these two studies with the Northeastern Gulf of Mexico Coastal and Marine Ecosystem Program: Coastal Characterization study. The area is defined as the region from the Chandeleur Islands of Louisiana to Apalachicola Bay, Florida, which includes all coastal counties/parishes and extends offshore to the federal leasing boundary. The project involved the collection, organization, and analysis of existing databases, the creation of new data, and updating of old data sets. The primary focus of the current characterization is on updating the two previous characterization studies for this particular area, the Mississippi Deltaic Plain Region and the Northeastern Gulf of Mexico Coast. This collection of data sets will facilitate the understanding of this ecosystem's functioning role, especially those areas sensitive to environmental impacts from the outer continental shelf oil and gas development.

The study had two primary objectives: developing an electronically accessible database, and creating a live bottom "Community Profile." The first objective has resulted in the creation of Northeastern Gulf of Mexico Coastal Characterization and Data Information Management System. The primary focus of this system is to organize and disseminate the aforementioned data sets. This would allow users from federal, private, state, local, and other sources to access, manipulate, and use the data and information. The data sets have been and will be collected and incorporated into a digital database that can be integrated into a functional GIS in the future. The second objective was to create a live bottom community profile for the region. The report was contracted to Continental Shelf Associates, Inc, and will be available online through the data transfer system.

To meet the data transfer objective, the existing data sets first had to be located. The National Wetlands Research Center contracted two U.S. Fish and Wildlife Service Ecological Service field offices (Daphne, Alabama, and Panama City, Florida) to assist in the gathering of information on known data sets; personnel from these two field offices searched for existing databases via the Internet, or had familiarity of nondigital databases for the region. Habitat databases housed at NWRC were assessed and updated, and a submerged aquatic vegetation database was developed. Metadata for these existing and new data sets are being developed, following the standards set forth by the Federal Geographic Data Committee. Existing data sets were analyzed to ensure adherence to procedures set forth by Executive Order 12906, "Coordinating Geographic Data Acquisition and

Access: The National Spatial Data Infrastructure." As data sets were located, the process of developing a data dictionary was initialized. The data dictionary is a brief synopsis of a data set; the dictionary includes the name of the data set, a brief description, geographic reference (name of or coordinates), date of, format type, size of file, source of data, and a link to the data set (via the Internet). Within the brief description, a link to the metadata may have been created, allowing access to more information about the data set. This data dictionary was then formatted onto a website, which is broken into three categories: habitat and submerged aquatic vegetation, natural resources and socioeconomic features, and the live bottom community profile. The development of the website will make the databases accessible to users who have an interest and concern for the gulf coast region.

As of December 1998, NWRC has produced a user-friendly website that includes a data dictionary, containing relative information for over 250 data sets. The beta version webpages are not yet available on-line and are in the stages of quality control and refinement. Information about other data sets will be added in the future as those data sets are developed, located, or converted into a digital format. Additions to the data dictionary can be made simply by modifying the existing web pages. Links to the actual data sets will be maintained to assure consistent accessibility.

In conclusion, the goals of data transfer system's objectives for the Northeastern Gulf of Mexico Coastal and Marine Ecosystem Program are being achieved. An electronically accessible database was created, consisting of a basic data dictionary about the known data sets. The approximate number of data sets found for the region was 250. Links to digital databases for the region were created, making data sharing and dissemination easier. Maintaining the links and searching for unknown data sets remain priorities for the completion of the study.

William Jones has worked at the National Wetlands Research Center (NWRC) for eight years, serving as a Geographer/GIS Specialist. Mr. Jones received his B.A. in geography from the University of Southern Mississippi. He has extensive experience with GIS software and coordinates and manages GIS activities. Current projects include habitat mapping for the Coastal Wetlands Planning, Protection, and Restoration Act Program and the submerged aquatic vegetation mapping of the Northeastern Gulf of Mexico.

Helena Schaefer has worked at the NWRC for over four years, as a Geographer. Ms. Schaefer received her B.A. in geography from the University of Texas at San Antonio. Current projects involve serving as spatial data manager, metadata coordinator, and web designer of the NWRC's Spatial Data and Metadata server.

SESSION 2E

GULFCET II—MMS/BRD OFFSHORE INVESTIGATIONS OF MARINE MAMMALS, SEA TURTLES, AND SEABIRDS IN THE GULF OF MEXICO

Co-Chairs: Dr. Robert M. Avent and Dr. Gary Brewer

Date: December 9, 1998

Presentation	Author/Affiliation
Introduction to the GulfCet Program: Study Background, Philosophy, Research Elements, and Design	Dr. William E. Evans Dr. Randall W. Davis Texas A&M University at Galveston
Cetacean Habitat Associations in the Northern Gulf of Mexico: An Overview	Dr. William E. Evans Dr. Bernd Würsig Mr. Joel Ortega-Ortiz Dr. Randall W. Davis. Texas A&M University at Galveston
Environmental Patterns and Oceanographic Processes during GulfCet II	Dr. D. C. Biggs Texas A&M University Dr. R. R. Leben University of Colorado
Biological Oceanography and Trophic Investigations in the Eastern Gulf of Mexico Document Not Submitted	Dr. John Wormuth Texas A & M University
Abundance and Distribution of Cetaceans and Sea Turtles in the Northern Gulf of Mexico from GulfCet II Surveys	Dr. Keith D. Mullin Mr. Wayne Hoggard Southeast Fisheries Science Center National Marine Fisheries Service, NOAA
GulfCet II Acoustic Survey	Dr. Jeffrey C. Norris Dr. William E. Evans Ms. Shannon Rankin Marine Acoustics Lab Texas A&M University at Galveston
Seabird Distribution and Habitat in the Northern Gulf of Mexico	Ms. Nancy Hess Dr. Christine Ribic University of Wisconsin, Madison

INTRODUCTION TO THE GULFCET PROGRAM: STUDY BACKGROUND, PHILOSOPHY, RESEARCH ELEMENTS, AND DESIGN

Dr. William E. Evans
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BACKGROUND

The U.S. Department of the Interior's Minerals Management Service (MMS) is a client agency of the BRD. The MMS has the responsibility for leasing, minerals exploration, and development of submerged federal lands on the U.S. Outer Continental Shelf (OCS) under the provisions of the OCS Lands Act Amendments of 1978 (92 Stat. 629). The National Environmental Policy Act of 1969 requires that all Federal Agencies use a systematic interdisciplinary approach that will ensure the integrated use of the natural and social sciences in any planning and decision making that may have an effect on the human environment.

As the Department of the Interior's bureau tasked with providing the scientific understanding and technologies needed to support sound management and conservation of the Nation's biological resources, the BRD administers this study.

The Endangered Species Act (ESA) of 1973, as amended, provides for the conservation of endangered or threatened animal and plant species. The act requires that major federal actions do not jeopardize the continued existence of listed species or result in the destruction or modification of habitats determined to be critical. It also requires interagency consultation regarding the potential effects of proposed activities on protected species in the northern Gulf of Mexico.

The Marine Mammal Protection Act (MMPA) of 1972, as amended, recognizes that certain species and populations of marine mammals are, or may be, in danger of extinction or depletion as a result of human activities, and establishes a national policy that marine mammal populations should be protected and encouraged to develop to the greatest extent feasible, commensurate with sound policies of resource management. The Secretaries of the Departments of the Interior and Commerce are charged with all responsibility, authority, funding, and duties under the ESA and MMPA.

CETACEAN SURVEYS OF THE NORTHERN GULF PRIOR TO 1991

There are several sources of information on the distribution, abundance, and diversity of cetaceans in the Gulf of Mexico (for a review see Jefferson and Shiro 1997). Cetacean stranding information has been systematically collected since the late 1970's. A considerable amount of research has been conducted on localized populations of bottlenose dolphins (Shane *et al.* 1986; Scott and Hansen 1989; Leatherwood and Reeves 1990). In U.S. Gulf of Mexico waters less than 200 m deep, bottlenose dolphins and Atlantic spotted dolphins appear to be the most abundant cetacean species.

Other directed studies, historic whaling records, animal strandings, and opportunistic sightings have expanded the list of cetacean species known to occur in the Gulf (Jefferson and Shiro 1997).

Until recently, relatively little was known about cetaceans inhabiting deeper waters of the Gulf of Mexico. From July 1989 through June 1990, NMFS conducted aerial surveys of cetaceans along the continental slope of the north-central Gulf of Mexico in water ranging from 180-1,800 m deep (Mullin *et al.* 1991; Mullin *et al.* 1994). The objectives were to: (1) examine cetacean species diversity in the region, (2) determine the temporal and spatial distribution of cetaceans, and (3) estimate relative abundance. Over 7,000 dolphins and whales were counted during 320 sightings. Ranked from most to least commonly sighted groups, with percentage of total sightings, these were (1) Risso's dolphins, 22%; sperm whales, 16%; bottlenose dolphins, 14%; Atlantic spotted dolphins, 13%; dwarf/pygmy sperm whales, 12%; striped/spinner/clymene dolphins, 9%; pantropical spotted dolphins, 8%; beaked whales, 3%; and short-finned pilot whales, 2%. The remaining 2% of group sightings were comprised of melon-headed/pygmy killer whales, false-killer whales, killer whales, rough-toothed dolphins, a fin whale and a Bryde's/sei whale. Average sighting rate for the entire study was 1.6 sightings per 100 transect km. Cetacean species had a wide spatial and temporal distribution on the upper continental slope. Six species were sighted in every season (summer, fall, winter, and spring) and two additional species were sighted in each season but winter. Twelve species were sighted in summer, 10 in spring and fall, and only six in winter. Except for the short-finned pilot whale, all species sighted more than once were sighted throughout the length (east-west) of the study area. Sperm whales were found throughout the study area, but were concentrated in the region near the Mississippi River delta.

THE GULFCET I PROGRAM: HOW MANY AND WHERE ARE THEY?

The most extensive survey of cetaceans in the offshore waters (100 to 2,000 m deep) of the north-central and western Gulf of Mexico was conducted jointly by Texas A&M University and the NMFS, Southeast Fisheries Science Center beginning in 1992 and called the GulfCet I Program (Davis and Fargion 1996). This three year study provided synoptic information on the distribution and abundance of cetaceans using both visual and acoustic survey techniques. It also provided limited information on habitat preference.

During shipboard visual Surveys a total of 21,350 km of transect was visually surveyed during the GulfCet I shipboard surveys. The cumulative survey effort for each season was: spring = 13,507 km; summer = 2,085 km; fall = 1,275 km; and winter = 4,483 km. It should be noted that oceanographically there are only two seasons in the Gulf of Mexico, summer and winter. The spring, summer and fall cruises are actually early, mid and late summer. The number of on-effort sightings each season ranged from 14 during late summer to 509 during early summer. Nineteen cetacean species were identified during 683 sightings made on-effort. Most of the survey effort occurred during the early summer, with the least effort during the late summer

The bottlenose dolphin, pantropical spotted dolphin, and sperm whale were the most commonly sighted species; each was sighted more than 70 times. Risso's dolphin, clymene dolphin, dwarf sperm whale, striped dolphin, and unidentified ziphiids were each sighted 21- 44 times, with the other species sighted fewer than 20 times. Average group sizes ranged from 1.2 for pygmy sperm whales and Cuvier's beaked whale to 141 for melon-headed whales. The estimated minimum abundance of cetaceans in the GulfCet I study area was 19,198 (coefficient of variation [CV]= 0.12) animals.

Shipboard acoustic surveys were conducted concurrently with the visual surveys. A total of 12,219 km and 1,055 hours of acoustic effort was completed. On-effort acoustic sampling occurred 95% of the time. A total of 487 acoustic contacts were recorded. Of that number, 124 contacts were from 12 identified species. Sperm whales were the most commonly recorded species, accounting for 56% of identified contacts. The most commonly recorded small cetacean was the pantropical spotted dolphin, with 22 contacts. A single recording of an unidentified baleen whale was made, probably a sei or Bryde's whale, based on its spectral characteristics. An additional 331 contacts were made of unidentified dolphins at times when there was no visual effort, such as during poor weather and at night. There were 30 contacts with unidentified cetaceans. These were typically pulsed signals that did not sound like sperm whales or dolphins and were possibly either dwarf/pygmy sperm whales or beaked whales. Also recorded were 19 unidentified biological contacts, probably shrimp. Approximately half of the species expected to occur in the Gulf as determined by Jefferson and Shiro (1997) were recorded, including the rarely recorded clymene and rough-toothed dolphins as well as the first recording ever of Fraser's dolphin (Leatherwood *et al.* 1993).

A total of 67 sperm whale on-effort, acoustic contacts were recorded along 85 transect lines. Assuming 7.3 individuals per group, the overall corrected mean sperm whale density was 2.041 individuals/1,000 km^2 (SD = 2.38, n = 85).. Within the 154,621 km^2 study area, the total estimated population of sperm whales is 316 individuals (265-377). On average, one sperm whale group was detected every 161 km.

A total of 369 dolphin on-effort, acoustic contacts were made along the same 85 transect lines used to estimate sperm whale abundance. On average, one dolphin group was detected every 31 km. The mean dolphin contact density was 1,298 groups in the study area. Using a weighted mean of 28.3 animals/group, the overall mean dolphin density was 229 dolphins/1,000 km^2. The total estimated dolphin population within the study area was 36,760 animals (30,835-43,821).

A total of 49,960 km of aerial survey transect was visually sampled during eight aerial surveys. The transect kilometers sampled by survey ranged from 5,330-6,592 km, and by season from 11,756-12,942 km. In total, 351 cetacean groups were sighted on-effort. The number of sightings each survey ranged from 24 to 61 for fall 1992 and winter 1994, respectively. By season the number of sightings ranged from 49 to 109 for late summer and winter, respectively.

At least 17 cetacean species were identified during aerial surveys (each of these species was also sighted during ship surveys). Seasonally, the number of species sighted ranged from 11 in the fall to 15 in winter. Eight species were identified in all four seasons, two in three seasons, four in two seasons and four in only one season. Five species, which were each sighted 20 or more times, accounted for 71% of the identified sightings: bottlenose dolphins, pantropical spotted dolphins, Risso's dolphins, pygmy/dwarf sperm whales, and sperm whales.

Overall, there were an estimated 16,986 (CV = 0.14) cetaceans in the GulfCet I aerial survey study area. There were an estimated 12,690 (CV = 0.23) cetaceans the first year and 20,669 (CV = 0.18) the second. Most of the difference between years resulted from two winter and the two spring estimates. In both cases, the point estimates were about twice as large the second year compared to the first. Cetacean abundance was about the same in winter (21,894; CV = 0.27) and spring (19,215; CV = 0.25), a little less in summer (14,959; CV = 0.24), but two to three times lower in the fall (6,051; CV = 0.32).

Pantropical spotted dolphins were the most abundant species in the aerial survey study area (5,251; CV = 0.22) followed by melon-headed whales (2,980; CV = 0.60), bottlenose dolphins (2,890; CV = 0.20) and Risso's dolphins (1,214; CV = 0.24). The sperm whale population was estimated to be 87 (CV = 0.27) and pygmy/dwarf sperm whales, 176 (CV = 0.31). All the other delphinid species were represented by less than 1,000 individuals each, and balaenopterids and ziphiids, by less than 100 individuals each. Mean group sizes ranged from 315 for melon-headed whales to less than four for pygmy/dwarf sperm whales, sperm whales and ziphiids.

The GulfCet I Program provided limited information on habitat preference, which showed the strongest correlation of species distribution with ocean depth. However, this study failed to establish strong correlation with other oceanographic variables such as sea surface temperature, salinity, water column structure and distinctive features such as warm-core and cold-core eddies. This may have resulted from the fact that: (1) the oceanography of the Gulf of Mexico is very dynamic with the periodic intrusion of the Loop Current from the southeast and the formation of warm-core eddies that move across the northern Gulf and (2) cetaceans are large, warm-blooded mammals whose wide-ranging movements are not physiologically constrained by water temperature or other hydrographic features.

GULFCET II: OCEANOGRAPHIC AND BIOLOGICAL CORRELATES TO DISTRIBUTION

In the GulfCet II program, we continued our studies of cetaceans in the northern Gulf of Mexico to determine their seasonal and geographic distribution in areas potentially affected by oil and gas activities now or in the future. This program included systematic aerial surveys and shipboard visual and acoustic surveys to document cetacean, sea bird and sea turtle populations. This work was accompanied by data acquisition designed to further characterize habitat and reveal cetacean-habitat associations. This study was intended as an areal and temporal extension of the GulfCet I Program. The study area included the entire continental slope of the northern Gulf of Mexico (i.e., the continental slope north of 26° N latitude) between the 100 and 2,000 m isobaths and was extended into the MMS Eastern Planning area. The specific objectives of the study were to

1. Obtain data on temporal and spatial patterns of distribution and minimum abundance of cetaceans and sea birds using visual line-transect and cetaceans using acoustic survey techniques directly comparable to those used in previous surveys. This included incidental sightings of sea turtles.

2. Identify possible associations between cetacean and sea bird high-use habitats and the ocean environment, and attempt to explain any relationships which appear to be important to their distributions.

Objective 1 was a continuation of surveys in the north-central and western Gulf that began during the GulfCet I program and extended into MMS's Eastern Planning Area. To accomplish this objective, we conducted aerial surveys and simultaneous shipboard visual and acoustic surveys using line-transect methods. We hypothesized that cetaceans and possibly birds and sea turtles were non-uniformly distributed (which we confirmed during GulfCet I) and that their distributions were related to variability in prey availability and physical oceanographic features in the marine environment.

To characterize habitat (Objective 2), we used a multidisciplinary approach and included physical features (i.e., sea surface temperature, ocean depth, oceanographic features such as warm-core and cold-core eddies, bottom topography) as well as biological features such as prey availability. We hypothesized that the distribution and abundance of marine mammals in the northern Gulf of Mexico were positively correlated with spatial and temporal variations in regional food stocks of zooplankton and micronekton. These food stocks are concentrated in nutrient-rich areas offshore from the Mississippi River, within cold-core eddies, or along the edge of warm-core eddies. To test this hypothesis we conducted focal cruises designed to transect the main oceanographic feature off of the mouth of the Mississippi River. These features were detected near real time using TOPEX/Poseidon radar altimetry images to detect cold core eddies or cyclones and warm core eddies (anticyclones). In addition to the standard visual and acoustic survey techniques used in GulfCet I, we collected synoptic data on several oceanographic features measuring salinity and temperature as a function of depth, measures of biomass using acoustic backscatter from the Acoustic Doppler Current Profiler and standard net tows using a Isaacs-Kidd midwater trawl (IKMT) with a mouth area of 6 m^2 and two multiple opening and closing nekton environmental sampling system (MOCNESS), one with mouth area of $4m^2$ and one with $1m^2$.

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Dr. Randall Davis is a Professor in the Departments of Wildlife and Fisheries Sciences and Marine Biology at Texas A & M University. He has served as GulfCet II Program Manager and co-PI for the GulfCet II program. He received his Ph.D. in physiology from the University of California, San Diego in 1980.

CETACEAN HABITAT ASSOCIATIONS IN THE NORTHERN GULF OF MEXICO: AN OVERVIEW

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Objectives of the GulfCet program were to identify possible associations between cetacean high-use habitats and the ocean environment, and thereby explain relationships that appear to be important in cetacean distribution. To accomplish this objective, cetacean distribution data gathered on 14 surveys in the northern Gulf of Mexico were compared with oceanographic features as identified from shipboard and remote sensing data.

During GulfCet I, from 1992-1994, 11 cruises were conducted in the northwestern and northcentral Gulf of Mexico. GulfCet II, from 1996-1997, included four cruises in the northeast Gulf of Mexico. The cruises were conducted by Texas A & M University (TAMU) and the National Marine Fisheries Service-Southeast Fisheries Sciences Center (NMFS-SEFSC).

During these cruises, line transect data were collected by observers using 25 X 150 "Big Eye" binoculars mounted on the ship's flying bridge. Effort was conducted during daylight hours, weather permitting (i.e., no rain, Beaufort Sea State < 5), using standard vessel survey data collection methods for cetaceans (Buckland *et al.* 1993). Vessel speed was usually 15 km/hr but varied with sea conditions.

The surveyed area was divided into six categories depending on oceanographic features: anticyclone, anticyclone edge, cyclone, cyclone edge, confluence, and other. The method used to delimit the oceanographic features varied by cruise. For GulfCet I TAMU cruises, the features were identified using sea surface height anomaly (SSH anomaly) computed from satellite data by the Center for Astrophysics Research –University of Colorado. SSH anomaly > 10 cm was considered as an anticyclone, SSH anomaly < -10 cm was considered as a cyclone. No confluence areas were identified for these cruises, and any area not labeled as anticyclone or cyclone was considered as "other." The features for the GulfCet I NMFS cruises were determined using the same criteria described above, as well as depth of the 15°C isotherm obtained from Conductivity-Temperature-Depth (CTD) casts and expendable bathythermograph (XBT) data registered from the ship. The SSH anomaly estimated from satellite data is not as accurate for the northeastern as it is for the north central and northwestern Gulf of Mexico. It reflects the spatially variable position of the Loop Current, as well as the variable position of the cyclone-anticyclone modon pairs frequently found in association. The temporal and spatial variability in the geographic locations of both make it problematic to assign a single SSH model mean to the northeastern Gulf. As a consequence, the use of the 15°C isotherm was necessary during cruises where surveys were conducted in the northeast Gulf of Mexico.

The features for GulfCet II cruises were determined using dynamic height relative to 800 m depth estimated from shipboard-collected CTD and XBT data. For the Gyre 96G06 (October 1996) cruise, any area with dynamic height < 100 dynamic centimeters (dyn cm) was considered as a cyclone. The areas with dynamic height > 125 dyn cm were considered as anticyclone. An area of confluence was observed between the cyclone-anticyclone pair (26.2-26.6° N Lat. by 86.5-87.5° W Long.).
For the Gyre 97G08 (August 1997) cruise, the cyclone was defined as < 105 dyn cm and the anticyclone as > 130 dyn cm. A confluence area was observed from 26.9-27.9° N Lat. by 86.3-87.8° W Long.

A more detailed explanation of the oceanographic processes and features present in the area during the GulfCet II cruises is included in the abstract by Biggs and Leben for these proceedings.

The edges of both anticyclone and cyclone were determined using the magnitude and direction of geostrophic velocity. Any area located within the anticyclone or cyclone dynamic height boundaries, with a geostrophic velocity > 45 cm/sec was considered as an edge. The areas between features with geostrophic velocities > 45 cm/sec were considered as confluence. Any area that could not be placed in any of the previous features was considered as "other."

To compare the presence/absence of cetaceans in the different oceanographic features of the study area, transect effort was divided into 18.52 km-long (10 nautical mile) units named effort-bins. If, during the division of the transect effort, the last bin of a transect line was less than 9.25 km, it was added to the previous bin. If it was greater than 9.25 km, it was considered as a separate bin. A total of 3,779 effort-bins were obtained from the transect effort of 14 cruises. The mean effort-bin length was 16.6 km and the standard deviation was 5.61. Each bin was assigned to a particular oceanographic feature.

Sightings registered during transect effort were assigned to their corresponding effort-bin, and binary variables were created to register the presence or absence of sightings within each bin for the following species or groups of species:

- CETACEAN – any species
- SPERM WHALE – *Physeter macrocephalus*
- STENELLAS – Oceanic dolphins of the genus *Stenella*: *S. attenuata, S. clymene, S. coeruleoalba, and S. longirostris*

Most species of cetaceans of the Gulf of Mexico occur in water deeper than 200 m, with the exception of Atlantic spotted dolphins and bottlenose dolphins, which inhabit the continental shelf (Mullin *et al.* 1994, Davis *et al.* 1998). For this reason, only the offshore effort-bins (n = 1985) were used for habitat association analyses.

Chi-squared analyses were used to test the hypothesis that the presence or absence of cetaceans was independent from depth regions or oceanographic features in the study area. Friedman-Tukey deviates were calculated to determine cells contributing significantly to the chi-squared values. The results of the significant tests ($p<0.05$) are discussed below.

Sightings of cetaceans were not independent from depth regions. Presence of cetaceans was higher than expected over the upper shelf and lower than expected over the abyssal region.

Presence of cetaceans was not independent from the six oceanographic features.
Cetaceans were sighted more frequently than expected in the cyclone, and less frequently than expected in the anticyclone.

Oceanic *Stenella* presence was higher than expected in the cyclone and cyclone edge, and less than expected in the anticyclone and "other."

The presence of sperm whales was also not independent from the six oceanographic features. Sperm whales were seen more often than expected in the edge of the anticyclone and less often than expected in the anticyclone and edge of the cyclone.

Our MMS/NBS sponsored study has given us the opportunity to compare cetacean occurrence and highly detailed oceanographic information from a large database of 14 ship-based surveys. We conclude that cetaceans are not randomly distributed in the northern Gulf of Mexico; they are influenced both by bottom depth and by the presence of mesoscale hydrographic features. Cetaceans tend to be associated with cyclonic features and the areas of confluence between cyclone-anticyclone pairs.

An important step for the future is to link knowledge of cetacean occurrence and movement patterns with detailed oceanographic studies. This can be accomplished by photoidentification and satellite telemetry, for example; and will provide information on habitat partitioning by species and species groups.

ACKNOWLEDGMENTS

We are grateful to the many volunteer observers who participated in the TAMU surveys. We thank Dr. Keith Mullin for providing the data from NMFS cruises, Dr. Douglas Biggs and Mr. Patrick Ressler for providing the shipboard oceanographic data for GulfCet II cruises, Dr. Robert Leben and Joshua Rigler for providing the satellite SSH data, and Dr. Christine Ribic and Ms. Nancy Hess for their advice on the statistical analyses. This ongoing research is supported by the USGS Biological Resources Division and by the US Minerals Management Service under USGS BRD contract 1445-C109-96-004 to Texas A & M.

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ENVIRONMENTAL PATTERNS AND OCEANOGRAPHIC PROCESSES DURING GULFCET II

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Four cruises of R/V *Oregon-II* and R/V *Gyre* were combined with tandem remote sensing of sea surface height using the Topex/Poseidon and ERS-2 altimeters to characterize the hydrographic regime of the northeast Gulf of Mexico for the GulfCet II program. In May-June 1996, October 1996, May-June 1997, and August 1997, the two ships dropped 560 expendable bathythermographs (XBTs) which profiled the temperature structure of the upper 760 m. These XBT stations were supplemented with conductivity-temperature-depth (CTD) and bottle stations, at 32 additional locations. The spatial distribution of the stations is summarized cruise-by-cruise in Figure 2E.1. The early summer cruises focused their survey work between 89° W and 85° W, from water depths of 100 m to 1,000 m, because this region of the continental slope is the region which MMS has designated its "Eastern Planning Area." The cruises later in the summer also surveyed this region of the slope, but in addition they surveyed farther seaward, within a deepwater "focal area" where altimetry data that were processed in near real-time at the University of Colorado Center for Astrodynamics Research (CCAR) indicated there was a "modon" circulation pair consisting of a mesoscale cold-core eddy (cyclone) and a warm-core eddy (anticyclone).

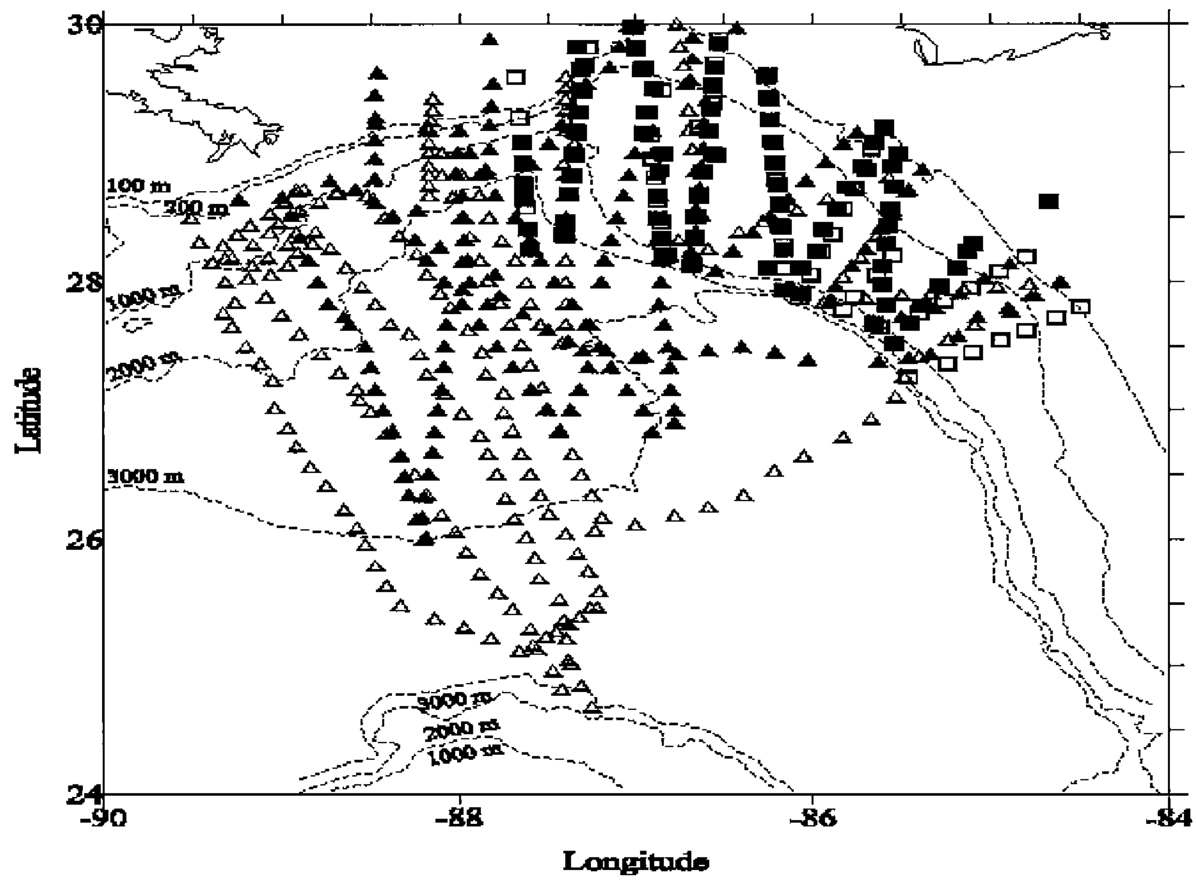

Figure 2E.1. Location of hydrographic stations made by R/V *Gyre* and R/V *Oregon-II* during four GulfCet II cruises that surveyed the NE Gulf of Mexico in early and late summer 1996 and early and mid summer 1997.

The altimetry data show that a broad area of cyclonic circulation was located in the NE Gulf throughout calendar year 1996. This showed up in weekly and monthly altimetry maps as a region of consistently negative sea surface height anomaly (SSH), depressed 20 cm or more relative to the climatological mean surface. This cold-core feature was seen January through September in the region 27-29° N, 88-84° W, even though for much of the year, the northern edge of the Loop Current extended north of 25° N and even though the Loop Current shed two large anticyclonic eddies during 1996. By October, the cyclone was centered 27-28° N, 87-89° W, roughly halfway between the Mississippi River delta and the NW edge of Loop Current Eddy C. The late summer dynamic topography of this cyclone- anticyclone eddy pair, as determined from ship survey lines, is shown in Figure 2E.2. The 62 dynamic cm difference in height between the interior of the cyclone

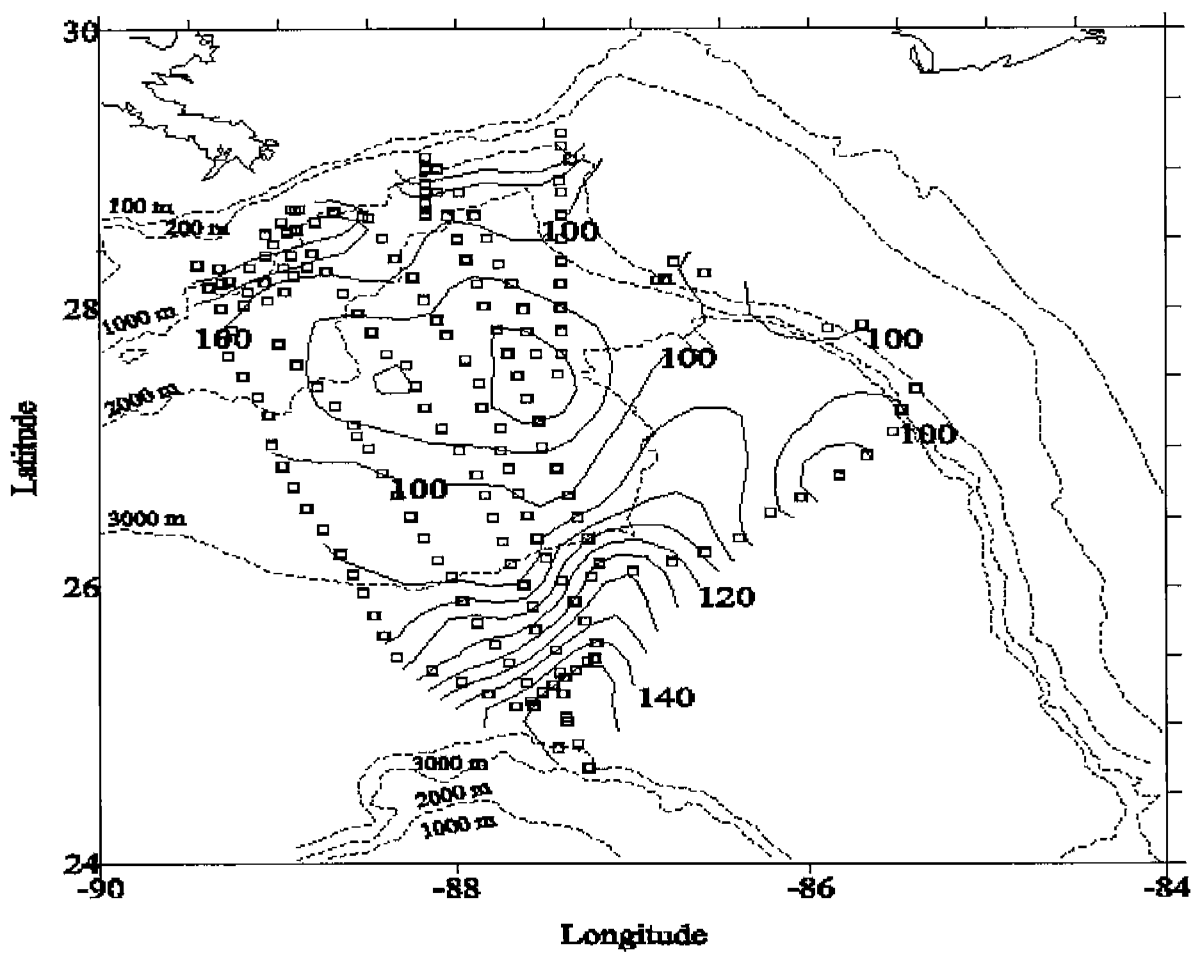

Figure 2E.2. Dynamic topography (cm, 0 m to 800 m) of the deepwater focal area, as determined from 152 hydrographic stations made on R/V *Gyre* cruise 96G-06.

(88 dyn cm) and anticyclone (150 dyn cm) was manifest as a flow confluence between the two features in which upper layer geostrophic volume transport was 24 x 10^6 m^3 s^{-1} (24 Sverdrups).

In mid-summer 1997, R/V *Gyre* cruise 97G-08 surveyed another deepwater cyclone-anticyclone pair. This time, the cyclone was centered over the DeSoto Canyon and to the NE of Loop Current Eddy E. The dynamic topography, as determined from ship survey lines, is shown in Figure 2E.3. The 84 dynamic cm difference in height between the interior of the cyclone (92 dyn cm) and anticyclone (176 dyn cm) was manifest as a flow confluence between the two features in which upper layer geostrophic volume transport was 31 x 10^6 m^3 s^{-1} (31 Sverdrups). Underway sampling of surface temperature, salinity, and chlorophyll concentrations while the vessel criss-crossed the confluence

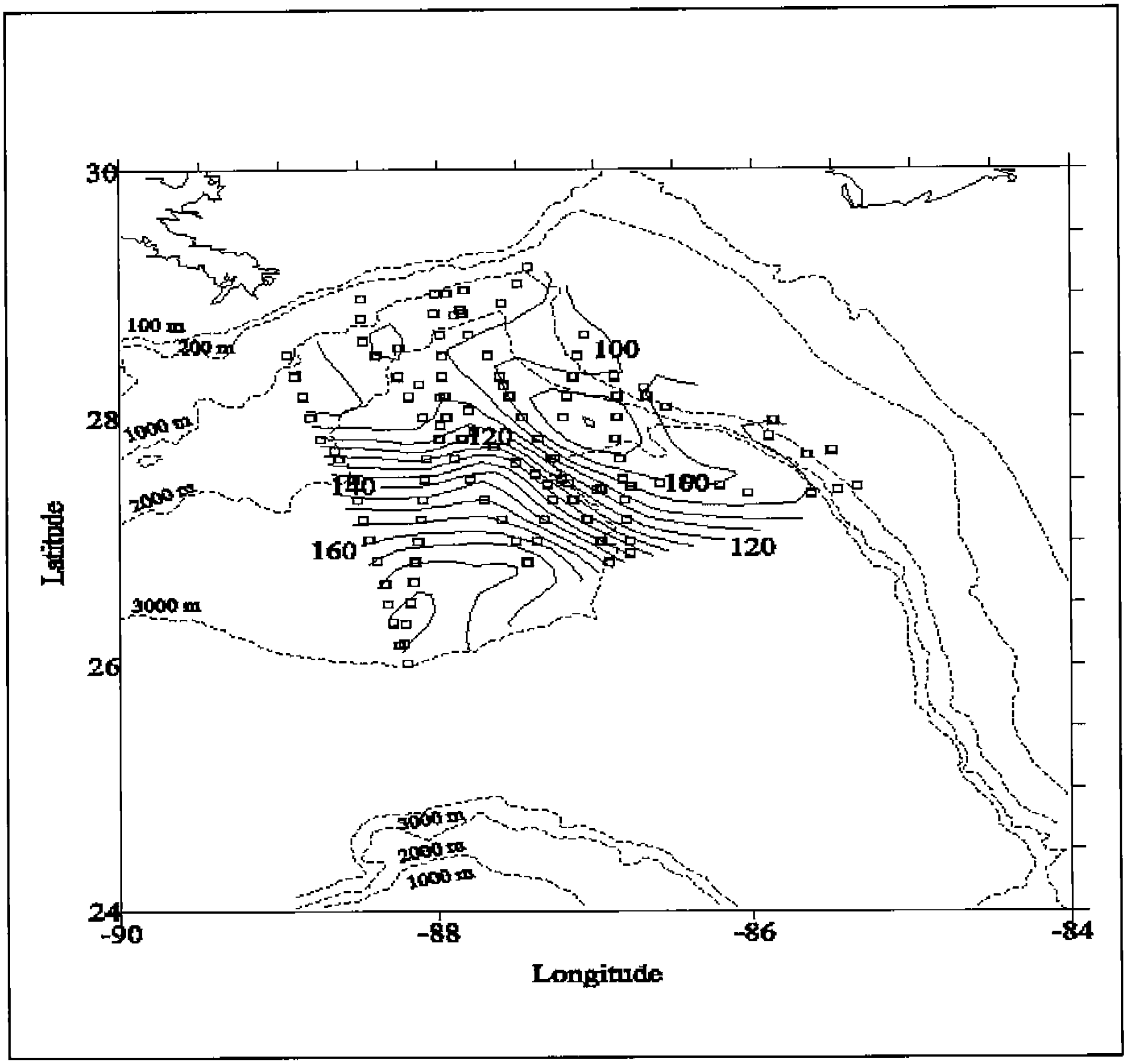

Figure 2E.3. Dynamic topography (cm, 0 m to 800 m) of the deepwater focal area, as determined from 107 hydrographic stations made on R/V *Gyre* cruise 97G-08.

region showed that low salinity, high chlorophyll river water was entrained from off shelf and then transported anticlockwise around the periphery of the cyclone.

From subsurface sampling at CTD and bottle stations, we learned that there was a highly predictable negative first order relationship between temperature < 22° C and nitrate concentration (Figure 2E.4). Temperature could thus be used as a proxy for nitrate concentration, and in particular the depth of the 19°C isotherm was a good estimation of the depth of the 10 uM nitrate concentration. Within the cyclone, the nitracline was domed 40-60 m shallower than in Loop Current Eddy C or

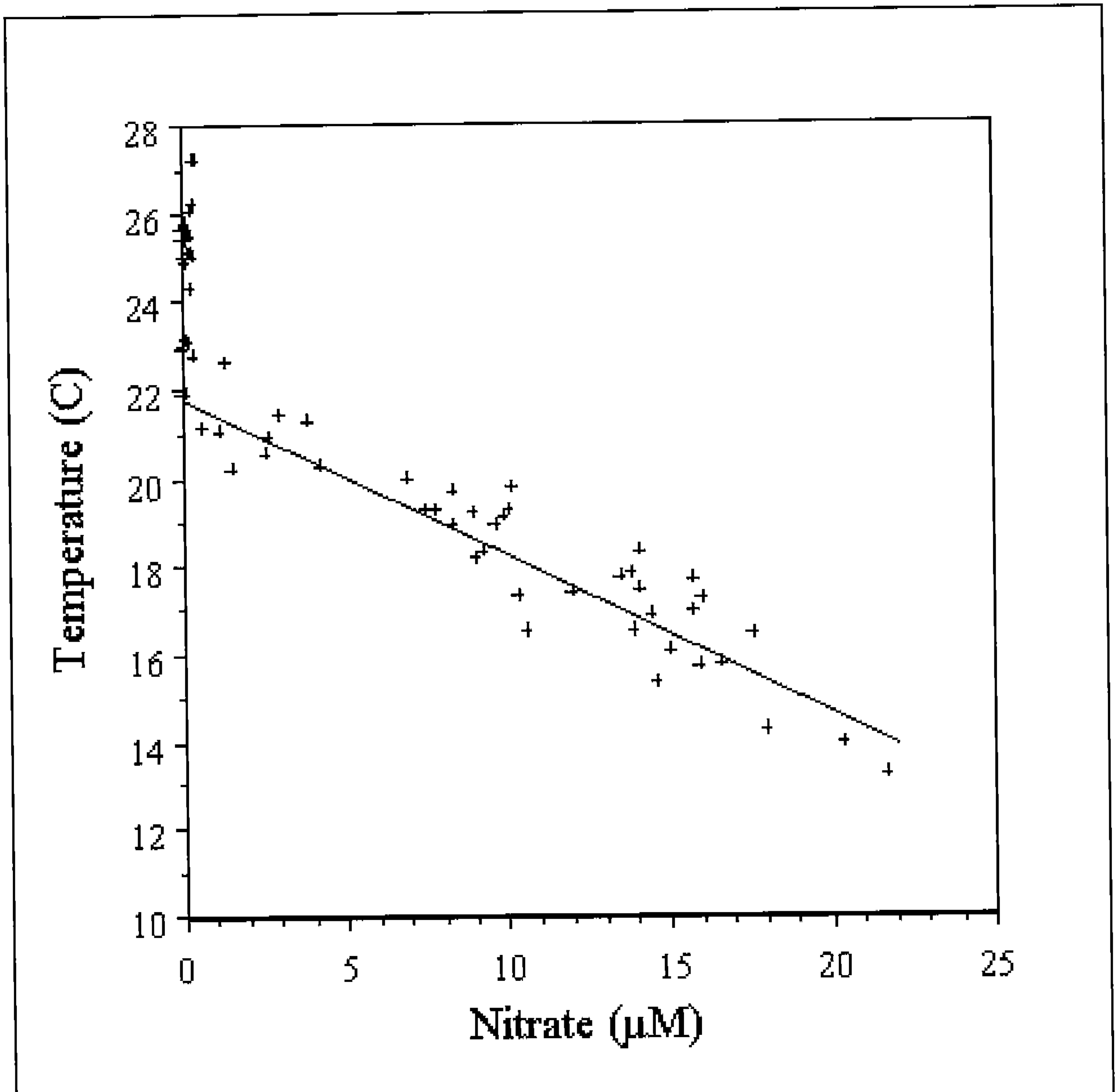

Figure 2E.4. Property-property plot of bottle data from R/V *Gyre* cruise 96G-06, illustrating how depth of the 19° C isotherm can be used as a proxy for 10 uM nitrate concentration.

Eddy E. Because this doming facilitated a higher flux of new nitrogen into surface waters in cyclone than in anticyclone, the cyclone had locally higher chlorophyll concentrations and also locally higher standing stocks of plankton and nekton (see summary by Wormuth *et al.*, this session). The higher biological productivity of the cyclone apparently also supported local aggregations of squid, which prey on the rich midwater fish fauna of the cyclones and which in turn are eaten as food by dolphins and sperm whales.

The four shipboard surveys also found that 19 °C depth was locally shallow at the shelf-slope break, particularly in the early summer. Unfortunately, we do not have surface chlorophyll data for either of the two early summer cruises, so we do not know whether this shelf edge upwelling was expressed at the surface as locally high primary production and/or surface chlorophyll concentration. In mid summer the shelf-edge doming of the 19 °C depth was not as strong, and the shelf-slope break was not marked by locally high surface chlorophyll. On the late summer cruise, we found no evidence for shelf edge upwelling from either surface or subsurface data.

Oceanographic habitat for all GulfCet I &II aerial and GulfCet I shipboard surveys have also been characterized using coincident altimetry from the TOPEX/POSEIDON and ERS-1 & 2 satellites. Daily fields of sea surface height topography on a 1/4 degree grid were estimated by adding the height anomaly fields, interpolated from the available along-track altimeter data, to a model mean surface. To quantify the relationship between sightings and the remotely sensed physical environment, the sea surface height, geostrophic velocity magnitude, relative vorticity and horizontal radius of curvature were computed at each sighting location from the gridded height fields. Randomization tests are in progress to test the null hypothesis that the marine mammals are sightings are purely by chance and unrelated to the ocean environment. These tests are very effective in identifying significant statistical relationships for small, sparse or nonrandom sample sets and take full advantage of the over six years of satellite altimetry.

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ABUNDANCE AND DISTRIBUTION OF CETACEANS AND SEA TURTLES IN THE NORTHERN GULF OF MEXICO FROM GULFCET II SURVEYS

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INTRODUCTION

GulfCet II surveys were designed to study cetacean and sea turtle diversity, abundances, and spatio-temporal distributions in the northeastern Gulf of Mexico and were a continuation of the GulfCet I surveys of the north-central and northwestern Gulf (Hansen *et al.* 1996). The surveys focused on continental slope waters (100-2,000 m) between Mobile Bay and Tampa Bay and a portion of the continental shelf adjacent to the western Florida Panhandle. The continental shelf area overlapped the Minerals Management Service Destin Dome leasing area.

Shipboard surveys were conducted in the northeastern Gulf during the spring, summer, and late summer. Spring ship surveys included oceanic waters of the entire U.S. Gulf (waters >100 m deep) and overlapped the GulfCet I study area. Aerial surveys were designed seasonally to complement the ship surveys and were conducted during both the warm (summer) and cold (winter) oceanographic seasons over two years. The primary objectives of both the aerial and ship surveys were to (1) estimate the minimum numbers of cetaceans and sea turtles (aerial surveys only) of each species in the study area, (2) determine when each species is present in the study area, (3) establish repeatable baseline estimates of cetacean and sea turtle abundances to compare with future estimates, and (4) determine how species are distributed in the study area.

METHODS

Ship Surveys—Line-transect data were collected using standard ship survey methods similar to those used during GulfCet I (Buckland *et al.* 1993, Hansen *et al.* 1996). Two observers searched for cetaceans during daylight hours using 25X "bigeye" binoculars mounted on the ship's flying bridge. The third observer searched near the ship using unaided eye and recorded data which included position, species, group-size, bearing and radial distance of a sighting, and environmental conditions.

Spring ship surveys were conducted from NOAA Ship *Oregon II* in 1996 and 1997 from mid-April to early June. Each year, Legs 1 and 2 were conducted along a predetermined trackline throughout the oceanic U.S. Gulf whereas Leg 3 focused on the northeastern Gulf. During late summer 1996 (10-29 October) and summer 1997 (4-22 August), the R/V *Gyre* was used to conduct line-transect surveys in the north-central and northeastern Gulf. Two areas were surveyed, the northeastern Gulf and a focal area in the north-central Gulf that was chosen based on oceanographic considerations. The focal area was sampled by five tracklines oriented NW-SE, south of Louisiana and Mississippi. In the late summer and summer, tracklines were transited 24-hours per day to accommodate acoustic sampling.

Aerial Surveys—Aerial surveys of the northeastern Gulf were conducted during summer 1996 and 1997, and winter 1997 and 1998. Seasonal sampling intensity during aerial surveys of the northeastern Gulf was similar to that expended during GulfCet I. Systematic transects with a random start that generally crossed isobaths orthogonally were uniformly spaced throughout the aerial survey area. Each season the goal was to survey 58 transect lines totaling 6,133 km of on-transect effort, including 42 transect lines (total of 5,220 km) on the continental slope (waters 100-2,000 m deep) and 16 transect lines on the continental shelf (waters <100 m deep).

A DeHavilland DHC-6 Twin-Otter with large concave windows on each side of the fuselage was used to survey transects. A window of 45-days and about 100 flight hours were allocated for each seasonal survey. Surveys were conducted from an altitude of 229 m (750 feet) and at a speed of 204 km/hour (110 knots). A pilot, co-pilot, and four observers participated in each flight. Data were entered on a computer. A suite of data characterizing survey conditions (e.g., sea state), effort status, and observer positions were updated throughout the day. When a cetacean group was sighted, the sighting angle was noted, a dye-marker was usually dropped to mark the position, and the aircraft was diverted to circle the group. Before continuing the transect, the species was identified and group-size was estimated.

Density and abundance estimates for cetacean and sea turtle species were made for each study area using line-transect methods (Buckland *et al.* 1993, Laake *et al.* 1993). GulfCet II study areas include the northeastern Gulf continental shelf, the northeastern Gulf continental slope, the oceanic northern Gulf, and the GulfCet I study area.

RESULTS

Ship Surveys—During spring surveys, 11,631 transect km were surveyed, 455 cetacean groups were sighted on-effort, and at least 20 species were sighted. The most commonly sighted species in waters >100 m deep were pantropical spotted dolphins (106 sightings), bottlenose dolphins (45), Risso's dolphins (47), sperm whales (36), and dwarf/pygmy sperm whales (29). In waters >100 m deep, these five species comprised about 65% of the identified sightings. Two sightings were of groups that were larger than any previously sighted in the Gulf of Mexico. One sighting had an estimated 750 spinner dolphins and the other, 650 pantropical spotted dolphins. Group-sizes of other species were more typical of previous years. Cetaceans were encountered in all areas of the Gulf surveyed. Sightings were more common in some areas than others (e.g., near the Mississippi River delta). Bottlenose dolphins and Atlantic spotted dolphins were the only species sighted in continental shelf waters.

During late summer and summer, 1,613 and 1,670 transect km, respectively, were surveyed visually in the northeastern Gulf. At least eight species were seen in 82 on-effort sightings in the northeastern Gulf. Pantropical spotted dolphins and bottlenose dolphins were the most common species sighted in waters >100 m deep. Bottlenose dolphins and Atlantic spotted dolphins were the only species sighted in continental shelf waters.

Aerial Surveys - During both summer surveys, the 58 proposed transect lines were completed (6,133 km). Due to poor weather, only 80% of the proposed effort was completed during the winter surveys.

Previous studies of cetaceans in the northern Gulf indicate that only bottlenose dolphins and Atlantic spotted dolphins are commonly found on the continental shelf, whereas other species occur in oceanic waters. Results of the GulfCet II aerial surveys agreed with this (Table 2E.1). On the continental slope, at least 16 species of cetaceans were identified. Overall, pantropical spotted dolphins were the most abundant species on the continental slope, followed by spinner dolphins, bottlenose dolphins, clymene dolphins, and striped dolphins. The abundance of some species appeared to be different for summer and winter. For summer and winter, respectively, the abundances of dwarf/pygmy sperm whales were 331 (0.33) and 36 (0.68), pantropical spotted dolphin abundances were 18,020 (0.29) and 8,226 (0.36), and Risso's dolphin abundances were 761 (0.51) and 2,007 (0.39). Aerial survey sighting rates of cetacean groups on the continental slope of the northeastern Gulf were about two times greater than the overall group sighting rate found during GulfCet I aerial surveys of the northwestern Gulf slope (Hansen *et al.* 1996). In general, cetacean groups were sighted throughout the entire study area. Certain species tended to be found over waters of different depths. Group-sizes varied among species.

Sea turtles were sighted 163 times. Continental shelf sightings were as follows: loggerheads - 85 turtles, Kemp's ridley - 3, unidentified chelonids - 10, and leatherbacks - 4. Continental slope sightings consisted of 28 leatherbacks, 27 loggerheads (25 during winter), and two chelonids. Leatherbacks were generally sighted in the northern half of the study area during summer, but during winter were concentrated in an area west of Tampa in the southern half of the study area.

SUMMARY

Twenty cetacean species were sighted during all ship and aerial surveys. By season, 19 species were sighted in spring, 14 in summer, 9 in late summer, and 14 in winter. Nine species were sighted in all four seasons (sperm whale, Cuvier's beaked whale, dwarf/pygmy sperm whale, striped dolphin, spinner dolphin, pantropical spotted dolphin, Atlantic spotted dolphin, bottlenose dolphin and clymene dolphin). Bryde's whale, *Mesoplodon* spp. and Risso's dolphin were sighted during three seasons. Cetaceans were sighted in all waters searched. With one exception, bottlenose dolphins and Atlantic spotted dolphins were the only species sighted in the continental shelf study area.

Loggerhead and leatherback sea turtles were sighted during both summer and winter aerial surveys. (Sea turtles are very difficult to see from a ship.) Leatherbacks were generally found in oceanic waters during both seasons. Loggerheads were found in shelf waters during both summer and winter and in oceanic waters primarily during winter only.

Table 2E.1. Group-size, density and abundance estimates of cetacean species from aerial surveys in the continental shelf and slope study areas in the northeastern Gulf of Mexico during summer and winter 1996-98 (n - number of groups, S - mean group size, D - animals/100 km^2, N - abundance estimate, CV - coefficient of variation, LCI and UCI - lower and upper limits of log-normal 95% confidence interval).

STUDY AREA Species	n	S	CV (S)	D	N	CV (N)	LCI	UCI
CONTINENTAL SHELF								
Dwarf/pygmy sperm whale	1	1.0	-	0.081	10	0.84	2	44
Bottlenose dolphin	58	7.3	0.19	14.798	1,824	0.25	1,123	2,961
Atlantic spotted dolphin	8	31.8	0.25	8.890	1,096	0.50	426	2,821
T. truncatus/S. frontalis	5	3.8	0.30	0.665	82	0.54	29	231
CONTINENTAL SLOPE								
Bryde's whale	2	4.0	0.75	0.035	25	1.06	2	273
Sperm whale	8	1.5	0.18	0.052	37	0.42	17	81
Dwarf/pygmy sperm whale	19	1.8	0.19	0.267	188	0.31	104	343
Cuvier's beaked whale	2	2.0	0.50	0.031	22	0.83	4	116
Mesoplodon spp.	5	2.2	0.22	0.084	59	0.51	23	155
Pygmy killer whale	3	15.0	0.50	0.309	218	0.75	49	964
False killer whale	1	31.0	-	0.213	150	1.06	27	830
Short-finned pilot whale	1	33.0	-	0.227	160	1.01	31	832
Rough-toothed dolphin	1	34.0	-	0.234	165	1.02	31	865
Bottlenose dolphin	83	9.9	0.16	5.617	3,959	0.22	2,579	6,076
Risso's dolphin	31	8.8	0.23	1.869	1,317	0.32	710	2,444
Atlantic spotted dolphin	15	24.8	0.43	2.555	1,800	0.43	772	4,199
Pantropical spotted dolphin	43	67.4	0.13	19.369	13,649	0.26	8,289	22,475
Striped dolphin	7	66.7	0.26	3.119	2,198	0.50	860	5,616
Spinner dolphin	7	263.1	0.28	12.302	8,670	0.48	3,462	21,707
Clymene dolphin	5	97.4	0.22	3.253	2,292	0.52	872	6,026
T. truncatus/S.frontalis	5	8.2	0.67	0.282	199	0.81	40	996
Unidentified small whale	1	3.0	-	0.023	16	1.03	3	86
Unidentified odontocete	6	1.3	0.25	0.061	43	0.51	16	113
Unidentified dolphin	1	1.0	-	0.008	5	0.98	1	27

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Mr. Wayne Hoggard has conducted aerial and ship surveys of marine mammals and sea turtles in the Western Atlantic since 1980. He is employed by the National Marine Fisheries Service in Pascagoula, Mississippi. He received his B.S. in wildlife biology from the University of Tennessee.

GULFCET II ACOUSTIC SURVEY

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Two acoustic surveys were conducted as part of the GulfCet II program. From 10-29 October 1996 and 4-22 August 1997, we surveyed, from the R/V *Gyre*, the pelagic waters of the central Gulf south of the Mississippi River mouth and the northeastern continental shelf and slope waters. These cruises permitted us to re-sample certain areas of the central Gulf previously examined during GulfCet I (Norris *et al.* 1996), while it was the first opportunity acoustically to survey the waters off peninsular Florida and the shallow shelf areas along the Florida/Alabama border. The area south of the mouth of the Mississippi River continues to be an area of intensive oil and gas exploration and production; therefore, the acoustic surveys permitted further examination of the potential effects these activities may have on the cetaceans of the area.

A new hydrophone array was used in GulfCet II. It was similar in basic design to the array used in GulfCet I, having multiple hydrophones variably spaced along a cable. The array is spectrally flat from 6 Hz to 18 kHz, with approximately 183 dB re. 1V/microPascal sensitivity at 7.2 kHz. Signals were split such that low frequency sounds were recorded on one system while higher frequency signals were recorded on a wideband recording system. Dolphin signals were analyzed using Canary software. Sperm whale signals were analyzed for bearing and range using RainBow Click software written by Dr. Douglas Gillespie. Bearing to the vocalizing whales are calculated by determining the difference in time of arrival for a signal arriving at two hydrophones within the array. This permits estimation of range to initial contacts and number of animals vocalizing over the duration of the contact.

There was a total of 5,228 km of acoustic effort, with 2,784 km on cruise Gyre 96G06 and 2,444 km during cruise Gyre 97G08. The average effort length during Gyre 96G06 was 60 km (n=46, σ =48, range: 3-199), while for Gyre 97G08 the average length of effort was 31 km (n=78, σ =35, range: 0-138). During Gyre 96G06, effort was fairly uniform throughout the main study areas north of 27°, with several lines of effort as far south as 25 ° along -88° longitude. Acoustic effort was in waters as shallow as 50m off of the Florida panhandle and Alabama. To the south and east, waters deeper than 3,000m were sampled. In contrast, during Gyre 97G08 there was no effort south of 26°, but with increased effort to the east along the Florida escarpment.

We had a total of 66 dolphin and 20 sperm whale contacts during the two GulfCet II cruises. There were twice as many dolphin contacts in cruise Gyre 97G08 during the earlier cruise Gyre 96G06. There were 11 sperm whale contacts during Gyre 96G06, while there were nine during Gyre 97G08. We had 13 and 17 unidentified dolphin contacts, respectively, in the two cruises. Sperm whales were the most commonly encountered identified cetacean during Gyre 96G06, while pantropical spotted dolphins were the most commonly encountered species during Gyre 97G08.

Cetacean distributions appeared to be affected by the presence during both cruises of paired cyclonic cold core eddies, to the north, and anticyclonic warm core eddies to the south. While the feature ages and size were similar in both years, their relative location and orientation were significantly different. In 1996, the cold core ring was south of the mouth of the Mississippi River, to the northwest of the warm core ring. In 1997, the cold core ring was northeast of the warm core ring, over the DeSoto canyon. In no case were cetaceans found in the center of the warm core ring, further emphasizing the perspective that this is a marine desert. These spatial differences appeared to have produced different amounts and densities of food, for the cetacean distributions were markedly different for the two years. In 1996, contacts were more dispersed, and in the case of the sperm whales, the contacts were significantly longer. In 1997, both sperm whales and pantropical spotted dolphins distributions were more compact, found either inside or on the periphery of the cold core ring. During all cruises, sperm whales were located again off the mouth of the Mississippi River, as was the case during GulfCet I. This area now contains a number of deep water oil platforms, which were not present at the beginning of GulfCet I. Sperm whales were found approximately 20 miles further out to sea than previously, though it is unclear whether this was in response to the increased human activities in the area.

An area covering over 6,800 kilometers of survey tracklines was monitored acoustically for the presence of seismic exploration pulses and visually for cetaceans. Seismic exploration signals were found on 21% of the recordings, for a total of 108.9 hours. For the seven GulfCet I cruises, where effort concentrated in the central and western Gulf of Mexico, seismic exploration pulses were present roughly 10% of the time. During GulfCet II, where effort concentrated in the central and eastern Gulf, seismic exploration pulses were present 34.1% of the time. There was no significant difference in the cetacean sighting frequency for the different acoustic zones (0 dB, 0-12 dB, and > 12 dB above ambient). This finding was consistent for GulfCet I, GulfCet II, and the combined data set. Hydrographic data was analyzed for the three GulfCet II cruises to understand the potential interaction of cetaceans within the different hydrographic regions. There was a significant difference in the cetacean sighting frequency for the combined hydrographic regions and acoustic levels. However, within each hydrographic region, there was no significant difference in cetacean sighting frequency based on acoustic level. It appears that the sighting frequency difference is due to the hydrographic region, not the acoustic level.

SEABIRD DISTRIBUTION AND HABITAT IN THE NORTHERN GULF OF MEXICO

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INTRODUCTION

As part of the GulfCet II program, two shipboard seabird surveys occurred from the R/V Gyre during October 1996 and August 1997. The October and August cruises surveyed an eddy pair in the north-central Gulf which contained a cyclonic eddy, an anticyclonic Loop Current eddy, and a confluence region between the eddies, and the northeastern region over the continental shelf and slope in the Minerals Management Service's Eastern Planning Area (EPA).

METHODS

Seabird observations occurred during daylight hours by two observers using hand-held 8X or 10X binoculars on the flying bridge of the R/V Gyre. The seabird surveys consisted of continuous strip transects, using the method of Tasker *et al.* (1984). The survey area was measured off one side of the ship, sweeping from the bow to 90° from the direction of the ship.

Total species numbers were tallied to assess overall abundance. Species abundance in the 300 m strip transect by hydrographic environment was tallied to initially assess species distributions, as well as species diversity, richness and evenness for both the October and August cruises. To conduct species specific habitat analyses, we split the continuous strip transects into approximately equal length strip segments with a target lengths of 15 kilometers. For the October 1996 survey a 300 m transect band width was used. For the August 1997 survey, a 600 m transect band width was used. For each transect, the presence or absence of seabirds was tallied for the most abundant species seen during the cruise. Analyses were conducted only for species seen in at least 10% of the transects.

To decrease the amount of correlation between the predictor variables, and to test competing hypotheses, we developed five models of seabird presence incorporating bathymetry, sea surface physical properties (salinity and temperature), sea surface height, predicted mean zooplankton biomass (from acoustic backscatter), and surface chlorophyll concentrations. We used generalized additive models, a nonparametric smoothing technique which allows for nonmonotonic nonlinear relationships that are difficult to model with standard regression techniques. We compared the fits of the different models based on the proportion of variance explained and Akaike Information Criterion.

RESULTS FOR OCTOBER 1996 SURVEY

Two-hundred and seventy-eight (278) seabirds were counted and 14 species were seen during the October cruise. Together terns, gulls, jaegers, and shearwaters comprised over 90% of the total birds enumerated. Frigatebirds, tropicbirds, boobies and storm-petrels were also seen. Many terns were not identified to species (55 out of 128 terns). Over a quarter of the total terns seen were royal terns (36 birds). Black terns (nine birds) and common terns (eight birds) were the next most abundant terns; sooty terns, bridled terns, bridled/sooty terns, and common/arctic terns accounted for the remaining twenty terns counted. The majority of gulls seen were laughing gulls (55 out of 65 gulls seen); seven herring gulls were seen, and three gulls were not identified to species level. Out of the 38 jaegers seen, 25 were identified as pomarine jaegers; the rest were not identified. Audubon's shearwaters comprised almost half of the shearwaters seen (11 out of 24 birds); seven Cory's shearwaters were spotted and the remaining six shearwaters were not identified to the species level. All 12 frigatebirds were magnificent frigatebirds. Four tropicbirds were seen, two were red-billed tropicbirds. The other two were not identified to species. Four masked boobies were seen. Three storm-petrels were seen, two of which were identified as band-rumped storm-petrels, and one was not identified to the species level.

Out of the birds seen within the 300 m continuous strip transect, some species were seen in many of the marine environments surveyed (see Evans *et al.*, these proceedings) and some species were seen only in one or two environments. Laughing gulls were present in every region except for the confluence; however, laughing gulls were present in the greatest numbers on the continental shelf. Audubon's shearwaters and pomarine jaegers were seen in five out of the seven environments. Audubon's shearwaters were not seen in either the Loop Current eddy or other regions in depth greater than 200 m but not contained within the eddy pair (other margin) and pomarine jaegers were not seen in the Loop Current eddy or the continental shelf. Royal terns were seen in the mouth of the Mississippi River and other margin regions. Cory's shearwater and masked boobies were seen only in the cyclone and in other margin regions. Herring gulls and magnificent frigatebirds were seen in other margin and continental shelf, however, a herring gull was also present in the cyclone. Band-rumped storm-petrels and the red-billed tropicbird were seen inside the cyclone. The sooty tern and common tern were seen in other margin.

Species richness (i.e. the number of seabird species seen) in the 300 m continuous strip transects varied with marine environment. The most species (nine) were seen in other margin (regions with bottom depth greater than 200 m not directly associated with the Loop Current eddy system); this area outside of the Loop Current system contained almost one-third the survey effort. The cyclone contained eight species, the next highest number in any environment. The mouth of the Mississippi River and continental shelf contained four species. The edge of the cyclone, the confluence, and Loop Current eddy contained three or less species. We note that these environments were covered with less effort than the others.

RESULTS FOR AUGUST 1997 SURVEY

During the August 1997 cruise, over 2,100 seabirds were counted, representing twenty-three species. Two-thirds of the seabirds seen were terns. Storm-petrels were the next most abundant group (323 birds). Shearwaters (194 birds), frigatebirds (178 birds), gulls (40 birds), jaegers (18 birds), boobies (four birds) and tropicbirds (two birds) were also seen. The majority of terns seen were black terns, which accounted for half of all seabirds seen. Sooty terns (111 birds) were the second most abundant tern species. Bridled terns (70 birds) and either bridled or sooty terns (73 birds) were the next most represented tern. Twenty-four sandwich terns were seen, and nineteen royal terns were seen. Two arctic terns, four common terns, three common or arctic terns, and one least tern were also encountered. One hundred and three terns were not identified to species. The majority of storm-petrels seen were band-rumped storm-petrels (250 out of 323 birds). Ten Wilson's storm-petrels, and one Leach's storm-petrel were counted. Sixty-two storm-petrels were not identified to species. Five different species of shearwaters were encountered during the August cruise. The majority of shearwaters seen were Audubon's shearwater (154 out of 194 birds). Ten Cory's shearwaters, five Manx shearwaters, three greater shearwaters, and one sooty shearwater were seen. Twenty-one shearwaters were not identified to species. One hundred and seventy-eight frigatebirds were counted. Most likely, these were all magnificent frigatebirds; no other frigatebird is known to be present in the Gulf. All of the gulls identified to species were laughing gulls (38 birds) and two gulls were unidentified. Three-fourths of the jaegers seen were pomarine jaegers (14 out of 18 birds). Two long-tailed jaegers, one parasitic jaeger and one unidentified jaeger were enumerated. All four boobies seen were masked boobies. The two tropicbirds seen were red-billed tropicbirds.

The distribution of species seen within the 300 m continuous strip transect across the different marine environments was not uniform; many species were only seen in certain locations. Frigatebirds were only seen on the continental shelf, as was the long-tailed jaeger. Royal terns, sandwich terns, and black terns were seen predominantly on the continental shelf. The two masked boobies seen within the 300 m strip transect were seen in the cyclone, and four out of the five Manx shearwaters were also seen in the cyclone. Band-rumped storm-petrels were seen in all of the environments except for the mouth of the Mississippi River. A large number of band-rumped storm-petrels were seen in the pelagic regions not directly influenced by the eddy pair in addition to the confluence and cyclone. Laughing gulls were found mainly on the continental shelf and confluence but also were present in the Loop Current eddy, cyclone and the edge of the cyclone. Black terns, while predominantly found on the continental shelf, were also found in the confluence, mouth of the Mississippi River, cyclone, and Loop Current eddy. Audubon's shearwaters were found in the confluence, cyclone, Loop Current eddy and the edge of the cyclone. Bridled terns were seen predominantly in the cyclone, confluence and Loop Current eddy. Sooty terns were also seen in the cyclone, confluence and Loop Current eddy, but were seen in larger numbers in other margin.

The pelagic regions outside of the eddy pair and cyclone contained the greatest number of species. Fewer species were found on the continental shelf, confluence and Loop Current eddy. Only four or five species were encountered in the mouth of the Mississippi River and edge of cyclone; however, these environments were covered with the least survey effort. Diversity was the greatest in the cyclone followed by the Loop Current eddy and confluence. The continental shelf had the lowest species diversity, resulting from the large numbers of black terns.

The results of both cruises indicate that the cyclone had the greatest species diversity out of all environments. Additionally, the confluence and Loop Current eddy during August 1997 had a greater species diversity than the continental shelf. On the scale of analysis for this report (15 kilometers), we found species-specific habitat relationships with the different marine environments. Audubon's shearwaters during the August survey were more likely to be encountered inside the cyclone. Black terns were encountered more frequently in the mouth of the Mississippi River during the August 1997 survey.

RESULTS FOR SEABIRD-ENVIRONMENT MODELS

On the scale used in this analysis, we found that a generalized additive model using indicators of plankton standing stock (measured by surface chlorophyll and predicted mean zooplankton biomass (from acoustic backscatter) integrated from 10-102 m depth) best predicted seabird presence for laughing gull, pomarine jaeger, Audubon's shearwater and band-rumped storm-petrel.

Laughing gull presence during October was predicted in transects of increased predicted mean zooplankton biomass (from acoustic backscatter) integrated from 10-102 m depths and increased concentrations of chlorophyll. Ribic *et al.* (1997) found laughing gulls to be found in areas of low salinity and steep thermoclines. These findings are consistent; during the October 1996 survey, there was an inverse relationship with salinity and chlorophyll concentration. Pomarine jaegers during October were predicted to be encountered in transects with low surface chlorophyll and higher predicted mean zooplankton biomass (from acoustic backscatter) integrated from 10-102 m depth. For the October survey, chlorophyll values were lower in more saline water. The relationship of the jaegers with chlorophyll may signify that they are present in more saline water (i.e. farther offshore). Ribic *et al.* (1997) found similar results of pomarine jaeger presence in water with lower primary productivity (as measured by the integrated values of chlorophyll in the top 100 m of the water column). We found pomarine jaegers in areas of lower surface chlorophyll, but in higher levels of predicted mean zooplankton biomass (from acoustic backscatter) integrated from 10-102 m depth.

Audubon's shearwater and band-rumped storm-petrel presence during August were best predicted by the model including surface chlorophyll and predicted mean zooplankton biomass (from acoustic backscatter) integrated from 10-102 m depth. Both species were predicted to be present at generally lower surface chlorophyll concentrations. This cutoff may signify that neither species is present in fresher water. Transects with higher chlorophyll concentrations were also in less saline water.

Black and sooty tern species' presence in transects was best predicted by the surface properties model of sea surface salinity and temperature. This was expected for black terns, which have been noted to follow the fresh water plume of the Mississippi River and coastal waters (Ribic *et al.* 1997; Davis and Fargion 1996). Although sooty tern presence in transects was best explained by the same surface physical properties model, the relationship was not the same as with black terns. Sooty terns were predicted to be present in salinity of about 32 psu which is more saline water than where the black terns were found. However, the percent of total variance explained by the model was low; there are probably other factors not considered that contribute to the distribution of sooty terns in the Gulf of Mexico.

CONCLUSION

The two cruises provided more information regarding the seasonal patterns of seabirds in the Gulf of Mexico. The role of hydrographic environments and species diversity was examined, and we found an increase in species diversity in the cyclone and lower species diversity on the continental shelf. On a species-specific level, black terns and Audubon's shearwaters tended to be present in specific environments. However, each of these species preferred a different region; black terns favored the mouth of the Mississippi River, and Audubon's shearwaters preferred the cyclone. Species' presence in a transect was analyzed with models incorporating bottom depth, sea surface properties, and indicators of plankton standing stock in the water column using generalized additive models. Our results suggest laughing gull, pomarine jaeger, Audubon's shearwater, and band-rumped storm-petrel presence was best predicted by indicators of plankton standing stock (using sea surface chlorophyll concentrations and predicted mean zooplankton biomass (from acoustic backscatter) integrated from 10-102 m depth). In contrast, the two tern species (black tern and sooty tern) presence was best predicted by sea surface temperature and salinity.

ACKNOWLEDGMENTS

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Dr. Christine Ribic is an Associate Professor in the Department of Wildlife Ecology at the University of Wisconsin, Madison. She is also Assistant Unit Leader of the USGS BRD Wisconsin Cooperative Wildlife Research Unit. Her areas of research interest are the importance of scale to seabird-habitat relationships and the influence of physical oceanographic features on seabird habitat selection. Dr. Ribic received her B.S. in wildlife biology from Colorado State University and her M.S. in ecology, M.S. in statistics, and Ph.D. in ecology from University of Minnesota.

SESSION 2F

NORTHEASTERN GULF OF MEXICO ECOSYSTEM PROGRAM: MISSISSIPPI-ALABAMA MARINE ECOSYSTEM MONITORING PROGRAM

Co-Chairs: Dr. Robert Rogers and Dr. Gary Brewer

Date: December 9, 1998

Presentation	Author/Affiliation
Northeastern Gulf of Mexico Coastal and Marine Ecosystem Program: Ecosystem Monitoring, Mississippi/ Alabama Shelf; Introduction and Overview	Dr. David A. Gettleson Continental Shelf Associates, Inc. Jupiter, Florida
Mississippi-Alabama Marine Ecosystems Study Geological Characterization: High-Resolution Geological and Geophysical Study of Outer Shelf Carbonate Mounds and Their Environs	Dr. William W. Sager Department of Oceanography Texas A&M University Dr. William W. Schroeder Marine Science Program University of Alabama Dr. Ian R. MacDonald Geochemical & Environmental Research Group Texas A&M University Dr. Ian D. Walsh Department of Oceanography Oregon State University
Northeastern Gulf of Mexico Coastal and Marine Ecosystem Program: Ecosystem Monitoring—Physical Oceanography and Hydrography in the Mississippi/Alabama Pinnacle Trend Area during May 1997 through April 1998 and during September 1998	Mr. F.J. Kelly Dr. Norman L. Guinasso, Jr. Mr. Linwood L. Lee, III Geochemical and Environmental Research Group College of Geosciences Texas A&M University

Presentation	Author/Affiliation
Northeastern Gulf of Mexico Coastal and Marine Ecosystem Program: Ecosystem Monitoring, Mississippi/ Alabama Shelf; Hard Bottom Communities	Mr. David B. Snyder Mr. Keith D. Spring Mr. Bruce D. Graham Mr. Steven T. Viada Continental Shelf Associates, Inc. Jupiter, Florida Mr. Dane D. Hardin Applied Marine Sciences Santa Cruz, California
Epibiont Recruitment	Dr. Paul Montagna Ms. Tara Holmberg University of Texas Marine Science Institute Port Aransas, Texas

NORTHEASTERN GULF OF MEXICO COASTAL AND MARINE ECOSYSTEM PROGRAM: ECOSYSTEM MONITORING, MISSISSIPPI/ALABAMA SHELF; INTRODUCTION AND OVERVIEW

Dr. David A. Gettleson
Continental Shelf Associates, Inc.
Jupiter, Florida

INTRODUCTION

Continental Shelf Associates, Inc. (CSA) was awarded a contract by the U.S. Geological Survey, Biological Resources Division to conduct an ecological study of an area offshore Mississippi/ Alabama. The project team consists of CSA, the Geochemical & Environmental Research Group of Texas A&M University, University of Texas, Applied Marine Sciences, Inc., and independent consultants.

GEOGRAPHIC AREA OF STUDY

The geographic area of study is the Mississippi-Alabama pinnacle trend area in approximately 50 to 150 m water depths (Figure 2F.1). Several studies have been conducted in the area, which was first described by Ludwick and Walton (1957). There have been four Minerals Management Service-funded studies (Woodward-Clyde Consultants 1979; Brooks 1991; Continental Shelf Associates, Inc. 1992; Shinn *et al.* 1993) and an oil and gas lease block clearance survey (Continental Shelf Associates, Inc. 1985) conducted in the area.

STUDY OBJECTIVE

The objective of this study is to describe and monitor biological communities and environmental conditions at hard-bottom features located within the geographic area of study. A number of oil and gas lease blocks are encompassed by the study area with at least one oil and gas production platform present. Information gained from this study will be used to review existing lease stipulations to determine their adequacy in protecting the biological communities present on the hard-bottom features. This study also meets several objectives of the National Research Council (1992) regarding the assessment of environmental impacts from oil and gas operations. These objectives include (1) identifying representative species; (2) describing seasonal patterns; (3) acquiring basic ecological information for key or representative species; and (4) obtaining information on factors that determine sensitivity of biota to outer continental shelf activities and their recovery potential.

STUDY COMPONENTS

The four-year study is divided into four phases of one year duration each with annual reports planned at the end of each phase. The phases are as follows:

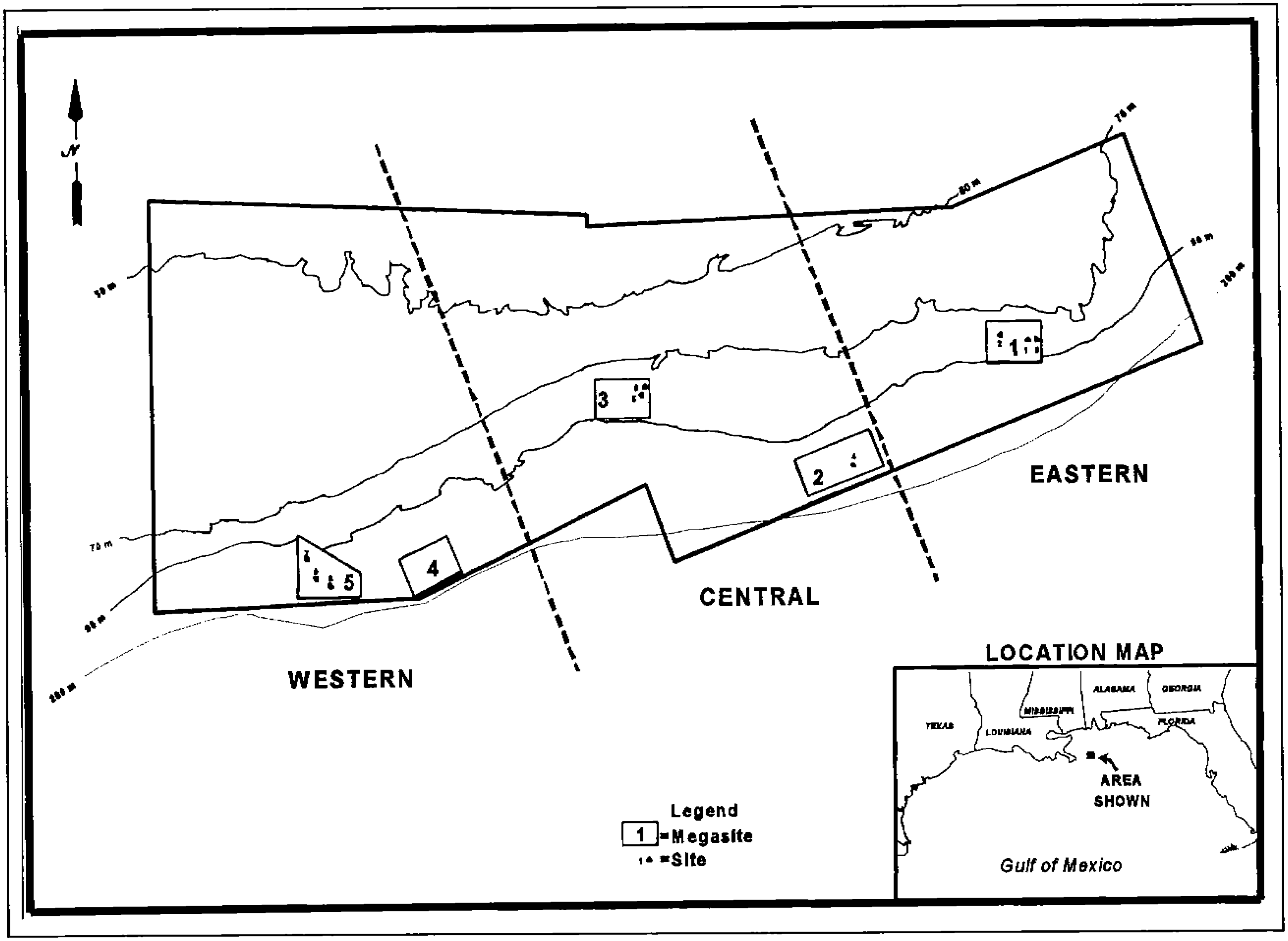

Figure 2F.1. Locations of final monitoring sites.

Phase 1 - Reconnaissance, Baseline, and Monitoring;
Phase 2 - Monitoring;
Phase 3 - Monitoring; and
Phase 4 - Data Interpretation and Information Synthesis.

Nine of the 11 cruises planned for the study have been completed. These encompassed reconnaissance (one cruise), baseline (one cruise), monitoring (three cruises), and mooring servicing (four cruises). During the reconnaissance portion of Phase 1, five "megasites" (Figure 2F.1) (approximately 25 to 35 km^2 areas) were selected for detailed study. These sites were selected as being representative of the hard-bottom features previously identified in the area (Brooks 1991; Continental Shelf Associates, Inc. 1992). The megasites were surveyed in November 1996 using swath bathymetry, high resolution side-scan sonar (11 and 72 kHz), and a subbottom profiler (2 to 8 kHz). Nine areas of approximately 0.2 to 1.5 km^2 size were selected during the cruise and surveyed in more detail. Previously collected video and still photographic data from these nine sites were reviewed and additional visual data collected using a remotely operated vehicle to aid in the selection of nine study sites. The study sites were selected to provide representative hard-bottom features of high, medium, and low relief in the eastern, central, and western portions of the study area (Figure 2F.1).

The focus of the baseline and monitoring portions of the study is to understand the geological and oceanographic processes as factors in controlling/influencing the hard-bottom communities at the nine study sites. Data were gathered during the reconnaissance survey on substrate characteristics; hard-bottom orientation, size, and morphology; and depth of surrounding soft sediments. Three of four baseline and monitoring cruises have been completed (April 1997, October 1997, and August 1998). The remaining monitoring cruise will be conducted May 1999. Data on microtopography are being obtained from the collection and analysis of rock samples and video and photographic data during these cruises. Grab samples collected during the monitoring cruises are being analyzed for grain size (four cruises) and concentrations of hydrocarbons and metals (first cruise only). Six instrument arrays composed of current meters; sediment traps; and temperature, salinity, dissolved oxygen, and turbidity (optical backscattering) sensors were deployed during the first cruise in the vicinity of the hard-bottom features. The arrays are being recovered and redeployed at three-month intervals and recovered on the fourth monitoring cruise. Sediment trap contents are being analyzed for grain size, total inorganic and organic carbon, and metals. During each of the four cruises, water column profiles are being made for conductivity, temperature, dissolved oxygen, transmissivity, and optical backscatter, and samples are being collected for analysis of particle sizes, dissolved oxygen, and salinity.

Biological data include quantitative still photographs from fixed quadrats and random stations and quantitative video from random transects during the four cruises. Voucher specimens are also being collected to aid in taxonomic identifications of biota observed in the visual data. Fish assemblages associated with the study sites are being described from the available visual data collected during the monitoring surveys. There are two additional biological "companion" studies. The first involves a more in-depth analysis of the biological, geological, and physical data on a micro-habitat basis. The second involves the deployment of settling plates on fixed arrays to study epibiota recruitment, growth, and community development. Settling plate arrays include enclosed and non-enclosed plates plus controls to study predation/disturbance effects. Plates were placed near bottom and above any identified nepheloid layer. Eight arrays were placed at one site and one array was to be recovered each quarter. Due to hardware failure, the arrays sank to the bottom. They were and will be recovered by a remotely operated vehicle (one array in October 1998; three in August 1998; and four in May 1999). One array also was placed at each of three additional sites to be recovered after one year. The arrays at two of the three sites were recovered in August 1998. Turbidity prevented the recovery of the third array, which will be recovered in May 1999. An additional array was deployed at each of the three sites plus the multi-array site in January 1998 and will be recovered in May 1999.

The data interpretation and synthesis efforts will involve understanding the relationship of the measured geological and physical factors to the hard-bottom communities through statistical analyses. A series of questions determined by the study objective with clearly stated null hypotheses also will be identified and statistically tested.

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Dr. David A. Gettleson is President and Scientific Director of Continental Shelf Associates, Inc. (CSA), located in Jupiter, Florida. He has 19 years of scientific management experience with major research programs for federal, state, and industrial clients. He has been involved in the preparation of numerous environmental assessment documents covering a wide range of human activities in the marine environment, including oil and gas operations, dredging and dredged material disposal, beach restoration, artificial reef siting, power plant effluents, sewage outfalls, and waste incineration. Dr. Gettleson received a B.A. degree in Biology from Rollins College in 1971 and earned his Ph.D. degree in biological oceanography from Texas A&M University in 1976.

MISSISSIPPI-ALABAMA MARINE ECOSYSTEMS STUDY GEOLOGICAL CHARACTERIZATION: HIGH-RESOLUTION GEOLOGICAL AND GEOPHYSICAL STUDY OF OUTER SHELF CARBONATE MOUNDS AND THEIR ENVIRONS

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INTRODUCTION

Sedimentation on the outer continental shelves in the northern Gulf of Mexico is an interplay between sediment supply and sea level fluctuations. Most sediments are deposited as deltaic wedges during sea level lowstands and are separated by condensed layers representing transgressive periods (e.g., Coleman *et al.* 1991). Such shelf-edge deltaic wedges are observed on the Mississippi-Alabama outer shelf in bathymetric contours and reflection seismic data (Kindinger 1988; 1989; McBride and Byrnes 1995). Sedimentation is low in this region today, and indeed much of the outer shelf is covered by relict transgressional sands (Ludwick 1964; Doyle and Sparks 1980). Shelf-edge delta sediments indicate sedimentation was higher during the last ice age and previous glacial intervals (e.g., Sydow and Roberts 1995). Siliciclastic delta sediments are not the only contributor to deposition on the outer shelf. Early studies of the Mississippi-Alabama outer continental shelf found calcareous topographic features (named "pinnacles") near the shelf edge that appeared to have formed near sea level. Although these pinnacles (henceforth we use the more generic term "mounds") probably formed during or shortly after the last ice age when sea level was lower, they are now senescent because they are too deep for active growth (Ludwick and Walton 1957). These mounds are apparently the source of calcareous sediments found in their vicinity (Ludwick 1964). Much of our current geological knowledge of the Mississippi-Alabama carbonate mounds and their surroundings come from two prior MMS-funded studies: Mississippi-Alabama Marine Ecosystems Study (MAMES; Brooks *et al.* 1991) and Mississippi-Alabama Shelf Pinnacle Trend Habitat Mapping Study (MASPTHMS; Continental Shelf Associates 1992) both of which mapped the occurrence of carbonate mounds and the distribution of surficial sediments. Thousands of carbonate mounds ranging from less than a few meters in diameter to nearly a kilometer were found arrayed mostly in two isobath-parallel bands (Sager *et al.* 1992). Isobath-parallel ridges were also mapped in the shallower of these two depth zones. Both features are thought related to sea level stillstands during the last deglaciation. Surficial sediments are largely related to three late Pleistocene deltas, the Lagniappe Delta (Kindinger 1988; 1989) in the western part of the present study area (Figure 2F.2) and the "eastern" and "western" deltas in the original MAMES study area (Sager *et al.* submitted). These delta sediments were deposited during sea level lowstands or in the case of the "eastern delta," during the early part of the last deglaciation (Sager *et al.* submitted). Atop these sediments is a thin, variable layer, consisting mostly of sand, that is thought to have been deposited by reworking of shelf sediments near sea level as it rose across the shelf during the last deglacial transgression (Sager *et al.* submitted).

The current project picks up where MAMES and MASPTHMS left off. Those projects were reconnaissance efforts to broadly characterize the Mississippi-Alabama outer continental shelf, whereas this study seeks more detail. The current project has two main goals: (1) detailed geologic and geophysical characterization of mound morphology, roughness, and locations and (2) an examination of sedimentation in the vicinity of the mounds. The first set of goals was addressed by collection of side-scan sonar data, seismic reflection profiles, grab samples, and ROV photos of the seafloor. Sedimentation is being examined in conjunction with the physical oceanography and hydrography portion of the program by the deployment of sediment traps and optical backscatter instruments.

METHODS

During November 1996, five sites (called "megasites" to distinguish them from smaller monitoring sites), typically several kilometers on a side and totaling 144.5 km^2 in area, were surveyed using the *TAMU²* digital side-scan sonar system to make acoustic images of the seafloor and bathymetric soundings (Figure 2F.2). In addition, a 2-12 kHz X-Star chirp sonar was used to acquire subbottom profiles. These acoustic data were collected along tracks spaced 175 m apart with image swaths that produced 100% overlap (so all spots on the seafloor were imaged twice from adjacent tracks). Positions were established to an accuracy of less than about 10 m using differential GPS and a short-baseline trackpoint system to determine the sonar towfish location. Sonar swaths were mosaicked into whole-megasite images (Figure 2F.3), with a resolution of about 1 m, for subsequent geologic

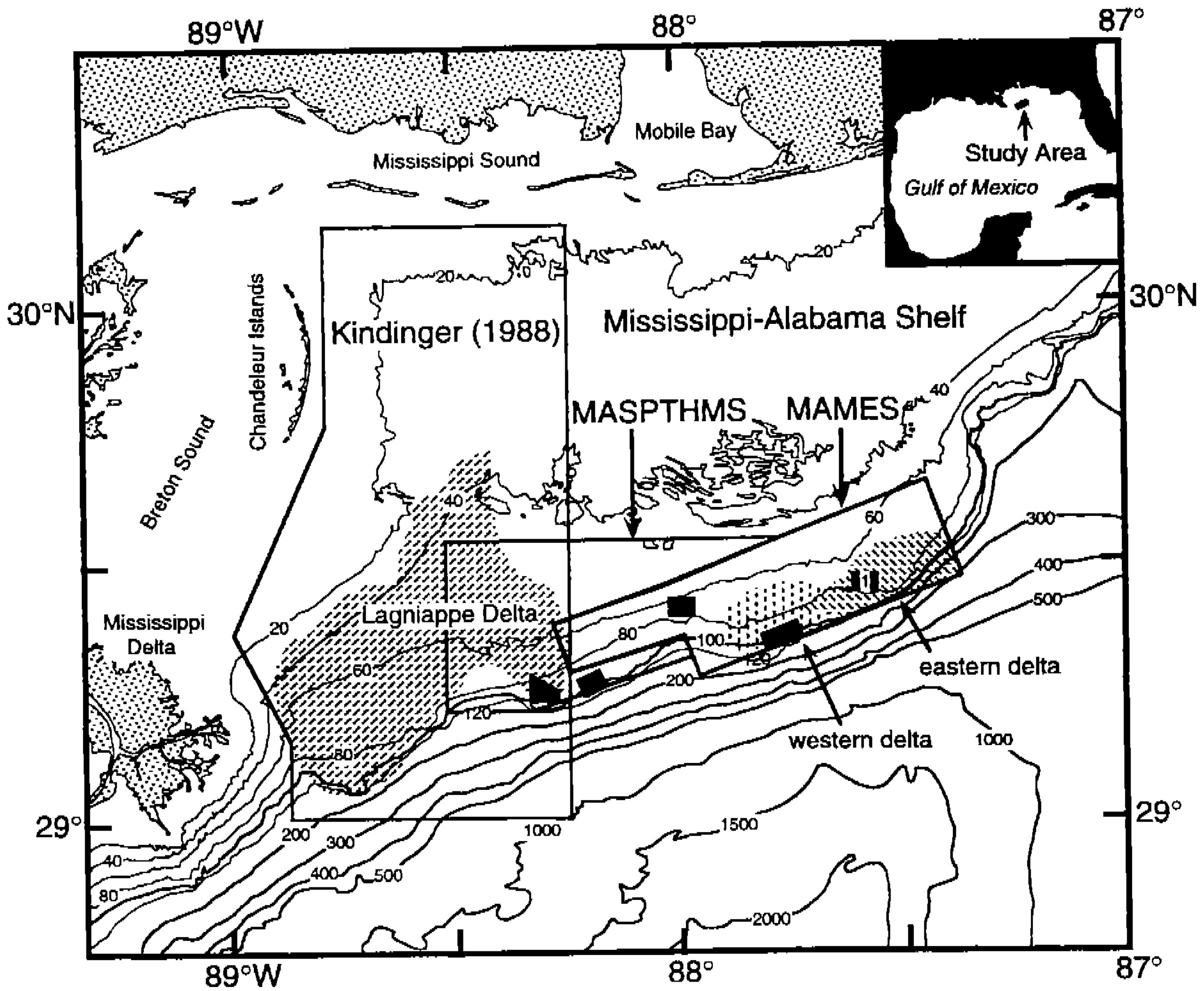

Figure 2F.2. Location map showing the study areas on the Mississippi-Alabama outer continental shelf. Boxes show prior studies in the area. Small, dark boxes show the five megasites surveyed with a side-scan sonar and subbottom profiler for this project. Hachured areas show deltas described in Kindinger (1988) and Sager *et al.* (submitted).

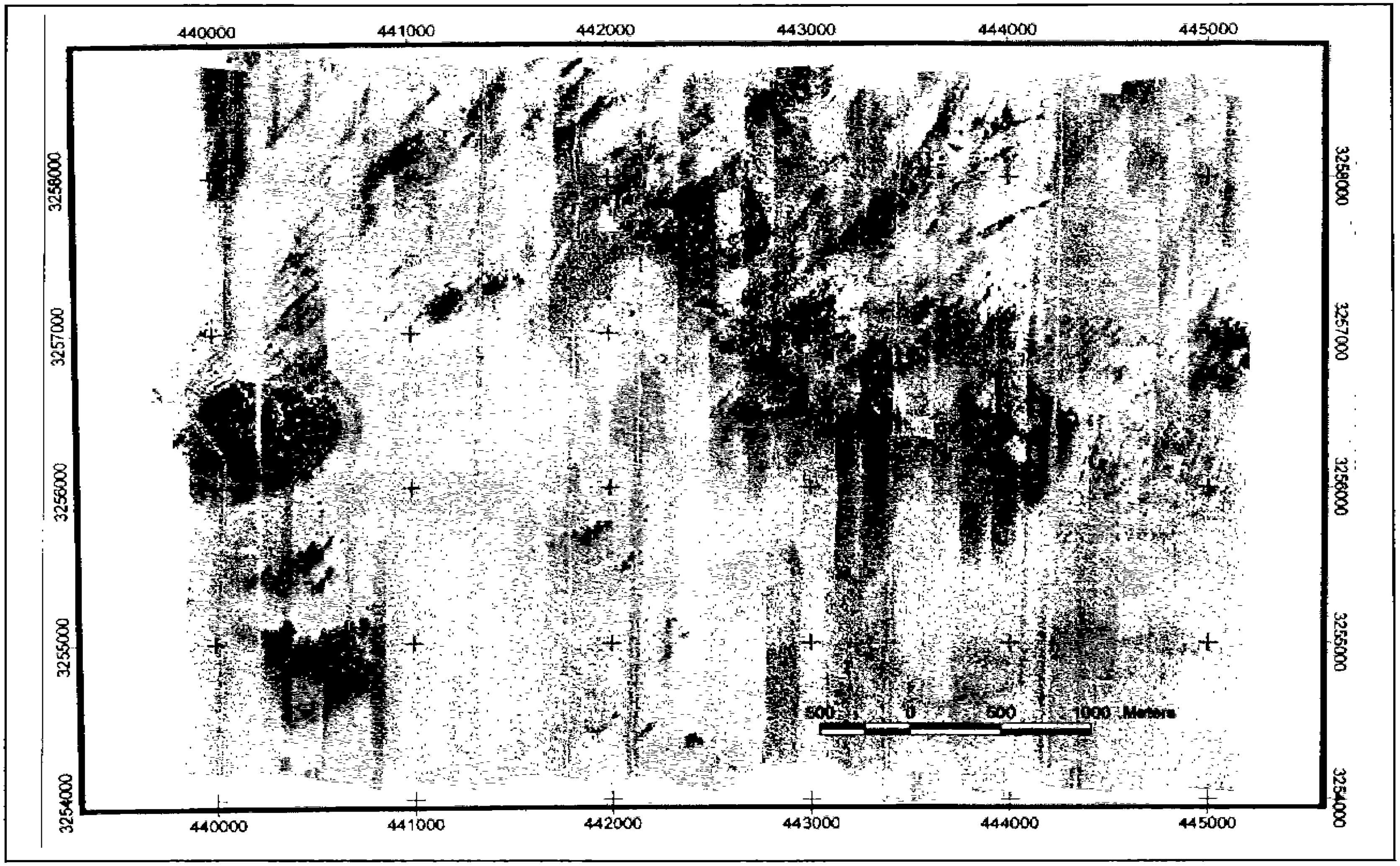

Figure 2F.3. *TAMU*^{2} side-scan sonar mosaic of Megasite 1. Vertical (north-south) image strips 175 m in width have been combined to make a sonar mosaic several kilometers on a side. Dark areas (sonar-bright) show places on the seafloor where sound is strongly reflected back to the sonar whereas light areas (sonar-dim) show places where sound is not strongly reflected or there is an acoustic shadow. In general, rough seafloor and coarse textured sediments yield sonar-bright returns (Johnson and Helferty 1990). The boxes labeled Site 1 to Site 3 show the locations of monitoring sites within the megasite. Coordinates are UTM x and y (in meters).

interpretation. Sonar images such as these show variations in acoustic returns, which are caused by topography and seafloor roughness (Johnson and Helferty 1990).

TAMU[2] bathymetry data were processed into depth grids with a 15-m spacing for the megasites and a 1-m spacing for small areas around the monitoring sites. These data have been plotted at a 1-m contour interval for interpretation (Figure 2F.4).

Subbottom profiler data are being studied to examine the thickness and character of shallow sediments in the study areas. The profiles have been analyzed using standard seismic stratigraphic techniques (e.g., Mitchum *et al.* 1977), which involves recognition and correlation of acoustic reflectors by their characteristics and mapping and interpretation of seismic facies.

During Cruise 1C in April 1997, 94 grab samples and 13 box cores were collected to provide surficial sediment samples for grain-size measurements. On each of two subsequent cruises, 45 grab samples were collected by re-occupying previous grab stations from the first cruise. These repeat samples reflect sediment variability. Standard grain-size analyses are performed on these samples.

Digital underwater photographs and videos were taken at 100 random stations at each of the nine monitoring sites on three monitoring cruises. Although these photographs were taken to characterize benthic organisms, they are also useful for examining geologic substrate character. We have examined these photographs for various geologic characteristics (Table 2F.1). The photographs show an area less than one meter on a side, so most of the characteristics are relevant to small-scale features (i.e., centimeter size); however, by using video camera records during the approach and departure from each station, other larger scale characteristics can be determined. By plotting the various characteristic descriptors at station locations and comparing, it is possible to examine relationships among characteristics.

Three sediment traps and one optical backscatter (OBS) instrument were deployed on each of six current moorings. The sediment traps were used to measure sedimentation rates and resuspension flux and the OBS devices were used to monitor the occurrence of nepheloid layers. The sediment traps were mounted on the moorings at 2, 7, and 15 m above the seafloor, the idea being that the lower sediment traps yield resuspended sediments near the seafloor. The OBS was mounted at 2.3 m. Four of the moorings were deployed at one location for the entire study, at monitoring sites 1, 4, 5, and 9. The other two moorings were periodically moved; they were deployed at Site 1 for the first year and Site 5 for the second year. Vertical profiles of conductivity, temperature, and optical backscatter were taken at each station on each mooring service cruise (approximately every 6 months).

RESULTS AND DISCUSSION

Geophysical Data

Three sites were similar in their bathymetric and side-scan image characteristics and two were dissimilar. Megasites 1, 3, and 5 all show mostly subcircular mounds of varying diameters typically arrayed in tight to loose clusters (Figure 2F.3). The mounds have relief ranging from less than a

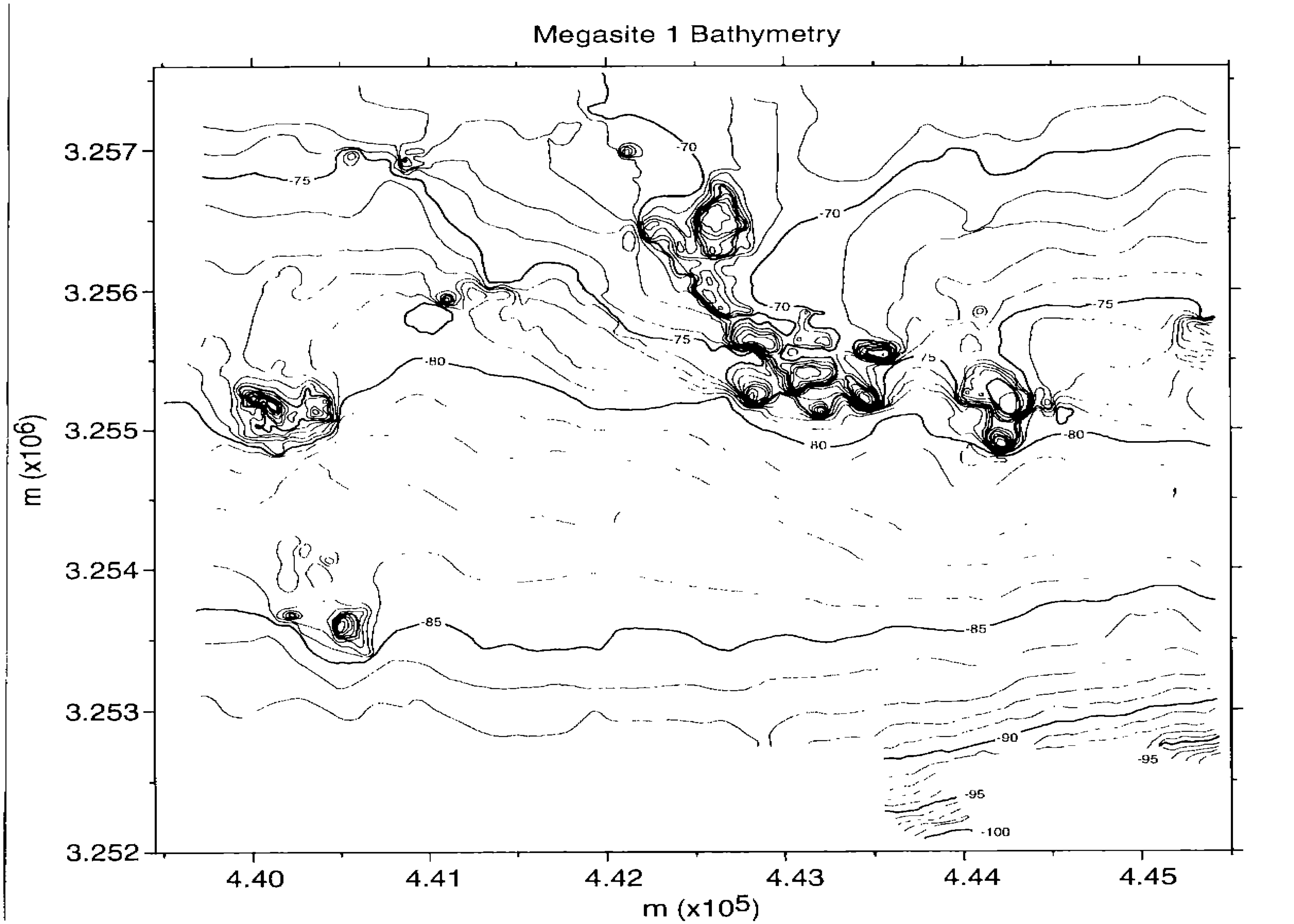

Figure 2F.4. *TAMU*[2] sonar bathymetry map of Megasite 1. Contours at 1-m intervals with every multiple of 5-m shown with a heavy line. Coordinates are UTM x and y (in meters).

Table 2F.1. Geologic descriptors of the seafloor at ROV photo stations.

General	Morphology (large scale)	RLM type	Relief (scale m)	Roughness (scale cm)	Sediment texture	Sediment Cover
No rock visible	NA	NA	Flat Depression Mound	NA	Fine Coarse Shell hash Rubble	NA
Rock outcrop	Boulder Ridge RLM	Base Face Top Flat Overhang	Low Medium High	Low Medium High	Fine Coarse Shell Hash	None Partial Complete Rubble

NA=not applicable

meter to greater than 10 m and have diameters ranging from several to hundreds of meters. Megasite 4 was found to be devoid of large mounds and mound clusters, whereas Megasite 2 contains many tall, irregular mounds often occurring atop broad, low, carbonate hard grounds. Megasite 3 also contained two somewhat similar low hard grounds. The mosaics show that most mounds are subcircular in shape (i.e., having aspect ratios near 1). Often larger mounds consist of smaller, subcircular elements, as if the bigger mounds formed by the coalescing of many smaller mounds. In several places, notably megasites 3 and 5, a few large linear mounds were observed and typically these are aligned along the isobath contours.

Flat seafloor in the survey areas typically shows up as light gray, which indicates weakly-reflective fine grained sediments. Grab samples indicate these are sands containing few larger grains. Mounds within the megasite mosaics are typically "sonar bright" (i.e., they give high-amplitude reflections) owing to their roughness. In addition, they are also typically surrounded by sonar-bright sediments. Grab samples indicate this high acoustic return from the sediments around the mounds is due to coarser texture caused by greater concentrations of carbonate and shell fragments. In megasites 1, 3, and 5, the sonar-bright sediments are preferentially located on the southwest sides of the larger mounds and mound clusters, suggesting currents have preferentially concentrated coarse sediments in these locations. In addition, many medium-sized mounds have long, sonar-bright "tails" that trend to the southwest. These tails are correlated with shallow erosional channels on subbottom profiles, implying the tails are an indicator of current direction. Interestingly, the trends of these tails are relatively constant within each megasite, although they vary slightly from one megasite to another. The similarity in feature orientations suggests that regional currents caused the sonar-bright sediment patches on the southwest sides of the larger mounds. Subbottom profiles often show some indication of erosion in these locations as well, suggesting a relationship of sonar backscatter to erosion. Perhaps the bright patches result from winnowing of finer sediments and the resulting development of coarse lag deposits. Interestingly, the two deepest megasites, 2 and 4, show no preferred orientation of the sonar-bright patches around mounds. Indeed, at Megasite 2, these patches are symmetric around most mounds. It is not yet clear whether the bottom currents that caused these features are normal currents or whether the features were caused by one or more transient events, such as storms.

Bathymetry data show the mounds in megasites 1, 3, and 5 occur in water depths of –90 to –72 m. Typically the mounds are subcircular in shape, but occasionally they are linear, following isobath orientation. In Megasite 1, the mound clusters are not obviously aligned, but in Megasite 5, they are aligned nearly parallel to isobaths along the shelf edge. In Megasite 3, a linear, isobath parallel cluster is observed in addition to looser clusters not obviously related to depth. Megasite 2 contours show large irregular mounds, some low and broad and others tall and steep-sided. These mounds are also arrayed in linear clusters and near the shelf edge, but the lineations cross isobaths and so there is no clear relation to depth. Depth contours are often more widely spaced on the north sides of the mound clusters in megasites 1, 2, 3, and 5, indicating the damming of southward moving sediments by these topographic features.

Subbottom profiles in the study areas have proven useful for interpreting sonar features, especially where mound flanks are buried by sediment. Typically the profiles show a relatively uniform 1 to 2 m surface transparent layer overlying a somewhat thicker and more variable layer. In some, but not all profiles, the erosional unconformity presumably formed during the last glacial lowstand can be discerned. Because this unconformity is not widely imaged in this survey, the thickness of post-glacial sediments cannot be mapped over large areas with the existing data. Nevertheless, the nearly uniform transparent layer argues that recent sedimentation has been relatively constant.

ROV Seafloor Photos

ROV photos show highly variable substrate characteristics on and around the carbonate mounds. Away from the mounds, the seafloor is typically flat and nearly completely covered with fine-grained sediments. However, on the mounds and at their periphery, outcrops are common, roughness ranges from low to high, sediment cover is incomplete, the texture is typically coarse, and topographic gradients can be high (Figure 2F.5).

Sediment Grain Size

Grab sample sediments are typically clayey sands with a bimodal grain size distribution. This distribution is typically strongly peaked in the sand size range, reflecting the fact that the sediments are part of the MAFLA sand sheet (Ludwick 1964; Doyle and Sparks 1980), a transgressive relict sand. The mean grain size for all samples is 2.8 φ, in the fine sand range of the Wentworth scale. However, many samples have a significant clay fraction. This is clear from the sample distribution on a sand-silt-clay ternary diagram (Figure 2F.6) in which most samples group near the sand apex, but the distribution is nearly linear and trends toward the clay apex. It appears the sediments are a well-sorted sand into which a fraction of clay has been introduced. A likely source of this clay is the sediment plume of the Mississippi River (Shepard 1956).

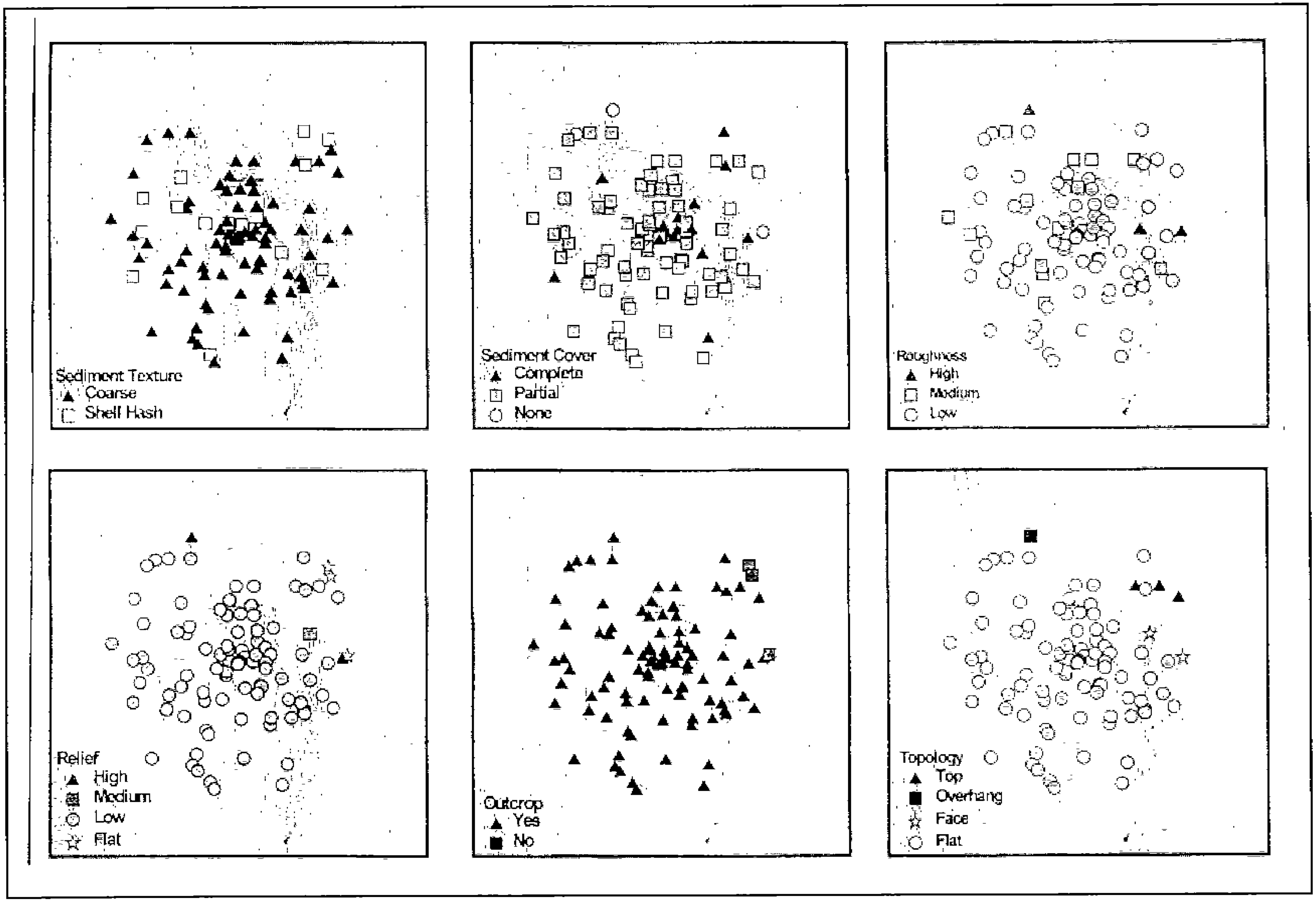

Figure 2F.5. Seafloor characterization from ROV photo stations for monitoring Site 1. Symbols show station locations; gray lines are 1-m bathymetric contours for reference. Each panel describes a different characteristic from Table 2F.1. The sides of each box are 300 m in length.

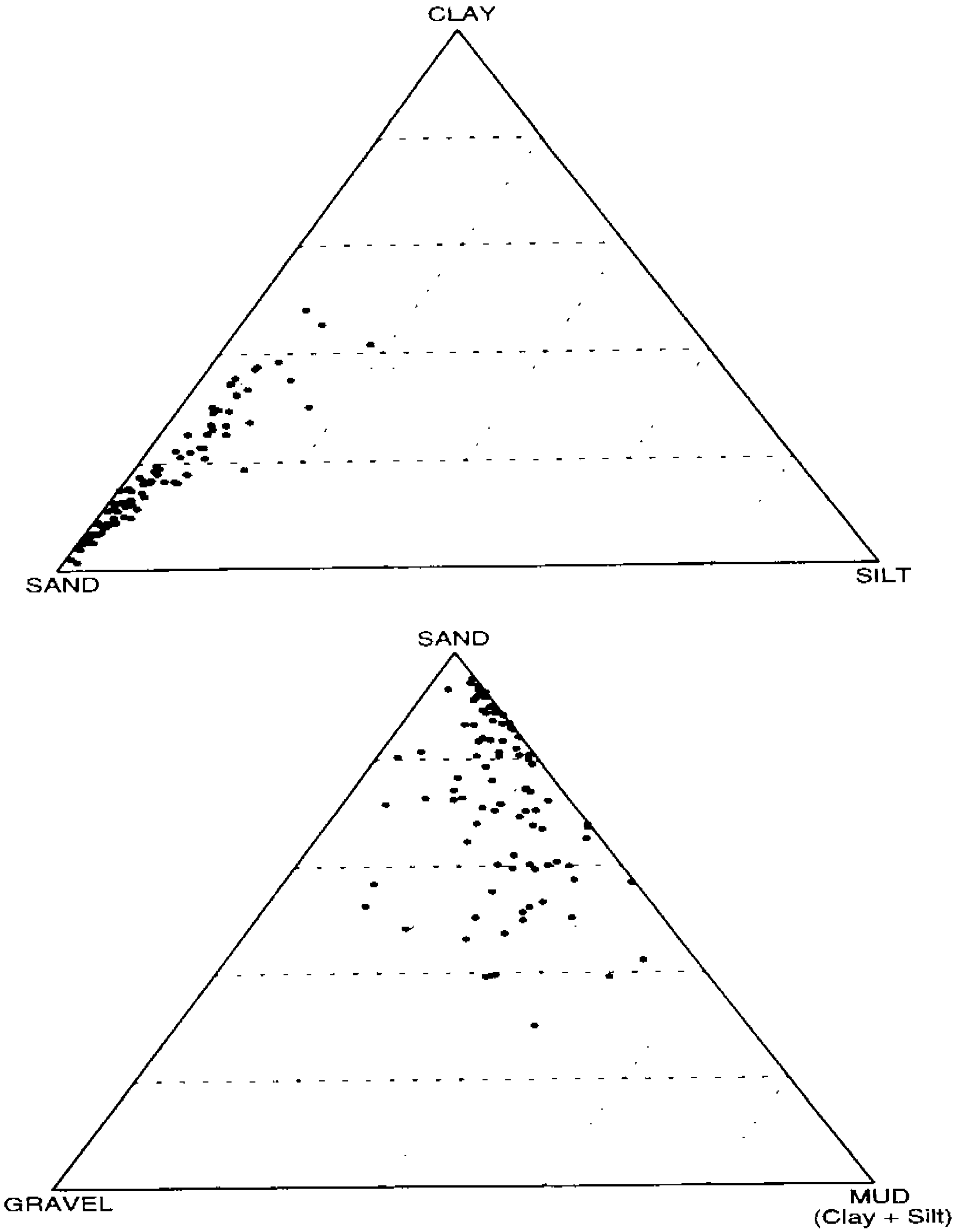

Figure 2F.6. Ternary diagrams showing the composition of Cruise 1C grab samples. At top, all samples are plotted on a sand-clay-silt diagram with values normalized after removal of the gravel fraction. At bottom, silt and clay are grouped (mud) and the gravel-size fraction is considered.

When the samples are plotted on a gravel-sand-mud (silt + clay) ternary diagram, the distribution shows greater scatter (Figure 2F.6). The samples still plot closest to the sand apex, but gravel concentrations range up to about 35%. This diagram shows that the greatest distinction in sediment character is the gravel fraction. This component typically consists of carbonate and shell fragments in addition to other biologic debris. It is typically greatest for samples near the larger mounds.

Sediment Dynamics

CTD casts show that particle concentrations are higher and salinity lower from east to west across the study area. This is consistent with the input of fresh, sediment-laden water from the Mississippi River. Nepheloid layers are present at most sites at most times. The nepheloid layers tend to be saltier and colder than surrounding water. Although benthic nepheloid layers are almost always observed, an intermediate layer is sometimes observed and the spatial and temporal variability is high. This indicates that the advective transport of sediment is important in the region.

Sediment traps show a steep mass flux gradient with the greatest mass flux at the nearest trap to the seafloor (Figure 2F.7). The logarithmic increase in mass flux to the bottom indicates significant resuspension of sediments at these stations. Temporal variability was large, with the highest fluxes recorded during January - May 1998 at Monitoring sites 4 (Megasite 2), 5 (Megasite 3) and 9 (Megasite 4), whereas fluxes at Monitoring Site 1 (Megasite 1) were highest during July - October 1997. The global average flux (all traps at all stations) was almost three times higher during the January - May 1998 sampling period than during the other periods.

SUMMARY

Geologic characteristics of carbonate mounds at five locations on the Mississippi-Alabama outer continental shelf have been assessed by the collection high-resolution geologic and geophysical data. Digital side-scan sonar data were collected to show mound morphology and sediment textural variations in addition to providing 100% bathymetric coverage. From these data a sonar mosaic and bathymetry map was made for each study site. The mosaics show mounds ranging in diameter from meters to hundreds of meters. The mounds are typically subcircular, but sometimes elongated or irregular. Acoustically-reflective sediments are associated with many mounds and the preferential occurrence of these sediments on the southwest sides of many mounds implies a relationship to current action. Bathymetry data show mounds ranging in height up to more than 10 m and occurring in tight to looser clusters. These data also indicate that many mound clusters occur along isobaths and that some restrict or dam sediment movement southward across the shelf. Seismic reflection profiles were also collected during along sonar track-lines to help with geologic interpretation and to show surficial sediment layers. These data suggest recent sedimentation has been relatively uniform throughout the region surveyed. Grab samples were collected to examine sediment grain sizes in comparison with the sonar mosaics. The grain size results show a three component system: a relict siliceous sand infiltrated by clay (probably from the Mississippi River) and gravel-size calcareous debris, shell fragments, and other biogenic material from the carbonate mounds. Close-up photographs and videos were taken of the seafloor using an ROV at each of nine monitoring sites and have been used to classify sea bottom characteristics. They show highly variable substrate

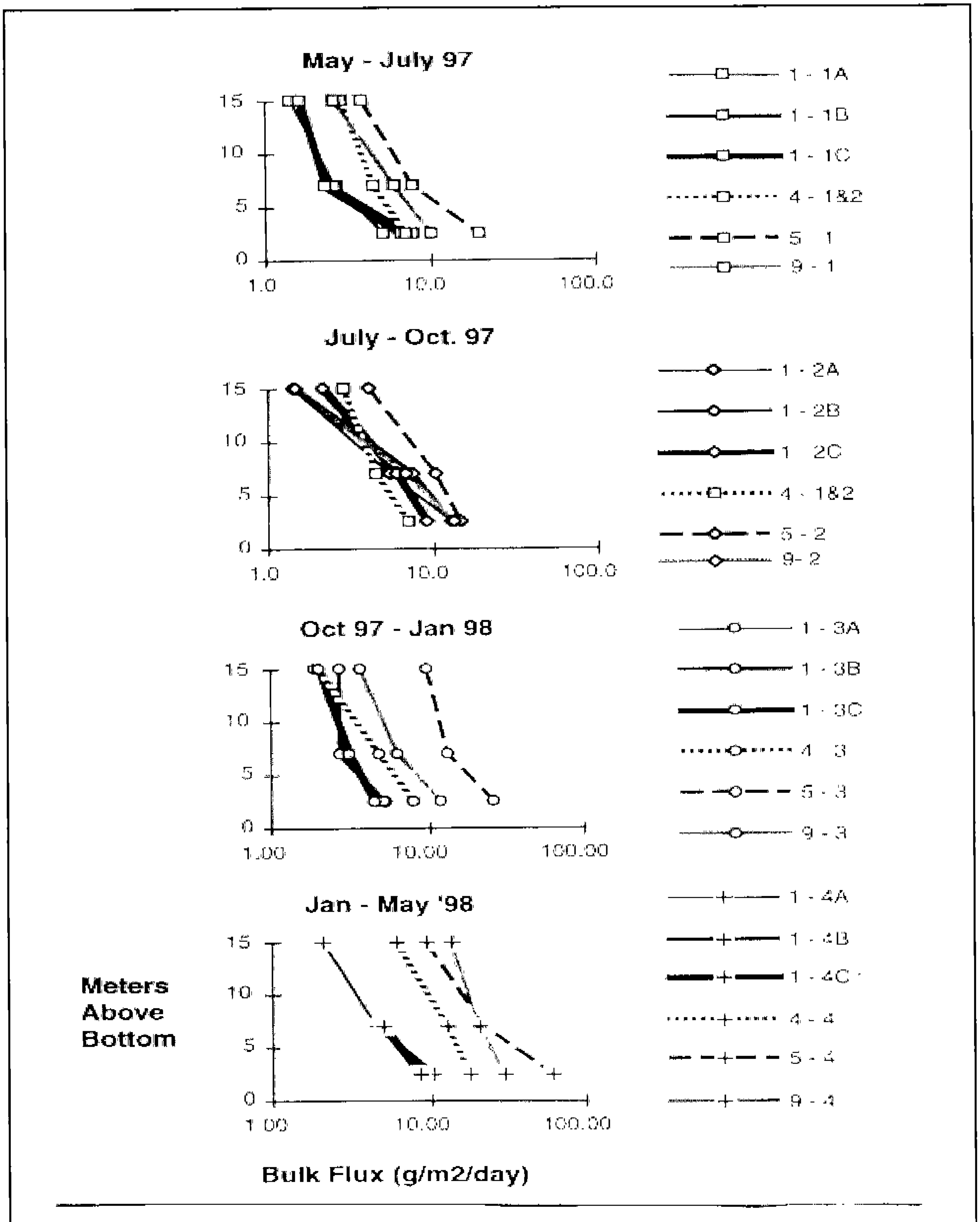

Figure 2F.7. Mass fluxes recorded in sediment traps during the four sampling periods of the first year of sampling (May 1997 to May 1998). Note the logarithmic flux scale.

characteristics around the mounds. Conductivity and temperature profiles and optical backscatter results collected at each of the monitoring sites show that nepheloid layers are prevalent, particularly near the seafloor. Sediment traps show a large particulate flux close to the sea bottom, consistent with significant resuspension. Together these results imply that advection is an important factor in outer shelf sedimentation. The overall picture given by this study is of a geologically complex and hydrographically-active regime.

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NORTHEASTERN GULF OF MEXICO COASTAL AND MARINE ECOSYSTEM PROGRAM: ECOSYSTEM MONITORING—PHYSICAL OCEANOGRAPHY AND HYDROGRAPHY IN THE MISSISSIPPI/ALABAMA PINNACLE TREND AREA DURING MAY 1997 THROUGH APRIL 1998 AND DURING SEPTEMBER 1998

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INTRODUCTION

The "Northeastern Gulf of Mexico Coastal and Marine Ecosystem Program: Ecosystem Monitoring, Mississippi/Alabama Shelf" is being conducted by Continental Shelf Associates, Inc. and the Geochemical and Environmental Research Group of Texas A&M University, for the U.S. Geological Survey (USGS), Biological Resource Division. The purpose of the physical oceanography and hydrography component of the program is to monitor environmental conditions at four of the topographic features in the study area (Figure 2F.8) so that other work elements can relate observed changes in community structure and zonation to changes in environmental conditions. The first year of observations from the moorings, May 97 – April 98, reveals the principal features of the flow field and the environmental parameters: temperature, salinity, turbidity, and dissolved oxygen. Observations during September 1998 were unique to the study thus far because of the passages of Hurricanes Earl and Georges and a 10-day period of persistent flow that suggests the intrusion of oceanic mesoscale flow onto the shelf.

METHODS AND RESULTS

Six physical oceanographic/sediment dynamics moorings were installed on 22-24 May 1997. Three moorings were installed at Site 1, and one each at Sites 4, 5, and 9 (Figure 2F.8). Each site will have at least one oceanographic mooring in place throughout the study. Two of the three moorings at Site

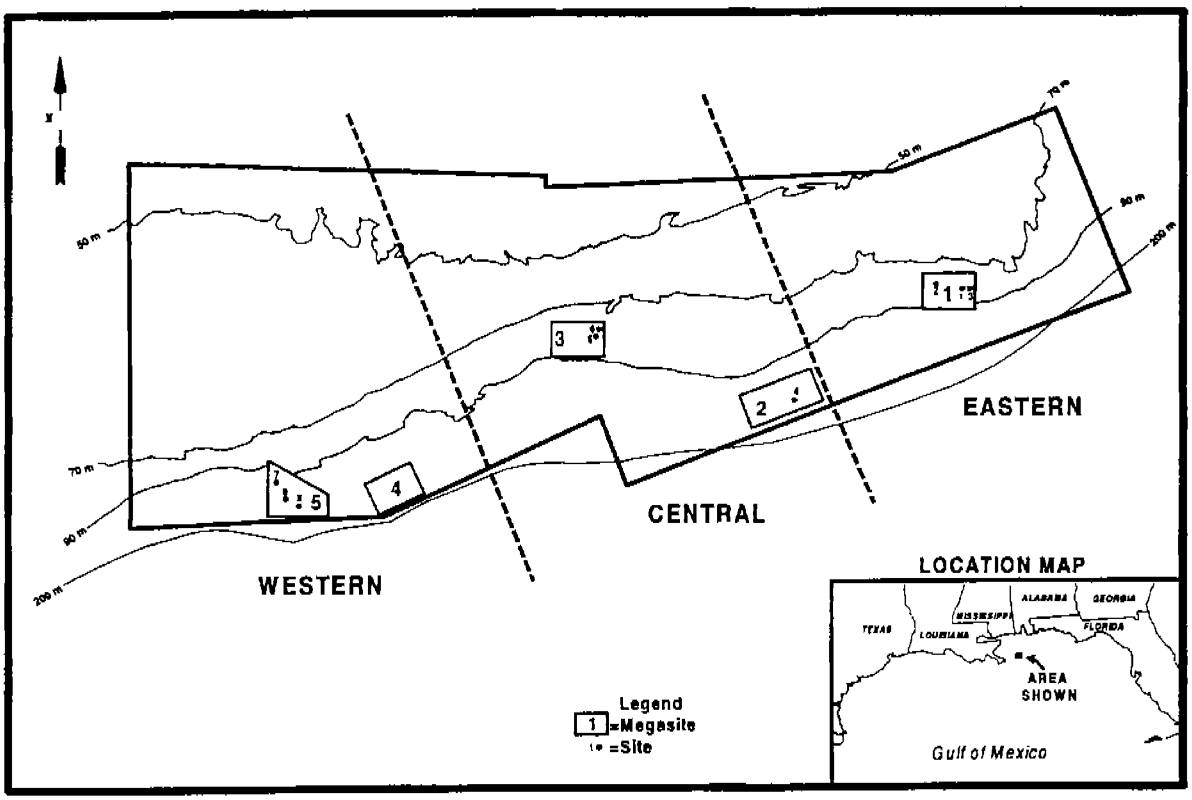


Figure 2F.8. Map showing the locations of the four sites at which instrument moorings are located. Site 1 is in Megasite 1; Site 4 is in Megasite 2; Site 5 is in Megasite 3; and Site 9 is in Megasite 5.

1 are "re-locatable" and were subsequently moved to Site 5 on 1 May 1998. Each mooring includes current meters, with temperature and conductivity sensors, at 4 and 16 meters above bottom (mab), sediment traps at 2, 7, and 15 mab, and an instrument at 2 mab that measures temperature, conductivity, DO, and turbidity.

The currents at 16 mab represent the mesoscale flow just above the pinnacles. This height is above the bottom Ekman layer. The larger pinnacles may slightly perturb the flow, a possibility that will be examined during the synthesis phase of the project. Across the entire pinnacle study region substantial similarity exists in the observed flow field. For example, Figure 2F.9 summarizes the current velocity observations at Site 1A (the northeast side of the pinnacle) over one year. The figure displays basic statistics, a scatter plot, and a table of joint frequency for speed and direction, which is the tabular version of a current rose. The most frequent direction octant and the direction of the vector mean current is northeast. The most frequent speed range is 5-10 cm/s, reflecting the normal tidal influence. Strong currents, i.e., greater than 35 cm/s, are most frequently directed to the southwest. The maximum currents at 16 mab approached 50 cm/s during the first year. Compared with the flow at 16 mab, the near-bottom flow at 4 mab was more site-specific. Bottom friction and the local topography influenced flow. The most frequent direction octants were those with a southerly component. Average scalar speeds were comparable at times to those at 16 mab, and mean vector speeds at some sites exceeded the overlying flow because of greater directionality.

Times series of dissolved oxygen and turbidity were collected at each mooring at 2.3 mab. Dissolved oxygen values were generally near or above 4 mg/L, except at Site 5 during the second deployment period. In this record, values were below 3.0 mg/L much of the time and fell below 2.0 mg/L during 18 to 28 August and 5 to 13 September 1997. Turbidity values at all sites were generally quite low, i.e., 0 to 2 NTU, with brief periods during which turbidity rose the 2 to 10 NTU range.

Temperature from the instrument moorings followed a small seasonal cycle with superposed variability caused by advective changes from tidal and inertial currents and possible intrusions by mesoscale water mass motion. Salinity ranged from about 34.9 to 36.8 but generally was in the 36.2 to 36.4 range. Values above 36.5 suggest possible intrusion of Loop Current related water.

CTD casts were taken during each of the monitoring and servicing cruises to assess the vertical profiles of salinity, temperature, photosynthetically-active radiation (PAR), transmissivity, backscattered light, and oxygen concentrations. During the monitoring cruises three profiles were generally taken around each site to assess variability at each site. In general, profiles at each site differed very little from one another. Figure 2F.10 summarizes the temperature-salinity relationships for the five cruises in the first year of the program. A composite T-S plot is given for each cruise (Figure 2F.10a-e), and for all casts of all cruises (Figure 2F.10f).

In May 1997 (Figure 2F.10a) salinity reached a maximum of about 36.5, which is typical of the upper waters of much of the Gulf of Mexico. In the upper part of the water column, the profiles at the shallower Sites 5 and 6 exhibited the coolest and freshest water, while the profiles at Sites 7, 8, and 9, which are closest to the Mississippi Delta, showed warmer fresh water. In July 1997 (Figure 2F.10b), all sites show little influence from fresh water. Fresher waters were again present in October 1997 (Figure 2F.10c), and all sites showed evidence of cooling. Colder waters in the upper layers were found at Sites 7, 8, and 9 and, interestingly, at Site 4. Warmer fresher waters were found at the other sites.

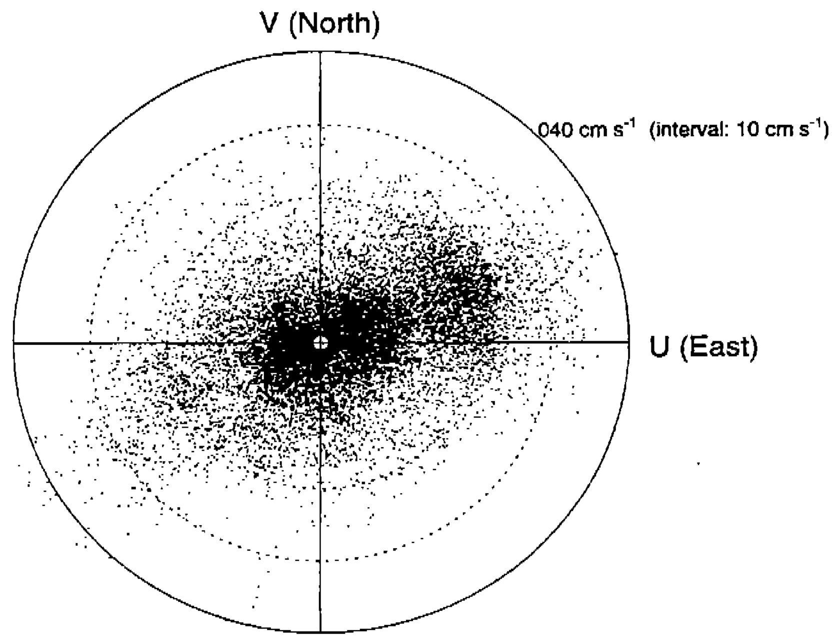
By January 1998 (Figure 2F.10d) all water temperatures were below 21C, and maximum salinities also decreased. Bottom salinities at many stations were below 36.0. This correlates well with the lower salinities recorded by the current meters during the third deployment period. In April 1998 (Figure 2F.10e), the upper waters were slightly warmer and much fresher. The freshest water was

C1A1 - 16 mab

START TIME: 05/23/1997 04:30 STOP TIME: 04/24/1998 15:00 GMT

	Num pts.	Mean	Std Dev	Minimum	Maximum
SPEED:	14105	11.12	7.91	1.10	49.60
U COMP:	14105	2.80	11.24	-45.07	40.02
V COMP:	14105	0.60	7.19	-36.36	29.87

MEAN CURRENT VECTOR: 2.86 cm s^{-1} @ 77.9° True



Speed (cm/s)	N	NE	E	SE	S	SW	W	NW	TOTAL
< 5	1.73	3.02	4.49	2.55	2.59	3.88	4.91	2.58	25.74
5 - 10	1.84	4.30	5.12	2.53	2.85	4.25	4.63	2.67	28.18
10 - 15	0.91	2.77	3.74	1.09	1.66	2.13	2.55	1.13	15.98
15 - 20	0.50	3.65	4.59	0.65	0.69	1.87	1.81	0.69	14.45
20 - 25	0.29	2.81	4.29	0.30	0.16	0.89	1.30	0.24	10.28
25 - 30	0.11	0.67	1.33	0.04	0.02	0.64	0.51	0.15	3.46
30 - 35	0.02	0.22	0.64	0.01	0.02	0.31	0.13	0.03	1.38
> 35	0.00	0.07	0.12	0.01	0.02	0.26	0.04	0.01	0.52
TOTAL	5.41	17.50	24.31	7.17	8.01	14.23	15.88	7.50	

Figure 2F.9. Summary of current meter observations at Site 1A at 16 meters above the bottom (mab) for the period 23 May 1997 through 24 April 1998: Basic statistics (top), scatter plot (middle), and percent joint occurrence of speed and direction (bottom).

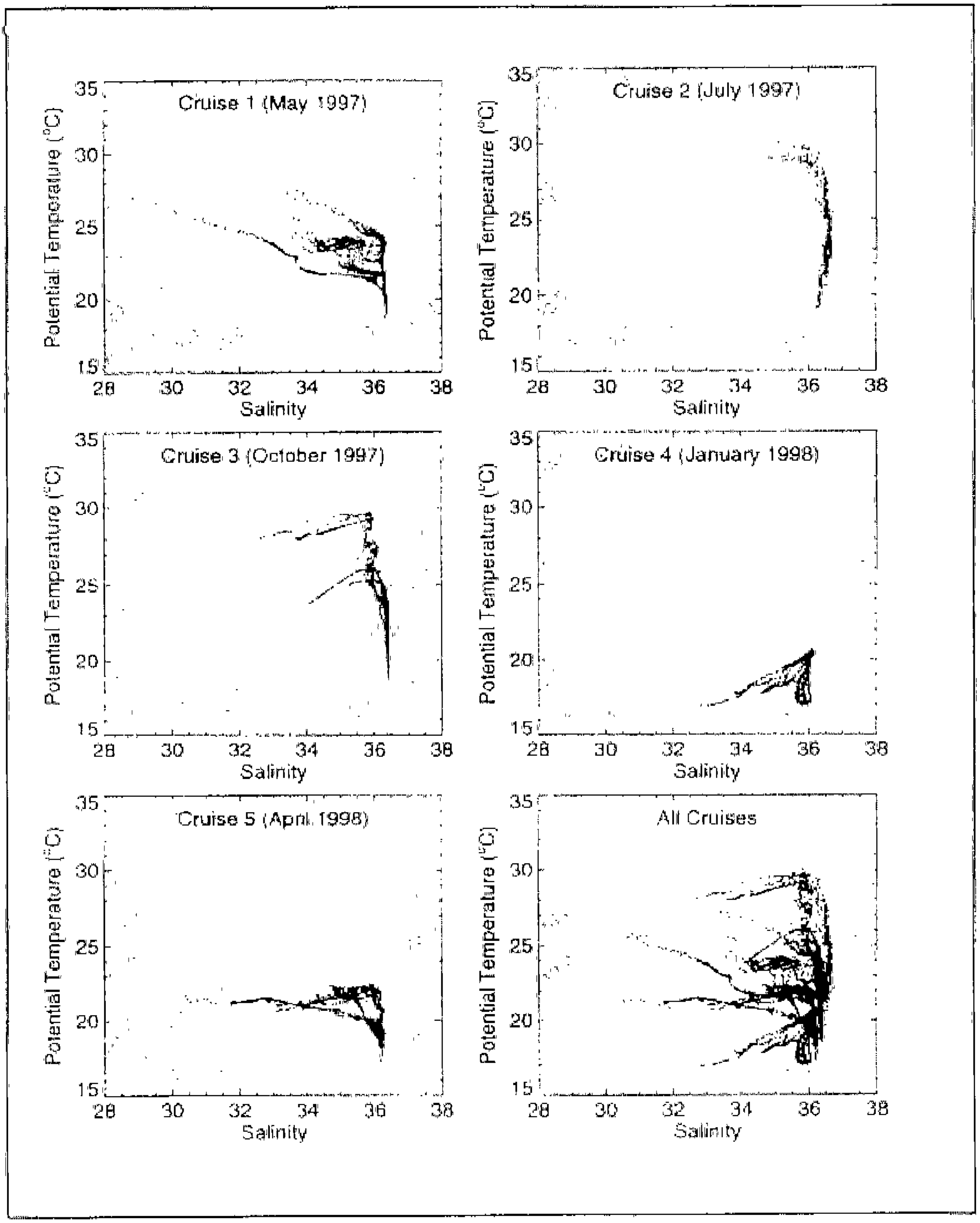


Figure 2F.10. Temperature-salinity relationships for the five cruises in the first year of the program. A composite T-S plot is given for each cruise (3a-e), and for all casts of all cruises (3f).

found at sites 4, 5, and 6 (lower cluster of points in Figure 2F.10e). Sites 7, 8, and 9 forming the middle cluster on this diagram with lower temperatures and salinities than at Sites 1, 2, and 3.

September 1998 was the most unusual month of the study thus far because of several events. Hurricane Earl's path crossed the eastern side of the study area on September 3 and the eye of Hurricane Georges passed directly over Site 5 on September 29. The resulting currents at 16 mab are shown in stick vector form in Figure 2F.11. Currents were strongest during Hurricane Georges. At Site 1, speed reached 96.7 cm/s. The direction of the hurricane driven currents was mainly southwest at Sites 1 and 4, and shifted between southwest and northwest at Sites 5 and 9. During Hurricane Earl, the response was about half that forced by Hurricane Georges, probably because Hurricane Earl moved more quickly across the shelf. Between the two events, an oceanic circulation feature may have intruded onto the shelf. Currents were persistently southwestward during September 11-21 at Sites 1 and 4, with speeds of 15-20 cm/s. This signature was also observed at Sites 5 and Site 9 for briefer periods.

The speeds recorded at 4 mab during September 1998 are shown in Figure 2F.12. The response to Hurricane Earl at this depth was strongest at Site 1, reaching about 50 cm/s, and almost nonexistent at Site 4. During Hurricane Georges, the response was strongest at Site 4, reaching 60 cm/s. Since the eye of Georges passed directly over Site 5, a barotropic response to sea level fluctuations is exhibited by the near bottom current. The intrusion event between the hurricanes is most evident at Site 4, where current speed exceeded 20 cm/s for eight days. The effect of the strong bottom currents during the hurricanes at Site 5 is shown in Figure 2F.13. Only during these events do turbidity values exceed normal background ranges.

SUMMARY

The statistics of currents measured at all sites measured are similar. The most frequent direction of the currents in the region is aligned with the trend of the large scale topography. At 16 mab, the most frequent current speeds are in the 5-10 cm/s range, which reflects the normal tidal currents in the region.

Hurricanes Earl and Georges forced large southwestward bottom currents, i.e., approximately 40-50 cm/sec for Earl and 90-100 cm/sec for Georges at 16 mab. At 4 mab the current speeds of 40-60 cm/sec were recorded.

Temperature and salinity profiles collected during five cruises in the first year of the program delineate a seasonal cycle that shows a pattern of mixing between the lower salinity shelf waters and higher salinity Gulf waters. Salinities rarely exceeded 36.5 and were often significantly reduced by freshwater influx into the area. Temperatures were always in a range of 17-31C during the CTD casts. However, the bottom moored instruments recorded temperatures between 10.8 - 23.4C.

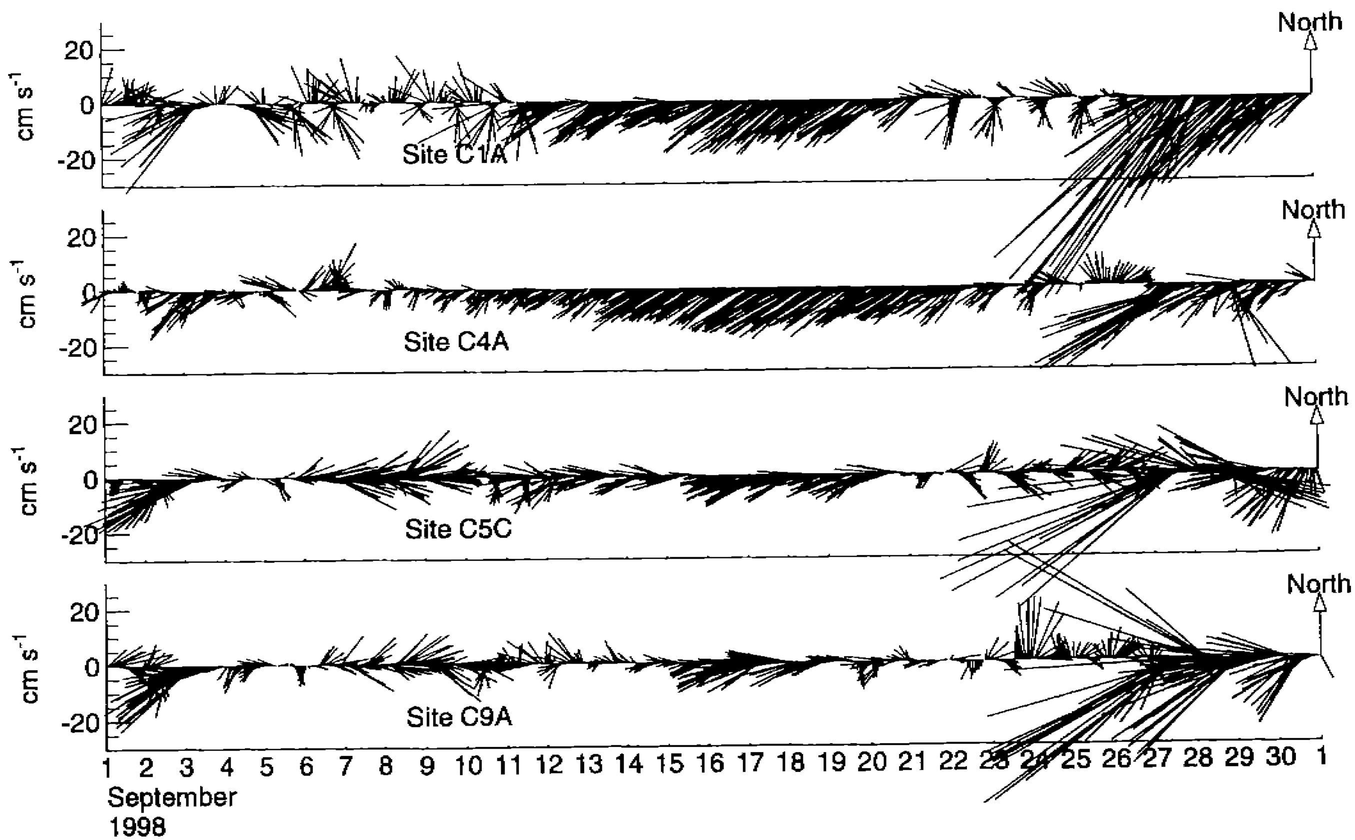


Figure 2F.11. September 1998 stick vector plot of currents recorded at 16 meters above the bottom (mab) at Sites 1, 4, 5, and 9. North is vertically upward, and a scale for the magnitude is in the left side of each panel.

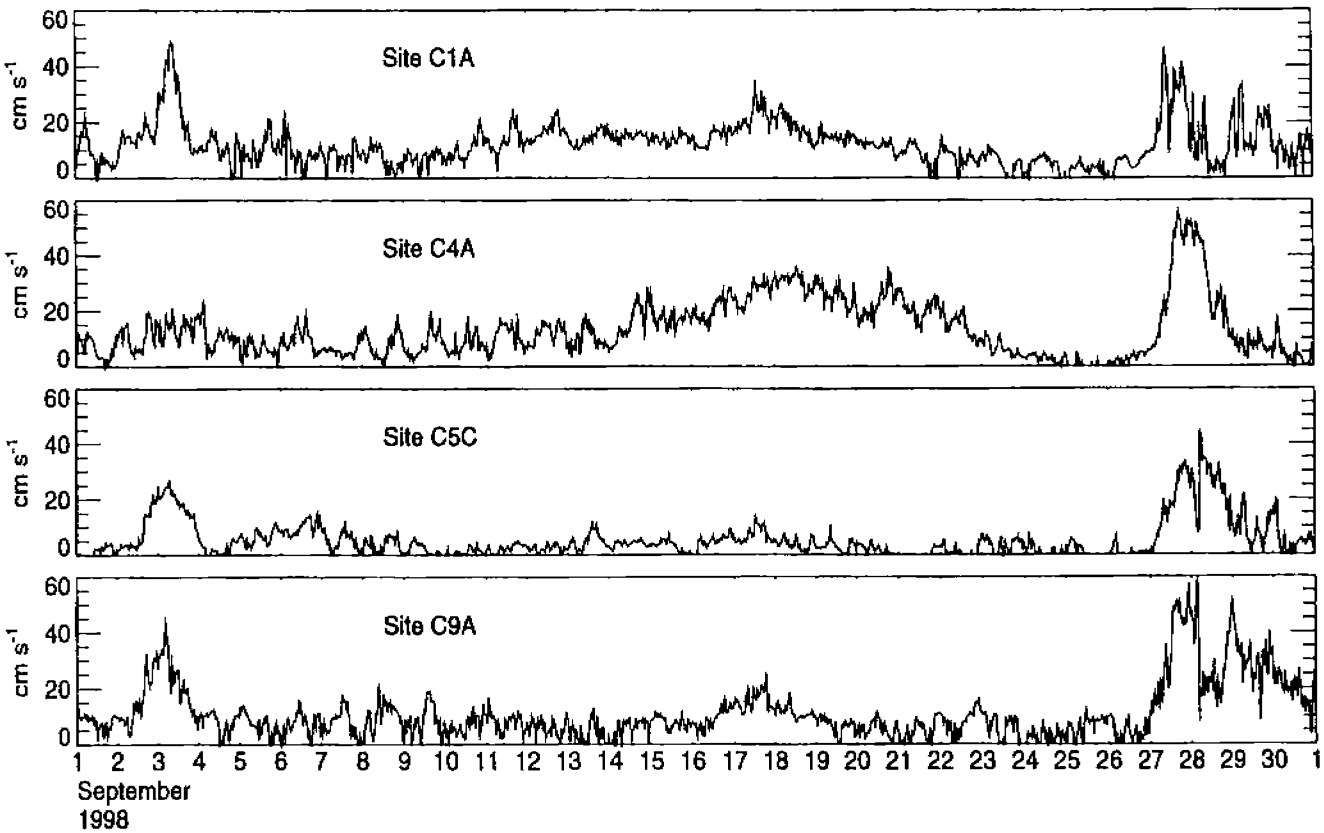


Figure 2F.12. September 1998 current speeds recorded at 4 meters above the bottom (mab) at Sites 1, 4, 5, and 9.

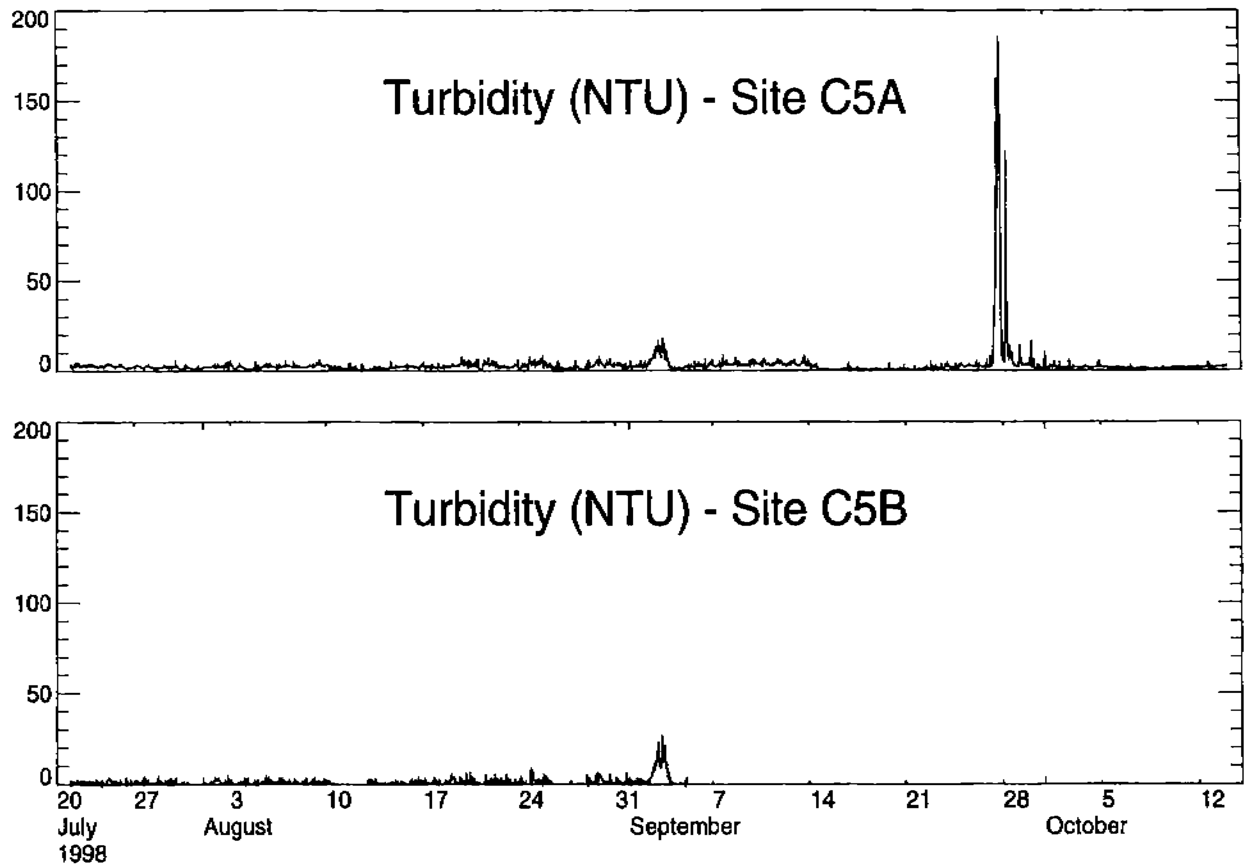


Figure 2F.13. Turbidity (NTU) recorded at Sites 5A and 5B at 2.3 meters above the bottom during 20 July through 14 October 1998.

ACKNOWLEDGMENTS

This work was supported by the U.S. Department of the Interior U.S. Geological Survey, Biological Resources Division, under BRD Contract 1445-CT09-96-0006, in cooperation with the Minerals Management Service, Gulf of Mexico OCS Region. The cheerful cooperation and assistance of the Captain and crew of the R/V Tommy Munro is gratefully acknowledged.

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NORTHEASTERN GULF OF MEXICO COASTAL AND MARINE ECOSYSTEM PROGRAM: ECOSYSTEM MONITORING, MISSISSIPPI/ALABAMA SHELF; HARD BOTTOM COMMUNITIES

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INTRODUCTION

A series of hard bottom features known as the Mississippi/Alabama pinnacle trend is the subject of this ecosystem monitoring program which includes geological, biological, and physical oceanographic study components. The primary biological component of the program is to describe and monitor epibiotal communities associated with nine hard bottom features within the Mississippi/Alabama pinnacle trend in water depths of 60 to 100 m (Figure 2F.14). A secondary biological component is to monitor and describe the fishes associated with the pinnacle features. This report describes preliminary results for epibiota and fishes from initial monitoring cruises.

OBJECTIVES

The objectives of this study component are as follows:

- to describe hard bottom (epibiota and fishes) community structure and seasonal dynamics at each site;
- to identify differences in community structure among sites differing in relief (low, medium, and high) and location (east, central, and west); and
- to understand relationships between community structure and environmental variables such as small-scale habitat variability, rock type, sediment cover, turbidity, and other geological and oceanographic variables.

MATERIALS AND METHODS

Hard bottom communities are being sampled at nine sites (Figure 2F.14) by remotely operated vehicle (ROV). Sampling sites were chosen to fall within three categories of relief (low, medium, and high) in three regions (eastern, central, and western). Site selection was based on data from geophysical surveys and ROV reconnaissance surveys. At each site, random photographs are taken

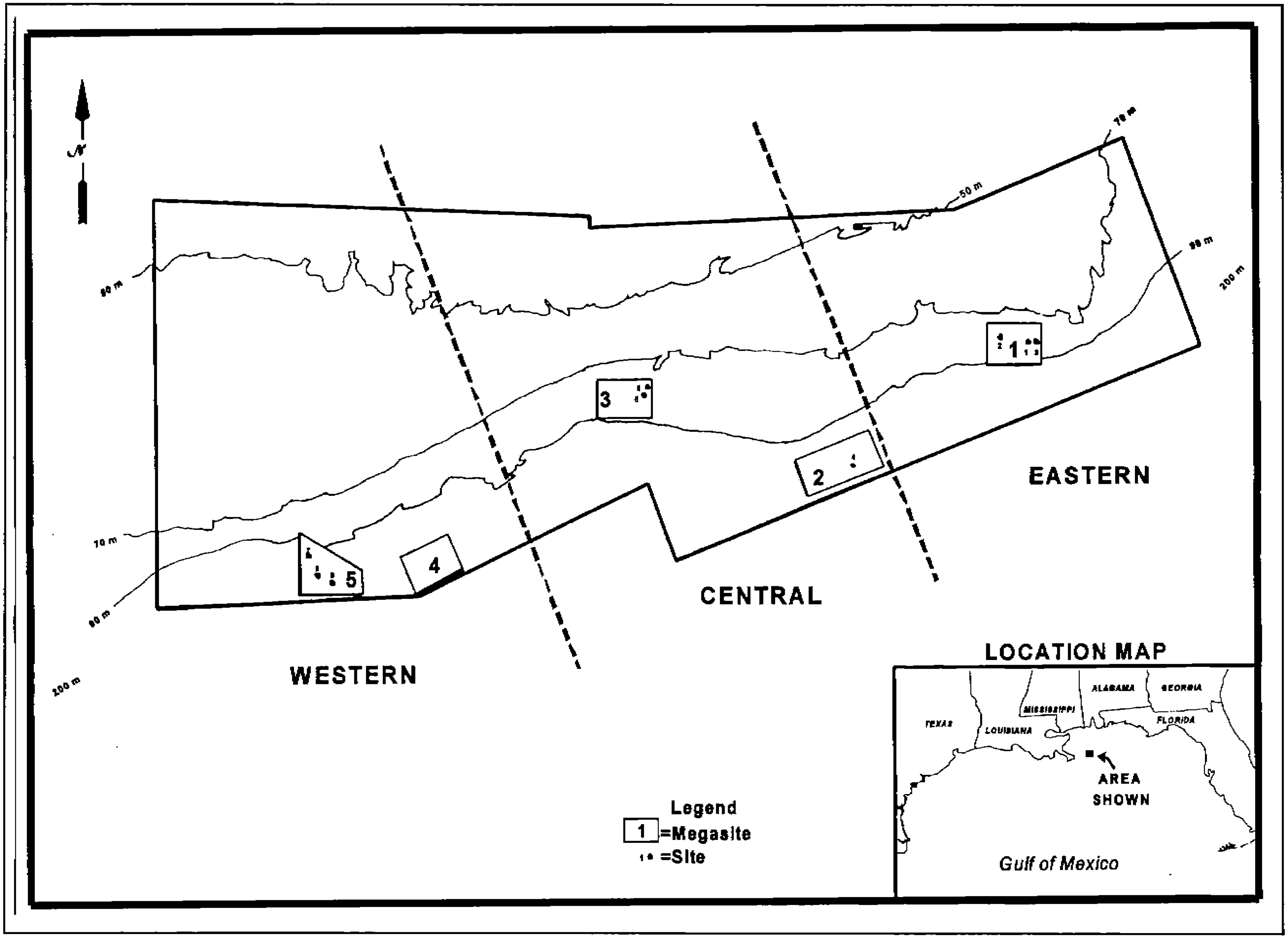

Figure 2F.14. Locations of final monitoring sites within the Mississippi/Alabama pinnacle trend in water depths of 60 to 100 m.

and random video transects are being surveyed using ROV during each of four monitoring cruises. Random photographs are used to estimate the abundances of sessile and motile epibiota, whereas video images are used to quantify larger and more widely dispersed organisms, including fishes, and to broadly characterize substrates and species composition. In addition, fixed video/photoquadrats have been established that are resampled on subsequent cruises; the data will be used to describe temporal changes related to growth, recruitment, competition, and mortality. Voucher specimens also are being collected to aid in species identification. Together with geological and oceanographic data collected during the program, these data will be analyzed and interpreted to describe hard bottom community dynamics, variation within and among sites, and relationships between the biota and physical variables. Frequency of occurrence of fishes is being recorded for the video transects made while navigating to the random photograph locations. A master list of fish species for all sites is being prepared from analysis of still and video photographic data. Four monitoring cruises have been scheduled to complete the field tasks. To date, three of four monitoring cruises have been completed: April 1997 (Cruise 1C), October 1997 (Cruise M2), and April 1998. At present, quantitative slide analyses have been completed for the April 1997 cruise. Fish analyses have been completed for the April and October 1997 cruises.

Percent cover, density, and diversity of epibiotal taxa are being estimated from quantitative photographs using random dot overlays and direct counts of solitary taxa. These biotic variables (particularly density) were related to physical variables using linear regressions. Associations among dominant epibiotal taxa were investigated through pairwise product-moment correlation analysis. For fishes, patterns of co-occurrence or association among taxa and similarity among stations were related to pre-defined location (east, central, and west) and relief (low, medium, and high) categories using multi variate analyses. These analyses included classification (cluster analysis) and Correspondence Analysis (CA) ordination of the taxa-by-samples data matrix.

RESULTS AND DISCUSSION

Hard Bottom Communities

A total of 790 random photoquadrats was analyzed from Cruise 1C. Most sites had at least 98 photoquadrats for analysis, but all but six photographs at Site 9 were rejected due to turbidity. Compiling the 10 most abundant taxa at each site yielded a list of 43 numerically dominant taxa. Cnidaria was the most-represented phylum with 13 taxa of octocorals, 10 of ahermatypic corals, 4 of antipatharians, and single taxa of hermatypic corals and actinarians (anemones). Porifera was next with five taxa, followed by Ectoprocta with four taxa. Ahermatypic corals had the highest mean density of 327.97 organisms/m^2 over all sites, due to the numerical dominance of *Rhizopsammia manuelensis*. Octocorals were second with 9.43 organisms/m^2, followed by poriferans, ectoprocts, and antipatharians with 5.30, 3.17, and 2.75 organisms/m^2, respectively. Densities and numbers of taxa at each site were highly variable.

Little of the biological variation among sites apparently is due to water depth, vertical relief, distance from the Mississippi River, or suspended sediment flux. Only 8 of the 21 taxa recorded at six or more sites had statistically significant regression coefficients for any of these physical variables, and there was no consistent pattern to the results. However, density of the numerically dominant *R. manuelensis* increased with proximity to the Mississippi River.

Significant correlations occurred between 20 pairs of taxa. Highly significant correlations among *Antipathes furcata*, *Ellisella* sp., and the large white solitary scleractinian are probably the result of their common significant positive association with depth. The tan-purple solitary scleractinian, the white solitary scleractinian, *Paracyathus pulchellus*, and *Madracis myriaster* also were significantly correlated, but with no apparent effect of the four physical variables.

Despite the preliminary nature of the results, several findings conflict with those reported by others. For example, Gittings *et al.* (1992) reported abundances of *Rhizopsammia*, and overall organism abundances were positively related to distance from the Mississippi River at a range of 27 to 70 km. The new data indicate, however, that abundances of this species and the combined densities of the 43 dominant taxa are negatively related to distance from the river at a range of 70 to 145 km. It is not known whether this contradiction is enigmatic or whether it indicates abundance maxima at approximately 70 km from the Mississippi River. Also, the results do not indicate increases in the density of epibiota or number of taxa with increasing vertical relief. However, this preliminary analysis focused on between-site variations, whereas the physical and biological variations within sites may be nearly as large as those between sites. The more detailed statistical analyses planned for future reports should help address these questions.

Fish Communities

Analysis of videotapes from Cruises M2 and 1C revealed 78 fish taxa in 27 families. The most speciose families were sea basses (Serranidae), squirrelfishes (Holocentridae), lizardfishes (Synodontidae), jacks (Carangidae), wrasses (Labridae), and butterflyfishes (Chaetodontidae). The most frequently occurring taxa in the videotapes were roughtongue bass (*Pronotogrammus martinicensis*), short bigeye (*Pristigenys alta*), bank butterflyfish (*Chaetodon aya*), red barbier (*Hemanthias vivanus*), and tattler (*Serranus phoebe*). These taxa represent the deep reef fish assemblage reported for water depths of 50 to 100 m in the western Atlantic. Similar species have been reported by previous investigations of the pinnacle features (e.g., Continental Shelf Associates, Inc. 1985; Brooks 1991). These species represent deep reef assemblages similar to those described for other portions of the Gulf of Mexico (e.g., Shipp and Hopkins 1978; Dennis and Bright 1988) and off the southeastern U.S. coast (Parker and Ross 1986).

Taxonomic richness recorded from videotapes for each cruise differed across all sites. During Cruise 1C the number of taxa observed ranged from 5 at Site 9 to 22 at Site 7 and averaged 15.3 taxa per site. Cruise M2 yielded an average of 20.7 taxa per site with a range of 13 taxa from Site 6 and 30 taxa from Site 1. The correlation between average depth at each site and number of taxa was ($r=0.55$) for Cruise 1C and ($r=0.69$) for Cruise M2.

Video transects from Cruise 1C yielded 44 taxa compared to those taken during Cruise M2, which produced 67 taxa. The similarity in taxonomic composition measured by the Phi coefficient for each site between the two cruises ranged from 0.30 at Site 4 to 0.51 at Site 2. The most frequently occurring taxa showed similar patterns across sites between cruises. Cluster analysis did not resolve distinctive patterns with respect to location and relief. Ordination showed some weak differences related to location, with eastern samples separating from the central and western samples. Also, western samples showed more variability than the eastern and central samples. Qualitative data on the scale of the study area as used here may be too coarse to resolve any differences of similarities that may exist among the sites, with respect to depth or location. A closer examination, at the level of transects within sites along with an analysis of substrate preference of the dominant species, will be undertaken in the final synthesis report.

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Mr. David B. Snyder is a senior staff scientist with Continental Shelf Associates, Inc. He has 15 years of experience with aquatic environmental assessment and research programs for federal, state, and industrial clients. He has participated as Research or Chief Scientist on over 50 scientific cruises conducted in domestic and international waters. Mr. Snyder has managed several fishery-related projects including bycatch studies, life history studies, and ichthyofaunal assessments in a variety of marine and freshwater habitats. Mr. Snyder received his B.S. in zoology from the University of Florida in 1978 and his M.S. in ichthyology/marine biology from Florida Atlantic University in 1984.

Mr. Dane D. Hardin, a senior scientist for Applied Marine Sciences, Inc., has pioneered the application of quantitative biometric techniques to rocky epibenthic communities, both intertidal and subtidal. These techniques have included utilization of manned submersibles and remotely operated vehicles (ROV) for photographic sampling of deep reef communities on the outer continental shelf (OCS). These methods are now standard on the California OCS for determining impacts on reef communities caused by oil development operations, and are presently being used on the Minerals Management Service (MMS) long-term monitoring study (CAMP Phase II) which was conducted in the Santa Maria Basin. Mr. Hardin received his B.A. from the University of California, Santa Cruz in 1967.

Mr. Spring is a senior scientist with Continental Shelf Associates, Inc. He has over 18 years of oceanographic and environmental science experience. He has served as Project Manager on numerous complex oceanographic studies, including multidisciplinary baseline studies, photodocumentation surveys, site clearance studies, and environmental monitoring programs for offshore drilling and dredged material disposal. He has served as Chief Scientist on more than 80 oceanographic surveys in the Gulf of Mexico, off the east coast of Florida, and within the Caribbean. Mr. Spring received his B.S. in biological sciences from S.U.N.Y. at Brockport and his M.S. in biological oceanography from Florida Institute of Technology in 1981.

Mr. Graham is a senior staff scientist with Continental Shelf Associates, Inc. He has extensive experience in field studies of marine benthic communities. He has served as Project Manager and/or Chief Scientist on numerous oceanographic studies, including multidisciplinary baseline studies, photodocumentation surveys, and environmental monitoring programs. He has been responsible for the analyses of more than 9,000 quantitative/ qualitative photographs of hard and soft bottom collected in areas that include the Gulf of Mexico. Mr. Graham received his M.S. in Biological Sciences from Florida Institute of Technology in 1983 and his B.S. in Biological Sciences from the University of New Hampshire at Durham in 1979.

Mr. Viada specializes in the ecology of benthic communities. He has had over 18 years of experience utilizing techniques of photography for the qualitative and quantitative analysis of benthic communities throughout the Gulf of Mexico, Alaska, California, the Sea of Okhotsk (offshore Sakhalin Island, Russia), the United Arab Emirates, Australia, the Bahamas, and the Caribbean. He also has over 18 years of experience as a specialist with the taxonomic identifications of Scleractinia and Octocorallia (stony corals and soft corals, respectively) within these localities. Mr. Viada received his M.S. in Biological Oceanography from Texas A&M University in 1980, and his B.S. in Zoology from Texas A&M University in 1978.

EPIBIONT RECRUITMENT

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Ms. Tara Holmberg
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OBJECTIVES

The goal of the companion study is to support the descriptive and monitoring portions of the program with experiments (based on testable hypotheses) that define ecological mechanisms responsible for spatial and temporal differences in hard bottom epifauna communities.

INTRODUCTION

Spatial and temporal variations of hard bottom communities are functional responses to biotic and abiotic processes. There are primarily three biological processes: recruitment, competition, and predation. Abiotic processes effecting spatial and temporal variability in shallow coastal zones are known to include seasonal temperature and salinity changes, desiccation, abrasion due to waves, turbidity due to resuspended sediments, turbulence, and stochastic disturbance events. In deep water (e.g., the Pinnacle Habitat), temperature, salinity, and desiccation are not important determinants, but abrasion, turbidity, turbulence, and stochastic disturbance events may play an important role in the distribution of epibiont abundance and biomass. The ecological processes affecting standing stocks and recruitment are jointly classified as disturbance. These processes are both physical and biological in origin, but distinguishing between the two in field experiments is difficult. For example, cages exclude predators, but disrupt normal water flow over settling surfaces. In the current study, water flow disruption was isolated, but other processes (e.g., predation and competition, and abrasion) were unseparated and are called disturbance.

EXPERIMENTAL DESIGN

Settling plate experiments with exclusion, settlement, and control treatments were used to study the biotic and abiotic interactions that regulate growth and settlement of epibiont communities. The settling plates are attached to a mooring, and the entire device is called a "biomooring." There are two major deployments: one for a spatial and one for a temporal study. The major elements of the settling plate experiment studies are

1. Spatial study at four stations to last for one year
2. Replication of the spatial study during the second year
3. Two settling surface treatments: hard and soft
4. Three settling plate treatments: uncaged, caged, and partially-caged

5. Three heights, or distances, from the bottom (0 m, 2 m, 13 m)
6. Time series study at one station, three cruises over two years

The temporal study at Site 4 consists of eight biomoorings and was designed to test for differences in recruitment and growth over time. Originally, quarterly retrievals of one biomooring each over a 2-year period were scheduled. Because of sampling difficulties and logistical problems, one cruise per year has been allotted for retrieval of the temporal samples. The slow recruitment rates observed from the first set of samples indicate that the longer time period improved the design. Sampling more frequently would not have detected differences among treatments because of the slow growth rates.

The spatial experiment is designed to test for differences among habitats. One biomooring was deployed at pinnacle Sites 1, 4, 5, and 9 at approximately the same water depth. This experiment is proceeding as originally planned.

The first deployments of biomoorings are resting on the bottom (0 m height) because of shackle failure. The second deployments of biomoorings were suspended at the planned heights of ~2 m and ~13 m from the bottom. This change enhances the project because we are now sampling three heights from the bottom (0 m, 2 m, 13 m). Recruitment may be more likely to occur at habitat surfaces, so the 0 m height may yield different results from those suspended in water.

FIELD METHODS

Settling plates are arranged in three experimental treatments: an uncaged treatment, a caged treatment, and a partially-caged control treatment. The uncaged settling plate measures net recruitment with biotic and abiotic interactions. This includes gross larval settlement, recruitment, growth, community development, and losses due to predation and disturbance. The caged settling plate is the experimental treatment to exclude ecological effects due to predation and disturbance. A common problem with enclosures is that water flow at the settling plate surface is changed. Therefore, a cage-control treatment is added to subtract effects due to the enclosure. This control is a partial cage that would have the same effects on water flow, but would allow predators access to the experimental treatment. Thus, the control treatment includes net recruitment in addition to water flow interactions. The effects on rates of recruitment by ecological processes, water flow, and net recruitment are then calculated by subtraction of the experimental treatments.

The three experimental treatments (uncaged, caged, and partially-caged control) are attached to one another forming a "Y"-shaped triad. Each treatment consists of four settling plates, or replicates, that has been attached to the triad. Three of the replicate settling plates are hard surfaces made of ceramic tiles and the other is a soft surface made of outdoor carpet. Each biomooring consists of an anchor, six triads, and a float. A common pitfall in these types of experiments is pseudoreplication, where the treatment levels (uncaged, caged, and partially-caged control) are not replicated. To avoid pseudoreplication, there are three replicate triads at two different depths on each biomooring. The replicate treatments have been placed on the wire so that there is no vertical bias in sampling. Each triad contains 12 settling plate replicates (3 experimental treatment replicates × 4 plate replicates).

Together, each depth treatment consists of 36 samples (3 treatments × 3 replicate treatments × 4 sub-treatment replicates).

LABORATORY METHODS

Settling plates are scored for abundance as per cent cover by both colonial and non-colonial organisms to the lowest taxonomic level possible. In many cases, identification is to the phylum level as many organisms are newly settled. Many larval forms have similar morphologies or characteristics and do not have adult characteristics that allow differentiation. For example, many species of bryozoans and hydroids both have stoloniferous morphology. The stolons may extend for several centimeters without any unique, identifiable characteristic to distinguish the two phyla. In addition, there are many unknown taxa, which are mostly gelatinous organisms without structures or are recently settled larvae without distinguishing features.

A $^{14\text{-mm}2}$ mesh grid is placed over the plate. The outer 7.5 mm edge is not scored to account for possible inconsistencies in the actual surface area exposed. By using a mesh grid, the 3-D coverage is scored accurately. The settlement plates are analyzed using a dissecting microscope at 250x magnification.

It is likely that some organisms settling on the plates are new to science. There has not been much systematic work done in this region of the Gulf of Mexico on small, epibiont, deep water organisms. As the Pinnacle Habitat is unique, it is quite likely that there are several new endemic species.

RESULTS

The first time-series biomoorings were deployed in May 1997, and a single biomooring from site 4 was retrieved in October 1997. The biomass of organisms is small and total coverage of organic matter is extensive. The organic matter is primarily due to stoloniferous bryozoan and hydroid colonies that comprise an average of 72% of total coverage by stolons on the settlement plates (Table 2F.2). While the sample size was too small to calculate statistical significance, coverage by all taxa except the uncolonized and Rhizopoda decreased in the uncaged and partial cage treatments (Table 2F.3). Most taxa appear to be limited by either water flow, disturbance, or both, but Rhizopoda recruitment appears to be enhanced (Table 2F.4). Gross recruitment rates over time are highest for bryozoans and hydroids and lowest for non-colonial organisms.

CONCLUSIONS

Gross recruitment rates are very slow while total coverage on settlement plates was high. Coverage was comprised almost entirely of small, stoloniferous, colonial organisms. There were also low numbers of annelids and other larger organisms (Table 2F.2). The plates contained an early stage succession community. Generally, early succession communities are characterized by low diversity, opportunistic (or *r*-selected) species, high growth rates, and small animals (Odum 1969, Rhoads *et al.* 1978). In contrast, late succession communities are characterized by high diversity, specialized

Table 2F.2. Mean coverage by taxa for all treatments after 6 months.

Taxa	Mean Coverage (%)
Stolon	72.14
Cnidaria	29.70
Bryozoa	25.97
Mollusca	0.87
Annelida	1.92
Rhizopoda	20.14
Uncolonized	1.53
Unknown (8)	37.68

Table 2F.3 Standing stock coverage by treatments after 6 months.

	% Coverage		
Taxa	Caged	Uncaged	Partial Cage
Stolon	80.37	78.56	57.49
Cnidaria	53.87	17.23	18.00
Bryozoa	32.75	27.15	18.00
Mollusca	1.33	0.32	0.96
Annelida	4.05	1.71	0.00
Rhizopoda	6.56	24.80	29.05
Uncolonized	0.00	3.63	0.96
Unknown (8)	38.72	45.76	28.57

Table 2F.4. Coverage changes due to ecological processes.

	Processes (cm^2/0.5 yr)		
Taxa	Flow	Disturbance	Gross Recruitment
Stolon	-1.68	-3.27	72.01
Cnidaria	5.93	-26.13	41.21
Bryozoa	-2.75	-7.65	31.41
Mollusca	0.84	-0.05	0.33
Annelida	-1.49	-3.55	5.04
Rhizopoda	12.18	28.14	-6.44
Uncolonized	-2.05	1.12	2.05
Unknown (8)	-6.72	-0.56	40.60

slow-growing (or *k*-selected), and large species (Odum 1969, Rhoads *et al.* 1978). Community succession on deep sea hard bottoms will be slow compared to coastal areas (Levin and Smith 1984). In the pinnacle habitat, settlement rates of larvae will decrease with depth and distance from shore (DePalma 1972). It will most likely take several years before a late-stage successional community will be observed on the current settling plates.

Several differences were noted between treatments. All taxa except Rhizopoda and the uncolonized category decreased in the uncaged and partial cage treatments where predation was present (Table 2F.3). Rhizopoda was enhanced, not negatively affected, by predation. It may be that foraminifera were able to take advantage to settle in the free space left when other organisms were grazed upon. Because uncolonized areas were more abundant in the uncaged and partial caged treatments, it is likely that predation enhances diversity by opening up more settlement area.

Most of the organisms appeared to be affected by small-scale turbulence produced by the caging material and disturbance, because nearly all had negative recruitment rates due to flow and disturbance processes (Table 2F.4). This is not surprising, because small scale turbulence is known to affect vertical and horizontal distributions of organisms in deepwater environments (Mullineaux 1989). While gross recruitment rates over time are very low for Rhizopoda, the settlement of these organisms is enhanced by the processes which limit other organisms. It may be that flow allows these very small organisms to collect in eddies and gives them extra time to settle while disturbance clears space for settlement.

At this point, all conclusions are preliminary because of low sample sizes, and difficulty in identification of larval stages and organisms without visible identifying characteristics. Initial analyses, however, have indicated interesting trends that may prove to represent generalities in the future.

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SESSION 1G

ACOUSTIC/PRESSURE WAVE EFFECTS ON MARINE MAMMALS AND SEA TURTLES, PART I

Co-Chairs: Dr. William Lang and Ms. Colleen Benner

Date: December 10, 1998

Presentation	Author/Affiliation
Acoustic/Pressure Wave Effects on Marine Mammals and Sea Turtles: Introduction	Dr. William Lang Minerals Management Service Gulf of Mexico OCS Region
An Overview of Use of Explosives by the G.O.M. Offshore Industry	Dr. David Leidel Halliburton Energy Service
Advances in Deepwater, High Resolution Seismic Survey Methods	Dr. Jack Caldwell Geco-Prakia, Houston
Cetaceans and Seismic Exploration in the Gulf of Mexico	Dr. Jeffrey C. Norris Dr. William E. Evans Ms. Shannon Rankin Marine Acoustics Lab Center for Bioacoustics Texas A&M University, Galveston
Marine Mammals and Seismic: The London Workshop	Dr. Mark L Tasker Joint Nature Conservation Committee Scotland
Office of Naval Research Concerns and Research Initiatives for Acoustic/Explosives Effects	Dr. Robert C. Gisiner Office of Naval Research Arlington, Virginia
The MMS Pacific OCS Region High-Energy Seismic Survey	Dr. Mark O.Pierson Minerals Management Service Pacific OCS Region
NMFS Acoustic Criteria Workshop and Related Activities Document Not Submitted	Dr. Roger Gentry NMFS, Office of Protected Resources

ACOUSTIC/PRESSURE WAVE EFFECTS ON MARINE MAMMALS AND SEA TURTLES: INTRODUCTION

Dr. William Lang
Minerals Management Service
Gulf of Mexico OCS Region

Historically "effects" of offshore oil and gas operations on the environment were mostly associated with water quality and chemical pollutants. Oil spills, of course, represent the major concern along with drilling discharges and other potential chemical releases and platform runoff. This session addresses another potential source of environmental effects – those from underwater pressure waves. In a sense, rather than chemical pollution, we are dealing with energy pollution.

In simplistic terms, we are dealing with a range of events from very high energy, supersonic "blast waves" resulting from underwater explosions to anthropogenic noise barely detectable above natural ambient noise levels in the ocean. Similarly, the range of potential effects may be physical destruction of tissues and death to subtle behavioral responses to either loud or novel sounds. This session will focus on two offshore industry activities that are of particular concern in regards to pressure wave effects: 1) Offshore structure removals and 2) Seismic exploration.

In the past, both activities involved use of underwater explosives. Today, the air gun or similar devices has replaced explosives in all but some shallow water situations for the marine seismic industry. However, despite efforts to develop nonexplosive technologies, explosive removal techniques remain a significant method to remove decommissioned offshore structures (Pulsipher 1997). Fish kills are an obvious effect of underwater demolitions. While certainly not desired, in view of harvesting and by-catch mortalities already inflicted on fish populations, the legal response to this effect has been one of tolerance or compensation. The situation is quite different for marine mammals and sea turtles given protection under the Marine Mammal Protection Act and/or the Endangered Species Act. These Acts have compelled the MMS and, in turn, offshore operators to define acceptable limits on explosive weights and operating procedures and to initiate a monitoring program operated by the National Marine Fisheries Service.

Potential death or injury from a blast wave is an obvious concern, but the effects of loud and/or disturbing sounds is rapidly elevating as perhaps a belated recognized but significant marine environmental effect. Particularly for marine mammals, loss of hearing or masked communications can ultimately lead to dire consequences. Sounds sources that scare fish away or disrupt feeding behavior can lead to resource conflicts between offshore operators and fishermen. Specific for the oil and gas industry, recent debates on renewing petroleum exploration on the Canadian Georges Bank has resulted in a series of studies and environmental analyses. One environmental assessment was devoted entirely to seismic exploration (Davis *et al.* 1998) and a preliminary report on environmental impacts by the Canadian Department of Fisheries and Oceans (Boudreau 1998) discusses seismic effects on a level equal to operational discharges and oil spills.

As the perception of potential harm from noise pollution intensifies and more information on biological effects of pressure waves increase, the technology for offshore removals and seismic exploration is also rapidly changing. Today's session has been assembled to give the audience and Proceedings reader an overview of explosive removal and seismic technology, information coordination, regulatory concerns, and biological effects of underwater pressure waves. The MMS is quite pleased that speakers from industry, academics, research institutions and other agencies have provided their time to contribute to this session. The Service both appreciates and thanks them for their effort.

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AN OVERVIEW OF USE OF EXPLOSIVES BY THE G.O.M. OFFSHORE INDUSTRY

Dr. David Leidel
Halliburton Energy Service

SUMMARY

The use of energetic materials has been an integral part of oil/gas exploration and production for many decades and will continue in the foreseeable future.

The use of energetic systems at or near the surface of a wellhead or on a platform is driven by

- safety risks to personnel; i.e., divers
- reliability issues with alternate methods
- lack of alternate methods
- emergency operations may require expedient and rapid deployment
- cost/rig time

The use of energetic devices in open water, near the water surface, or at shallow depths of burial beneath the midline requires consideration of the vulnerability of

- swimmers or divers
- fish, bottom dwellers, marine reptiles and marine mammals
- nearby active oil, gas or water pipelines
- nearby vessels or other floating or fixed structures
- submarine cables (power or communication)
- submerged instrumentation such as hydrophones or transponders

BACKGROUND OF UNDERWATER EXPLOSION RESEARCH

Serious study began in 1942 to enable the Allies to develop weapon systems to defeat the U-boat and protect the fleet from submarine attack in a two-ocean war. Early theoretical work was done by John Kirkwood, Stuart Brinkley, and Hans Bethe (Cornell University), for O.S.R.D. Reports were published from 1942 to 1945, overseen by George Kistiakowsky. Parallel work was performed in the United Kingdom by Geoffrey Taylor. "Underwater Explosions" by Robert Cole, the classic text on the subject, was published by Princeton University in 1948. Cole's study was based on Kirkwood's earlier work with thorough description of scaling laws. The study, later published by Dover Publications, is now out of print.

PHYSICS OF THE UNDERWATER EXPLOSION

The detonation of a chemical high explosive underwater results in a shock wave propagating outward from the source of the explosion as well as an initially oscillating bubble containing the products of detonation which, at later time, rises to the surface. Other results include

- seismic effects in the vicinity of or below the seabed, (acoustic energy transmitted through the seabed)
- gas flumes and surface waves at the water surface from shallow explosions
- airborne shocks from energy delivered to the atmosphere
- possible "afterburning" of fuel-rich explosives for deliberate enhancement of the blast effects

The Initial Underwater Shock Wave

By definition, a shock wave is a sharp discontinuity in pressure, particle velocity, internal energy, density, temperature, or entropy of the medium in which the shock propagates. The relationship between the material properties in front of and behind the shock (Table 1G.1) are governed by the shock jump relations:

- Conservation of Mass $\rho_o U = \rho (U - u)$
- Conservation of Momentum $(P - P_o) = \rho_o Uu$
- Conservation of Energy $Pu = \frac{1}{2} \rho_o Uu^2 + \rho_o U (E - E_o)$

Table 1G.1. The relationship between the material properties in front of and behind the shock.

Behind		Ahead
u		$u_o = o$
P	→ U	P
ρ		ρ_o
T		T_o
E		E_o

The previous three equations containing the five parameters U, u, P, ρ, and E comprise the Hugoniot Equation. An additional equation termed the equation of state or constitutive relation is required to calculate the other four. The equation of state characterizes the material in which the shock is propagating. While the E.O.S. for many pure materials exist, only limited E.O.S. data exist for geologic materials.

The shape of the initial shock from an underwater explosion may be approximated as a decaying exponential function of the following form (Figure 1G.1):

$$P(t) = P_{max}^{\,e-t/\Theta}$$

Definitions

- Peak Pressure, (P_{max}), represents the maximum positive magnitude at the initial shock rise
- Time Constant, (Θ), is the time for shock to decay to 1/e of peak pressure magnitude, (e ~ 2.71828)
- Specific Impulse, (I_o), represents the area under the pressure-time curve as
  $$I_o = \int P(t)dt$$
  - The upper limit on integration is difficult to assess due to the extended tailoff of a shock pulse, but 6.7 Θ is used in some literature
- Energy Flux Density, (E_f) means the energy flux across a unit area of an arbitrary fixed surface normal to the direction of shock propagation.

COMPUTATIONAL /EXPERIMENTAL METHODS

Subtasks include the following:

- Characterize the initial shock: peak pressure, time constant, and specific impulse

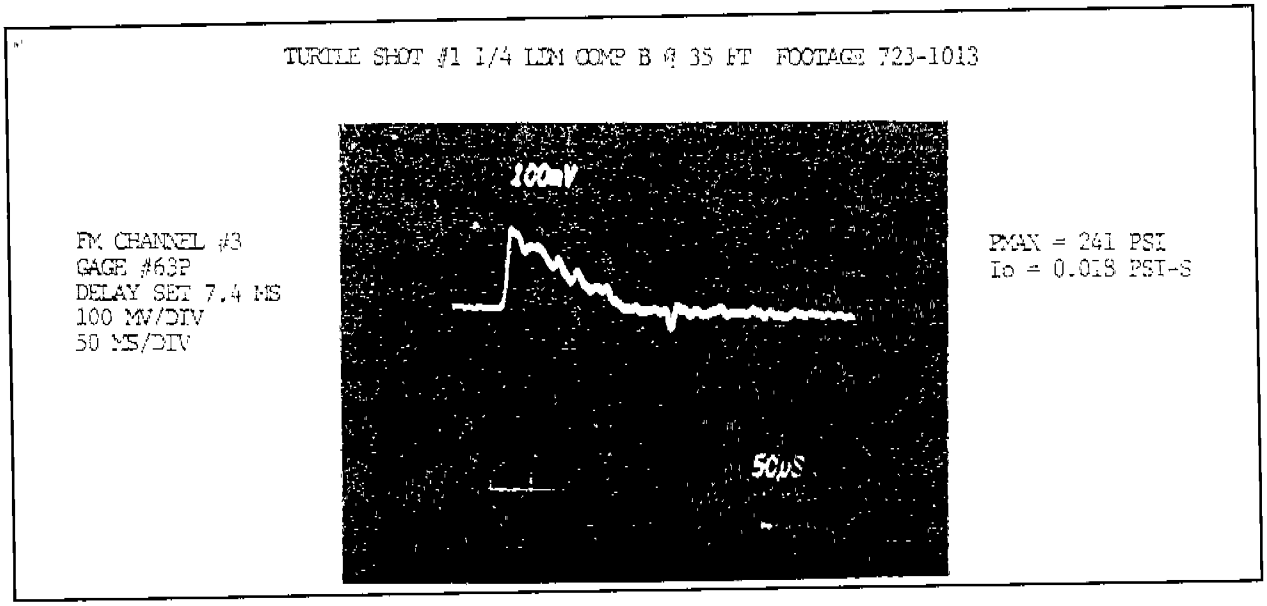

Figure 1G.1. Turtle shot #1.

- Understand shock propagation effects: seabed burial, effect of nearby structures, effects of charge shape and explosive type, multiple charges, near-surface effects
- Understand shock loading effects on structure of organism

Computational Methods

- Semi-empirical algebraic shock scaling equations for shock estimation and approximate closed-form solution for structural response
- Langrangian finite-element method
- Eulerian finite-difference method

Semi-Empirical Methods

Semi-empirical algebraic models of shock wave and approximate closed form solutions for structural response are available for very simple geometries such as elastic or elastic-plastic clamped plates, shells, and membranes only. Very limited data and incomplete equations are available for charges buried beneath the seabed. Non-spherical charge geometries are very limited in treatment as are effects of nearby reflective surfaces and refractive effects. Although semi-empirical methods can produce considerable error compared to actual measured values, these methods allow analyses to be conducted quickly and conveniently, without expensive computer facilities or expensive and specialized software (analyses can be performed on a programmable hand calculator).

Summary of Semi-Empirical Shock Equations for Underwater Explosions

Equations for Shock Wave Scaling: (after Cole and Faux)

I. Shock Scaling for Spherical TNT charge in open water:

W = weight of explosive (lbm)
R = distance from blast to receiver (ft)
P_m = peak shock pressure (psi)
I_o = specific impulse (psi-s)

$$P = (2.16E{+}04)(W^{1/3}/R)^{1.13}$$
$$I_o = 1.46W^{1/3}(W^{1/3}/R)^{0.89}$$

II. Shock Scaling for Cylindrical charge of Comp. C-4 at a seabed burial depth of 7.5 feet:

$$P_m = (8.51E{+}03)(W^{1/3}/R)^{1.18}$$
$$I_o = 0.931W^{1/3}\,(W^{1/3}/R)^{1.11}$$

Langrangian Finite-Element Method

This method uses the Langrangian model for material elements; i.e., each material element is "tagged" and its displacement, strains, loads, and stresses observed as time progresses in analyzing the dynamic response from a transient load or loads. Also used are the JWL equation of state for HE (an equation of state for water) and a model for nearby surfaces. The structure is modeled using quadrilateral material elements; the computational scheme uses a formulation for handling nonlinear, elastic-plastic structural response. A fluid-structure interface model must be used to handle the de-coupling of the water from the structural surface, and some form of "hourglassing" control is required to maintain mathematical stability in the solution.

A model is also required for soils and geologic materials. The codes are expensive, and the model requires technical staff knowledgeable in the physics of underwater explosions and the mechanics of structural behavior from rapid dynamic loads to run problems. It also requires computational facilities of at least IBM RISC 6000 or equivalent. Figure 1G.2 shows an example of a Langrangian computational mesh.

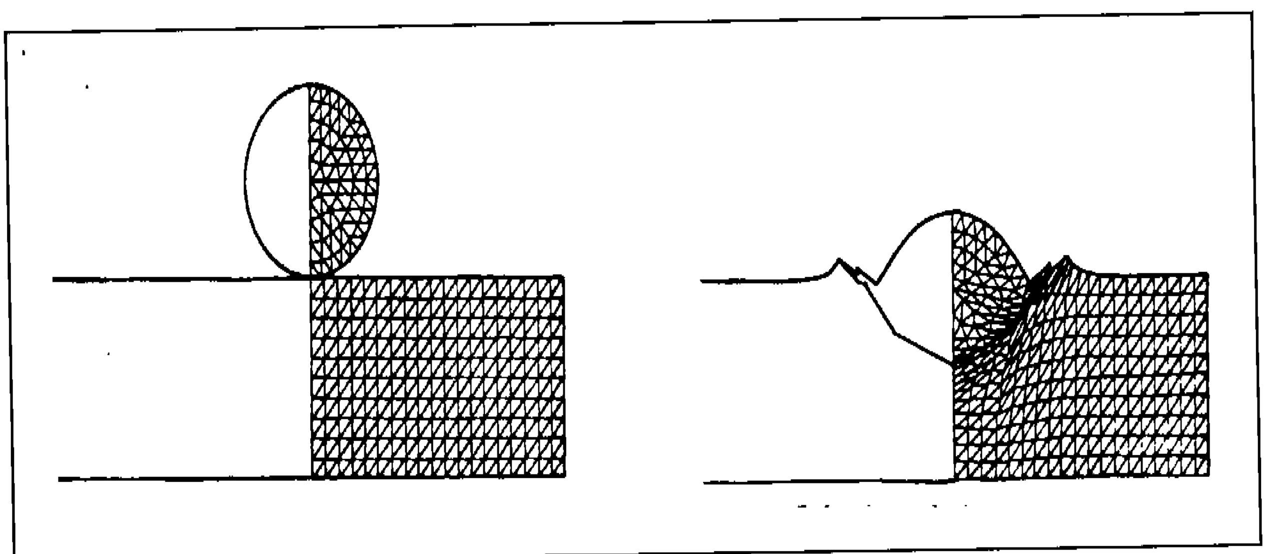

Figure 1G.2. An example of a Langrangian computational mesh.

Eulerian Finite -Difference Method

A mesh is constructed in a stationary or moving laboratory coordinate system, and a material model is constructed overlaying the computational grid. Equations of motion require that material transport terms be added to track material as it flows through the grid, much as a fixed observer watches fluid flow in a wind tunnel. The method requires careful mathematical tracking and control of material diffusion across grid boundaries. It utilizes a JWL equation of state for explosives, libraries of equation of state models for metals, concrete, rock, water, and soils. Rock and soil are data limited. The method also requires material failure models or models for porous materials undergoing crushing.

The advantage of the Eulerian Finite-Difference Method is that there are no problems with an "hourglassing" grid as in the case of Langrangian methods. On the other hand, very stiff portions of structures may require very small time steps to accurately model response requiring large computational time. Moreover, it requires at least a workstation equivalent to an IBM RISC 6000 and hours of computational time to solve even 2D problems. 3D problems require parallel processing capability or supercomputers. Figure 1G.3 shows an example of a Eulerian computational grid.

Eulerian-Langrangian Codes

Some hydrocodes perform cell calculations using the Langrangian form of governing equations, (conservation equations, equations-of-state and material constitutive models) and then re-map the distorted mesh onto the original mesh to avoid problems encountered with large deformations. The mesh distorts to follow the material motion. Conservation of mass is solved trivially since no material flows across mesh boundaries. Mesh remapping results in material motion through the mesh; material interfaces are reconstructed. The user may elect to discard materials if not required for further computation when the computational cycle is completed.

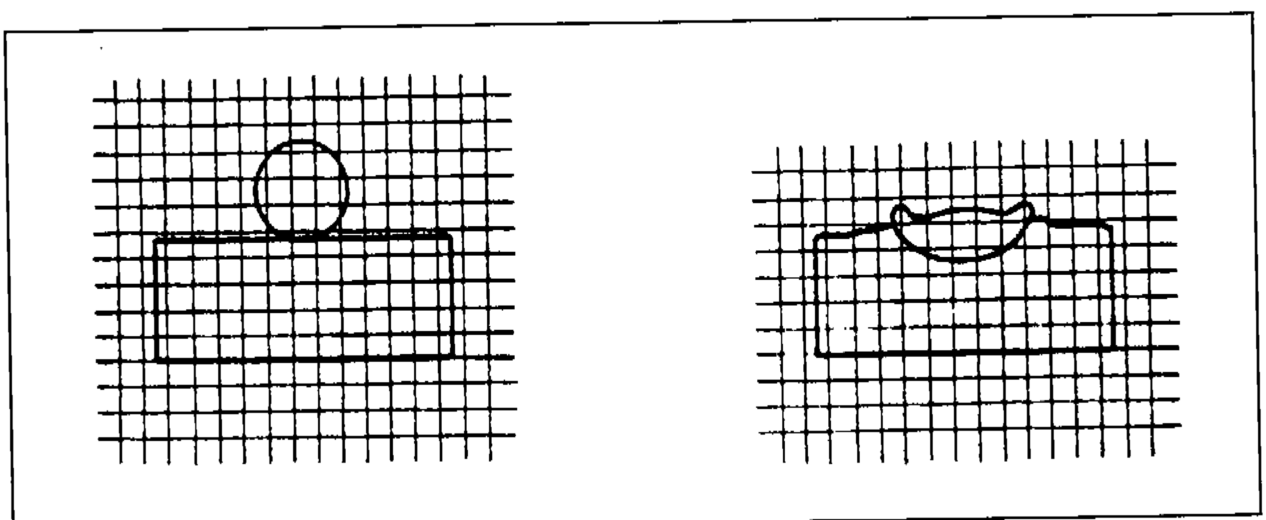

Figure 1G.3. An example of a Eulerian computational grid.

ENERGETIC SYSTEMS CONFIGURATIONS USED IN SURFACE OPERATIONS

Lined-Cavity Charges

Explosive cutting systems using the lined-cavity (shaped charge) effect:

- outside circular cutters
- inside circular cutters
- articulated or collapsible circular cutters

These systems utilize straight or circular segments of linear-shaped charge typically of 900, 1,000, 1,200, 1,400, 2,000, or 3,200 grain/ft explosive load in a copper sheath contained in a water-tight housing to sever structural members.

The water depth limitation for such systems is restricted by the hydrostatic collapse pressure rating of the subsea housing. Designs have been tested to 18,000 feet water depth, and operations performed to 5,200 feet. Liner-shaped charge cutters larger than 3,200 grain/ft may be manufactured to special order from fabricated housings and cast Composition B.

The use of lined-cavity (shaped charge) devices is the most effective method of metal cutting per unit weight of explosive since the cut is achieved not be blast effects but by the directed impact of a hypervelocity metal jet into the material to be severed.

The limitations on applications of lined-cavity charges may be a difficulty in charge emplacement while maintaining the correct standoff, very thick target materials, or difficulty with access to the section to be cut. However, these charges can be divers emplaced, ROV emplaced or lowered and remotely deployed. The cuts resemble a torch cut.

Bulk Charges

Simple bulk charges generally consist of a right circular cylindrical housing containing a cashable solid or liquid explosive. They can be lowered into the member to be cut or diver emplaned. They are usually initiated at one end. Simple bulk shots, unless well tamped, are relatively inefficient in cutting capability. They use relatively large amounts of energetic materials for the size of the member to be cut, and cuts are not clean but often flared and ragged. Bulk charges are relatively inexpensive to fabricate by any vendor with melt-casting capability unless liquid explosives are employed. Liquids can be mixed on location and transported as flammable liquids and not as explosives.

Collision Charges

These consist of bulk charges with a system that initiates the charge simultaneously at opposite ends by EBWs or by a special detonating cord initiator train. Collision charges improve the effectiveness of a bulk charge by using a strong combined shock from opposite ends of the charge to focus the cutting effect on a single plane. These charges are often used in liquid explosive wellhead severing. Multiple strings of surface conductors from 11-inch diameter to 30-inch diameter cemented together, have routinely been severed with 27 pounds net explosive weight of sensitized nitromethane. The cost is not much higher than simple bulk charges.

Ring, Focused, and Specialty Charges

These charges utilize some form of wave shaping, place explosives in direct contact with the material to be cut, or are deliberately configured to produce tensile fractures in a target at a specific location. These are specialized explosive charge configurations that do not utilize the lined-cavity effect, but are shaped more nearly to optimize the cutting effectiveness over simple bulk energetic systems. These charges are more effective than bulk charges in cutting effectiveness. The problem with these charges is that their designs are generally proprietary, with their originators and their configurations covered by patent protection, trade secret protection, or license agreements. Thus, they are inaccessible as to design details or free use.

SUMMARY OF THE ISSUES

- Shock propagation from buried charges and non-spherical charges is not well documented; little data exist. A set of scaling laws needs to be developed.
- Shock propagation near seabed or water surface requires additional study. We need to develop guidelines for understanding the effects on shock front.
- With attenuation systems, air curtains are usually effective in reducing peak pressure, although they are not as effective on reducing specific impulse.
- Explosive systems using minimal explosive weight should be encouraged without unnecessary design or operational restrictions.
- Lethal distances for marine life are difficult to assess; they are highly statistical in nature and affected by species, orientation to the blast, body weight, and depth of submergence. Considerable data is required for P_k estimates.

David Leidel graduated from Drexel University with a Bachelor of Science degree in mechanical engineering, a Master of Science degree in applied mechanics, and a Doctor of Philosophy degree, also in applied mechanics. He served in the U.S. Army Combat Engineers in a Special Weapons Unit. He was employed by BEI Defense Systems Company, Inc. as the chief engineer on a tri-service weapons system prime contact. He worked for Halliburton Energy Service or its subsidiaries for a total of thirteen years in support of their oilfield products and services, their defense and aerospace products and their marine services projects. He as authored a number of papers in ballistics, energetic materials, and their applications. He is currently employed by Halliburton Energy Service's Explosive Products Center as a Principal Engineer.

ADVANCES IN DEEPWATER, HIGH RESOLUTION SEISMIC SURVEY METHODS

Dr. Jack Caldwell
Geco-Prakla, Houston

INTRODUCTION

This paper provides a brief overview of some of the continued improvements and recent advances in the acquisition and use of deepwater 3D seismic data. Length constrains the topics to be covered in this talk to (1) the fact that more and more in-sea equipment is being towed behind purpose-built and purpose-modified seismic vessels, (2) the development of techniques and equipment that allows for the simultaneous acquisition of multiple purpose 3D surveys using a single vessel, (3) the rebirth of the marine vibrator, (4) the potential to better manage oil and gas reservoirs through the use of repeat 3D seismic surveys (popularly known as 4D seismic), and (5) the high interest in using mode-converted shear wave data in the marine setting, and the increasing variety of marine seismic acquisition geometries. Emphasis is placed on topics 4 and 5, since they have potentially huge economic effects with regard to optimizing production from oil and gas fields.

MORE IN-SEA EQUIPMENT

Improvements in vessel technology as well as in towing systems, recording systems, safety systems, etc., ensure that the seismic industry will continue to increase the amount of in-sea equipment for the acquisition of 3D seismic surveys (Figure 1G.4). Spreads of up to 1,200 meters or greater and streamer lengths of up to 12 km will be seen in 1998, deliverable by some contractors with a single

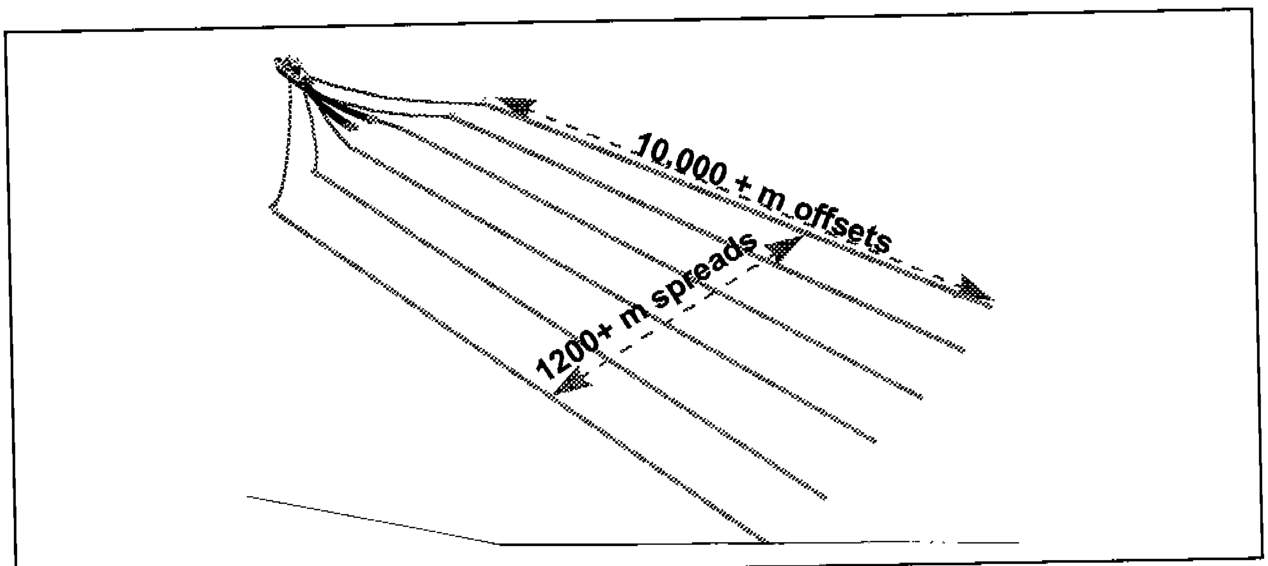

Figure 1G.4. The seismic industry will continue to increase the amount of in-sea equipment for the acquisition of 3D seismic surveys with spreads of up to 1,200 meters or greater and streamer lengths of up to 12 km.

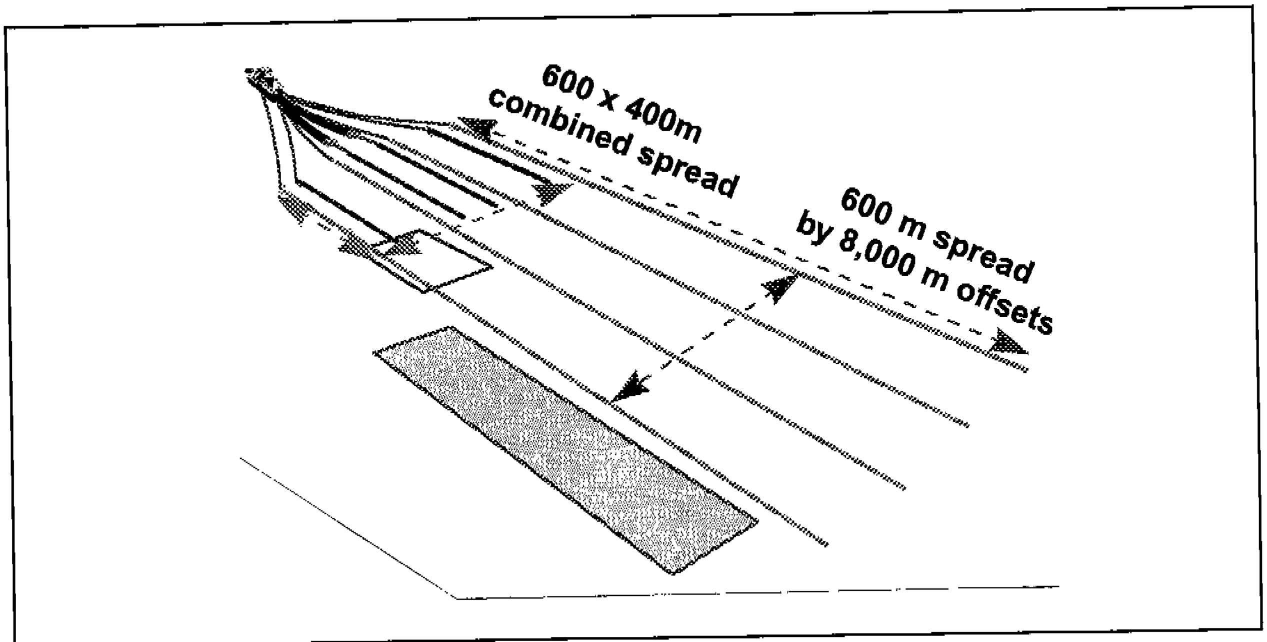

Figure 1G.5. The industry can configure the equipment to accomplish two objectives at once.

vessel, and deliverable by other contractors with up to three vessels. The acquisition footprint associated with a single traverse of a seismic vessel will increase in area over the next couple of years, and the deep water tracts provide the open water areas where operations of this type are most cost-effective.

MULTIPLE PURPOSE 3D

In addition to putting longer, wider configurations together, the industry can also configure the equipment to accomplish two objectives at once, as the multi-3D concept has already demonstrated in the Gulf of Mexico (Figure 1G.5). In this technique, a high resolution site survey is acquired simultaneously with a conventional, long offset, deep imaging, exploration/development 3D seismic survey. The rectangular blocks drawn in Figure 1G.5 indicate the different subsurface image areas generated by the two different spread geometries, one composed of smaller bins yielding higher resolution data, and one composed of larger bins yielding conventional 3D resolution. Operationally, this technique requires some special expertise, as well as the novel use of some fairly standard equipment. Note the dual source and unequal streamer separations and streamer lengths employed.

MARINE VIBRATOR

The marine vibrator (illustrated in Figure 1G.6) idea is not new, having been experimented with sporadically for the last 15 - 20 years. It appears that the vibrator is ready as a viable technology and that the industry may be ready to support it commercially in some specific applications. The primary attractiveness for the marine vibrator is in its potential to provide higher resolution data than airguns currently deliver. This is accomplished because the vibrator output signal is very stable and

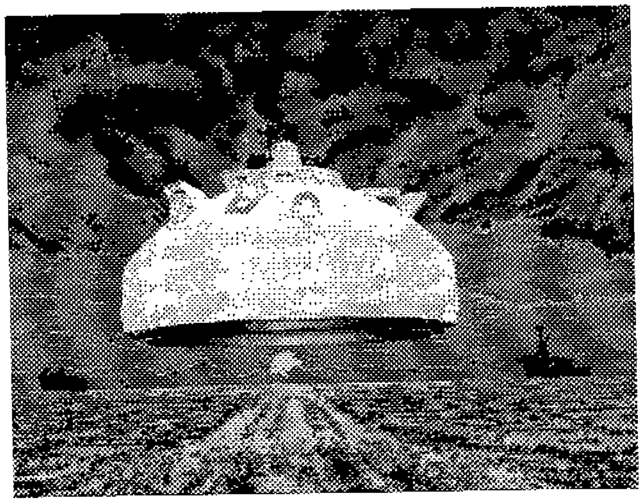

Figure 1G.6. The marine vibrator.

repeatable (Figure 1G.7), and because it has a wide, programmable bandwidth—the signal can be tailored to the particular target of interest. If you look closely at Figure 1G.7, you can see a variability in the details of the peaks and troughs of the five traces associated with five firings of a single airgun. In comparison, note the much greater similarity among the five traces associated with five sweeps of a vibrator. This illustrates the improved stability and repeatability of the vibrator over the airgun. While airgun arrays today have greater productivity than vibrators, an array of vibrators may be a more environmentally friendly source than an array of airguns, due to the lower peak output power levels of the vibrator.

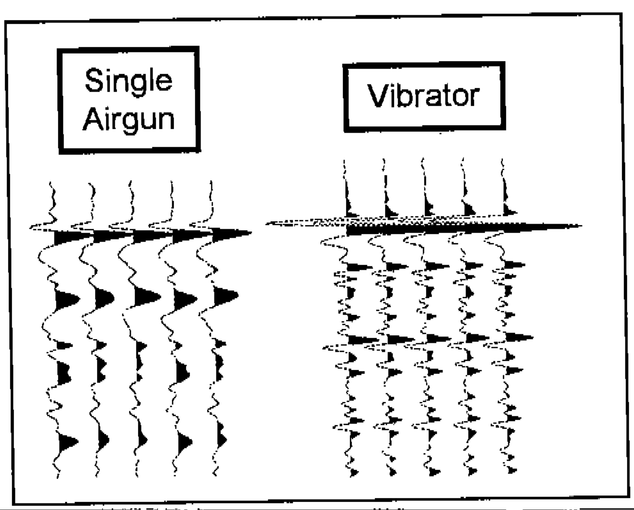

Figure 1G.7. The vibrator output signal is very stable and repeatable..

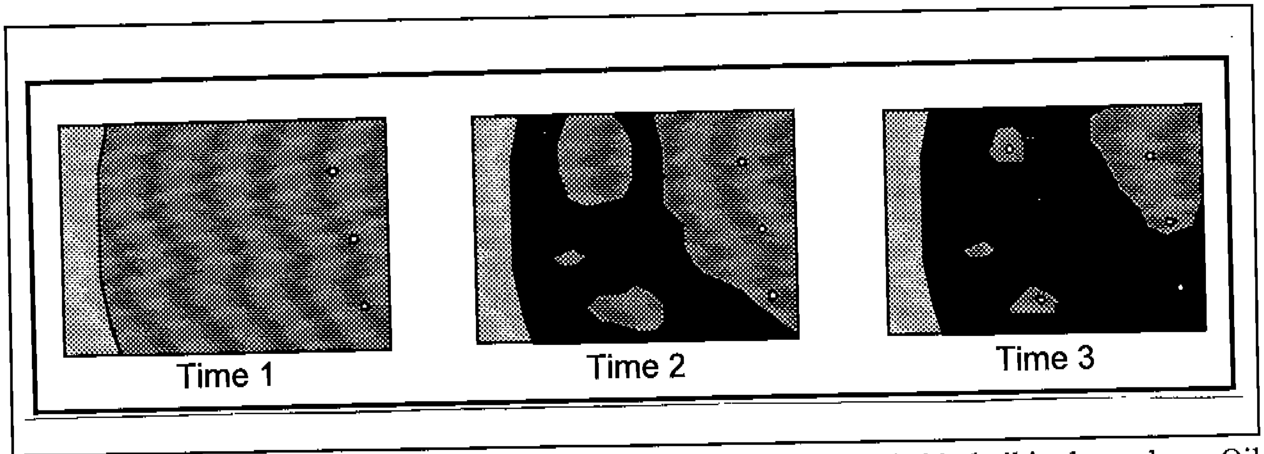

Figure 1G.8. The idea of water pushing out oil, or water flowing in behind oil is shown here. Oil is medium gray, water is black.

SEISMIC TIME-LAPSE MONITORING (STLM) OR 4D SEISMIC

In cartoon fashion, the idea of water pushing out oil, or water flowing in behind oil (oil is medium gray, water is black), is shown in Figure 1G.8, with three different times in the life of the reservoir portrayed. If we could accurately picture the movement of fluids in a reservoir, then we could use that information to drill additional wells to drain the bypassed areas, or otherwise better manage our reservoirs. It has been shown in a few published studies that seismic holds much promise in actually being able to monitor the movement of fluids, when used in conjunction with all other data available (well log, geologic, core, production, etc.). The basic concept of 3D seismic time-lapse monitoring is illustrated through the use of synthetic data in Figure 1G.9: in a perfect world, the difference between seismic data acquired before a field starts production (the Base survey), and seismic data acquired after a field has undergone some production (the Monitor survey) will be zero everywhere

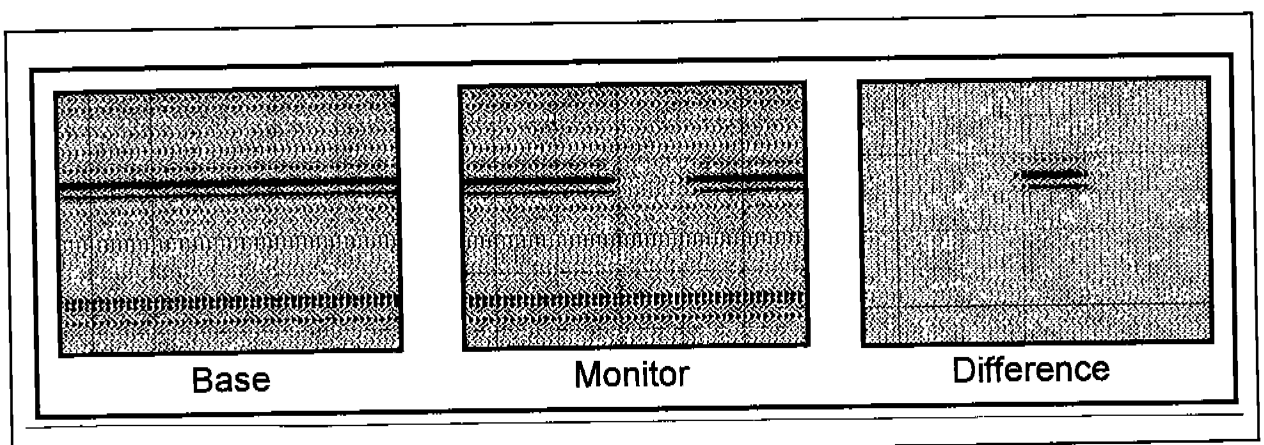

Figure 1G.9. The basic concept of 3D seismic time-lapse monitoring is illustrated here through the use of synthetic data.

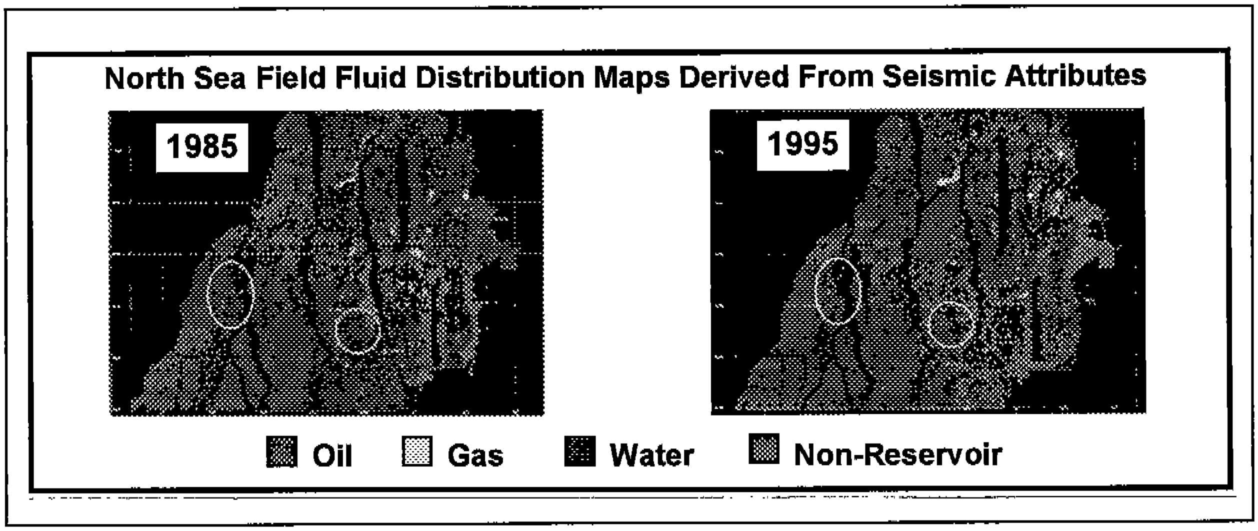

Figure 1G.10. A North Sea field example of seismic attributes used to map the fluid distribution in a reservoir under production.

except where the production of oil and/or gas from a reservoir causes a change in the seismic response (this "differencing" between data sets yields the "difference" data set). in reality, it has been determined, for at least some situations, that some attribute(s) of the seismic data will change as a result of the movement of the fluids, and that by mapping the change(s) in that (those) seismic attributes, we will be able to infer the movement of the fluids. In Figure 1G.9, the change is in the amplitude of the seismic event in the middle of the section.

Figure 1G.10 shows a real world, North Sea, field example where seismic attributes were used to map the fluid distribution in a reservoir under production. 3D seismic surveys were shot in 1985 and 1995, although the survey shot in 1985 was not shot with time-lapse monitoring in mind. Both data sets were reprocessed so as to maximize the consistency in the two data sets.

Fourteen (14) seismic attributes were used to achieve the fluid characterization illustrated here. Although there are numerous places where there are differences in the depicted fluids, the circled areas show where perhaps the largest changes in the reservoir have occurred in the intervening time between the two surveys, indicating places where water has replaced oil. Subsequent drilling has confirmed the correctness of this picture.

The repeatability of one seismic survey to the next is probably the major question the industry has with respect to STLM. The following list of statements sum up the situation:

- Monitor Surveys Must Look Forward and Backward
- Newer Surveys Must Take Advantage of Advancements
- Newer Surveys Will Be Bastardized to Compare to Older Surveys
- TLM Objectives May Be Quantitative and/or Qualitative
- Acquisition and Processing Will Affect Repeatability

The fourth statement in this list may require a bit of explanation: if the information to be derived from a STLM project is quantitative, then more than likely, the repeatability will have to be greater than if the objectives are qualitative. So acceptable repeatability will be related to the desired objectives of the STLM.

The major potential culprits that may affect repeatability, outside of the reservoir changes themselves (which we wish to see), include the seismic source, the elements of the seismic acquisition system, the processing system, the weather, and the structures and facilities associated with the producing oil field:

- Is the source itself repeatable? Is its coupling repeatable? Does the source occupy exactly the same positions in a later survey as it did in an earlier survey (location)? Do we assign to the source the proper location (positioning)?
- Is the receiver itself repeatable? Is its coupling repeatable? Does the receiver occupy exactly the same positions in a later survey as it did in an earlier survey (location)? Do we assign to the receiver the proper location (positioning)?
- Was the same recording system used in all surveys to be compared? Are the system responses the same from survey to survey? Were the acquisition parameters (filter settings, etc.) set in the system the same way for all surveys?
- Were weather conditions the same for all surveys, and were they done at the same time of year? Was wind/precipitation noise the same for all surveys? Was the sea state the same, or were wave action/currents much worse for one survey than for another? Was the ground wet, frozen, ploughed, snow-covered. etc., for all surveys?
- Are there facilities present now that were not there for earlier surveys and are the same facilities running the same way as they were for earlier surveys?

To do quantitative STLM, we have to be able to address many of these questions. As we move from quantitative STLM to qualitative STLM, the importance of repeatability diminishes, but certainly does not completely go away.

Partly to address some of the repeatability issues, and partly to acquire higher quality and/or more complete seismic data, the industry is beginning to use cables either temporarily or permanently placed on the seafloor, or trenched down into it, and vertical arrays of cables containing many sensors. The reasons for burying cables are (1) to improve repeatability from survey to survey by ensuring that the receivers are in exactly the same position for each survey, (2) to ensure higher quality data because the sensors are in a quieter environment on the seafloor than they are when being towed near the sea surface, (3) to reduce sensitivity to weather, and (4) to reduce overall cost when doing numerous repeat surveys (see Figure 1G.16).

Figure 1G.11 depicts an array of vertical cables and the trenching of a cable into the seafloor. Cables laid temporarily on the seafloor, as well as vertical cables, provide true 3D seismic, equivalent to land 3D, in which full and complete azimuth and offset distribution can be achieved, unlike marine towed streamer 3D in which the azimuth distributions are quite limited due to the swath style of shooting (the sources are essentially in-line with the streamer receivers).

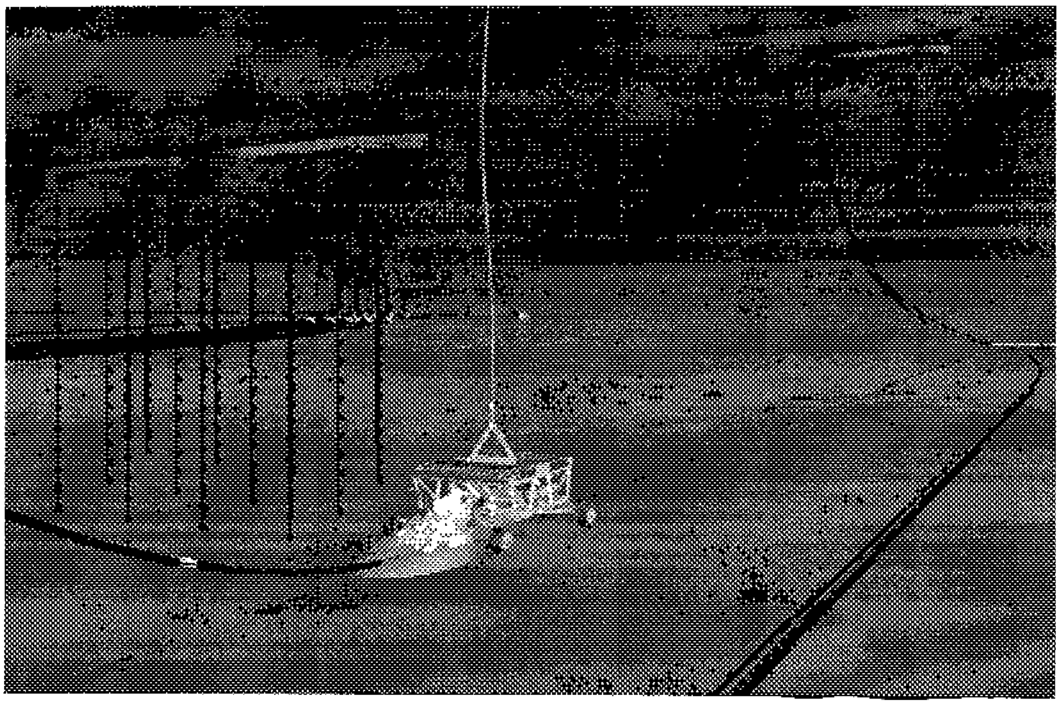

Figure 1G.11. A depiction of an array of vertical cables and the trenching of a cable into the seafloor.

MARINE 4-COMPONENT SEISMOLOGY

Another application makes use of either sensor-filled cables or individual sensor packages which are placed in direct contact with the seafloor is that of 4-component seismic. The four components are a hydrophone, a vertical geophone, and two horizontal geophones oriented perpendicular to each other. All four are included at each receiver station location.

Although they have been in use only for the last 18 months so their track record is brief, the second generation seabed cables (the first generation of seabed cables being those commonly known as ocean bottom cables - OBC) routinely deliver data which are higher quality than conventional towed streamer data (see Figure 1G.12) for several reasons: higher fold, less smear, broader bandwidth, the absence of towing and weather-related noise, and the ability to combine the vertical geophone output with the hydrophone output (combining these outputs results in the removal of much downgoing multiple energy). Figure 1G.12 is a data comparison indicating the improved resolution and greater continuity in events delivered by the seabed cable Systems.

The fact that these cables deliver better data than towed streamers notwithstanding, the reason for going to the hardship and expense of deploying such seabed systems is to record a type of wave not

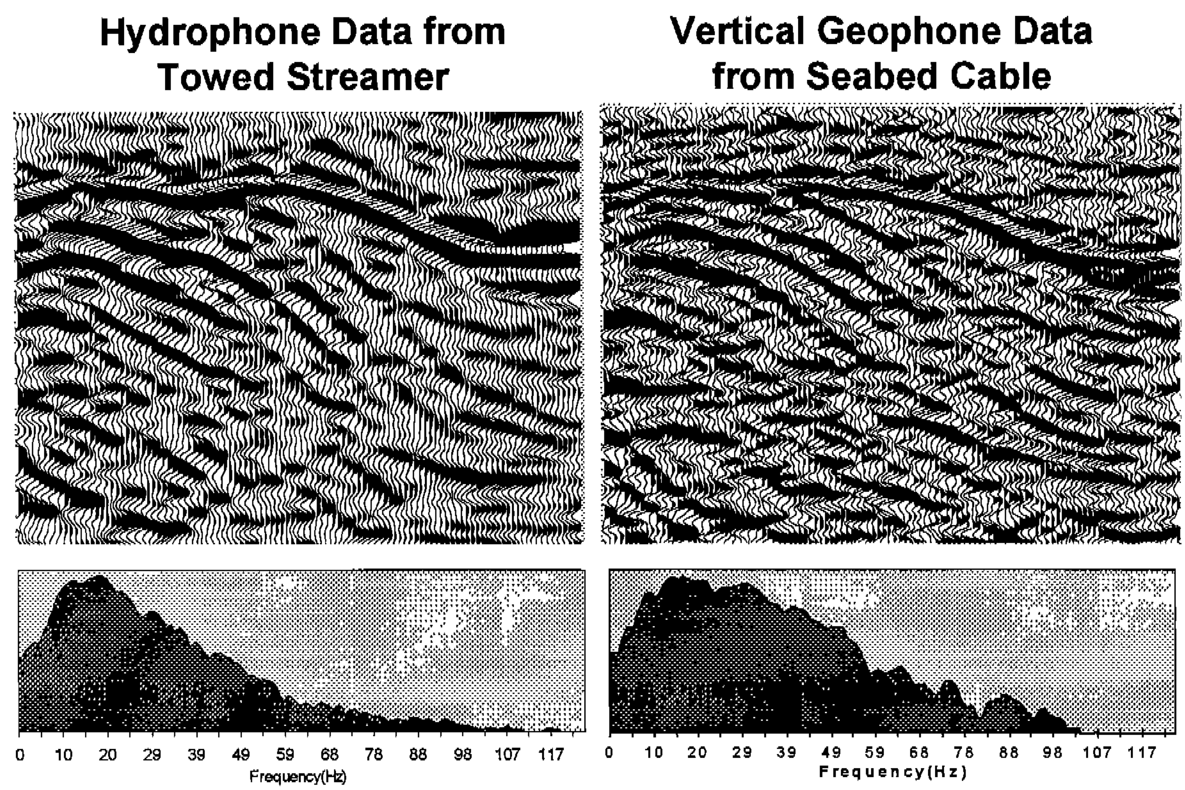

Figure 1G.12. A data comparison indicating the improved resolution and greater continuity in events delivered by the seabed cable systems.

recordable by streamers: the shear (S-) wave. Conventional towed streamer marine systems only record compressional (P-) waves. When a P-wave passes through a rock, its behavior is affected by both the matrix of the rock (the solid part) and the pore spaces of the rock (that portion filled with liquids and/or gases). To a first approximation, when an S-wave passes through a rock, its behavior is affected by only the matrix of the rock. Two other important properties of S-waves are that they travel at roughly half the speed of P-waves, and they can not exist in fluids (hence the necessity of placing the recording sensors on the seafloor).

The recording of both of these wave types makes it possible to infer much more information about the rocks in the subsurface and the fluids they contain, and it is the hope of acquiring this additional information has caused the industry's recent strong and active interest in recording both P-waves and S-waves. There are several applications of this technology apply equally well in both the onshore and offshore environment:

- Improved lithology (mineralogy) prediction
- Improved pore fluid prediction
- Better SIN in areas of low P-wave impedance contrast or high P-wave attenuation
- Calibration for AVO (amplitude versus offset) studies

- Azimuthal anisotropy (the variation of seismic properties with horizontal direction)
- Another parameter for seismic reservoir monitoring (4D seismic)

There are other applications listed below that are primarily relevant to the offshore situation:

- Imaging within and beneath gas-invaded zones, shale diapirs, mud volcanoes
- Imaging base of salt, volcanics
- Illuminating P-wave shadow zones beneath salt bodies, particularly those with tops and/or bases that show significant topography
- Deep water multiple removal
- More cost-effective when compared to the cost of offshore wells.

Figure 1G.13 is an example of imaging beneath gas using S-wave energy. It was this particular example presented in 1994 (Berg, E., Svenning, B., and Martin, J. 1994) that kick-started the interest in marine multicomponent seismology leading to the multicomponent campaign of about a dozen tests in the North Sea during the Fall of 1996. This figure shows the P-wave data (the PP section, which means P-wave downgoing energy and P-wave upgoing energy) being obliterated in the area of the gas chimney, whereas the PS section (P-wave downgoing energy and S-wave upgoing energy) provides a relatively clear picture beneath the gas. This particular application of 4C seismic has been

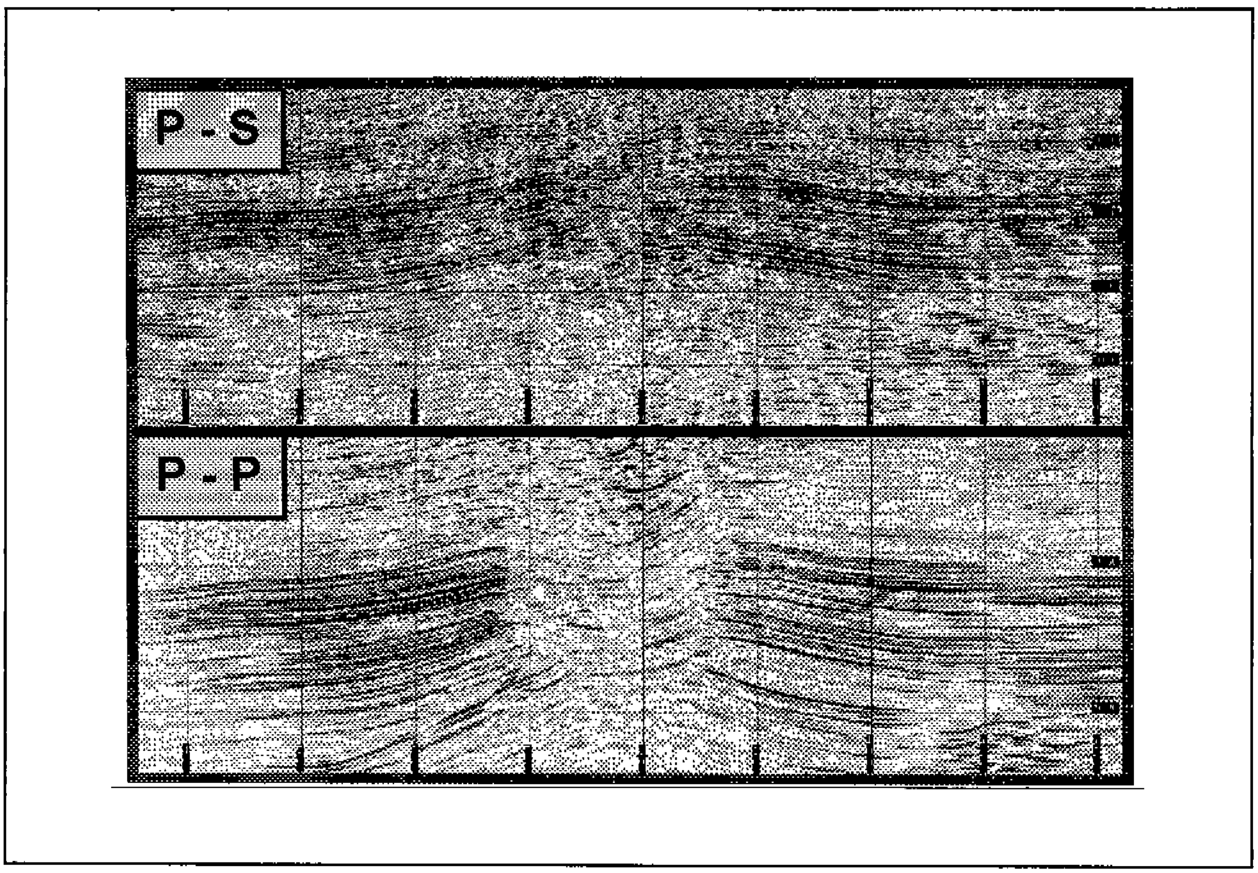

Figure 1G.13. An example of imaging beneath gas using S-wave energy.

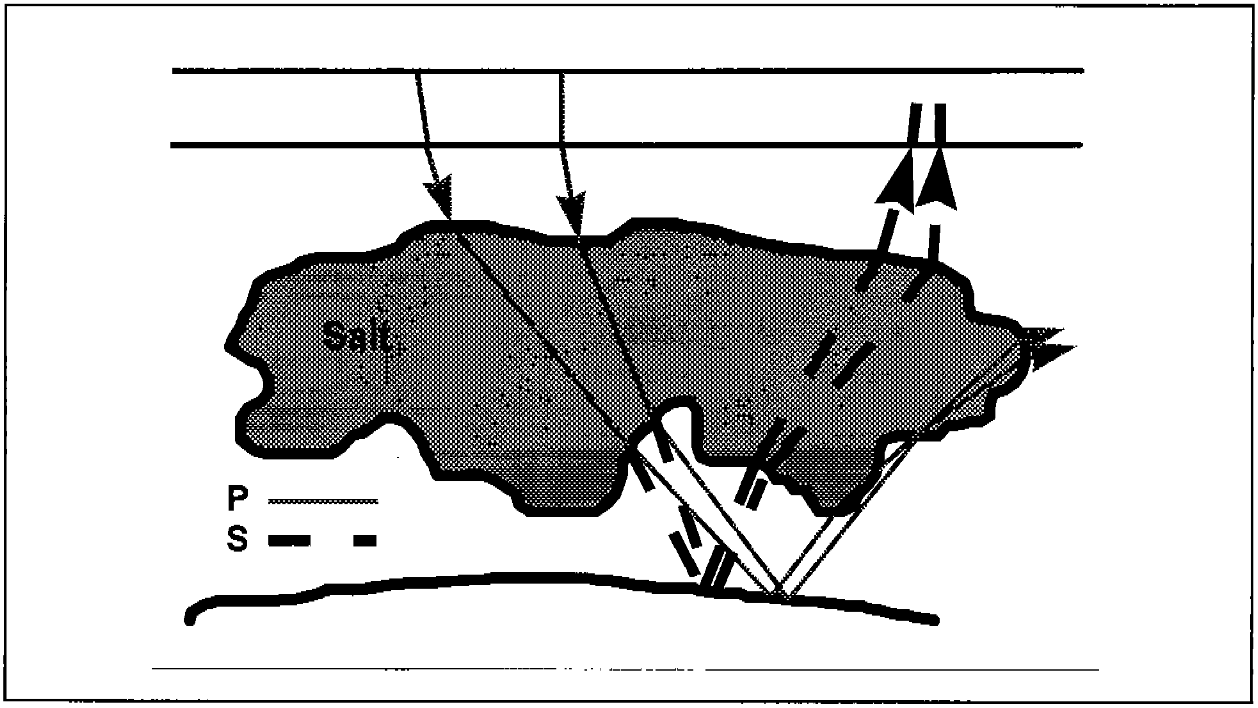

Figure 1G.14. P-wave and S-wave velocity imaging beneath salt bodies.

successful in more than a dozen cases since 1996. The other application with about the same number of successes is that of diagnosing the lithology and/or the fluids filling the pore spaces of a reservoir rock. Both of these applications are very important in field development work and reservoir management, so the interest in marine 4C seismology is quite high.

An application not seriously tested in the extensive North Sea activity in 1996 and 1997 is that of imaging beneath salt bodies. The interest in subsalt is very high in the Gulf of Mexico, but it has tailed off some with the relatively poor results to date of using seismic imaging to obtain a clear picture of the structure and stratigraphy beneath salt. It is thought that 4C seismic might provide a breakthrough, and a survey to test that application was completed in January 1998. The processing results, not available yet, are eagerly awaited.

Because salt has much higher P-wave and S-wave velocities than the sediments above and below it, each type of wave is strongly refracted at the salt boundaries, and significant mode-conversion occurs (see Ogilvie, Jeff S. and Purnell, Guy W. 1996). It is believed that large amounts of S-wave energy are obscuring the P-wave events beneath the salt. If the S-wave energy is recorded, then either it can be removed, or it can be used to obtain an image from beneath the salt body. Additionally, as Figure 1G.14 illustrates, the refraction of one type of wave due to the roughness of the salt surface will create uneven illumination of reflectors beneath the salt. This uneven illumination results in zones where a particular wave type will be focused or defocused. The shadow zones so created to one type of wave are likely to be bright zones to the other type of energy. The use of both types of energy will thus yield a more complete picture of the geometry of the reflectors beneath salt.

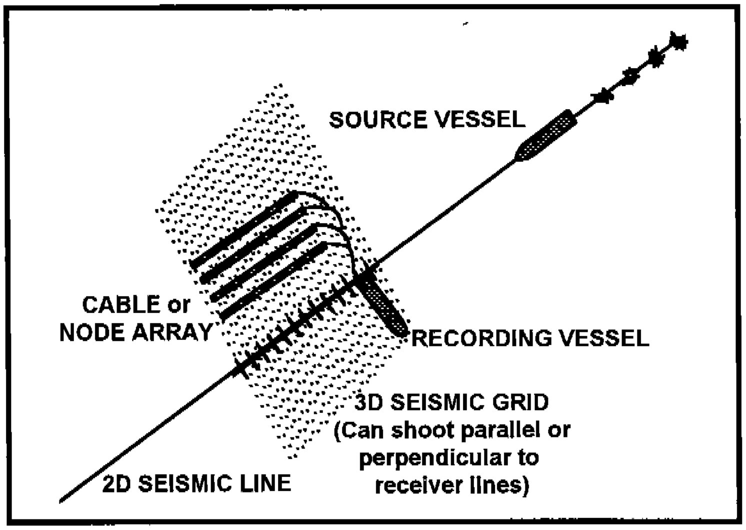

Figure 1G.15. An illustration of how a 4-component seismic operation might be laid out.

Figure 1G.15 illustrates how a 4-component seismic operation might be laid out. A side-scan sonar survey is run prior to placing the cable on the seafloor to ensure that there is nothing on the seafloor which can damage the acquisition system, and that there is nothing on the seafloor which the acquisition system can damage. Depending on the length of the cable, and the conditions on the seafloor, the cable is either dragged into or draped in position. For 2D work, the source vessel shoots along the line of a single seabed cable. For 3D work, generally two or more receiver cables are laid out parallel to each other, and the source vessel shoots several lines overlying the area covered by the seabed cables. These source lines may be shot parallel to the seabed cables or perpendicular to them, and the orientation chosen depends on the specific requirements and economics of the particular survey. One thing to keep in mind about these seabed cable surveys is that if a cable is dragged on the seafloor, particularly in deeper water areas, then the permitting process will probably take a longer lead time than commonly required for towed streamer surveys.

Finally, the issue of cost of seabed cable surveys should be mentioned. Figure 1G.16 summarizes the present situation in a generic way. Retrievable 4C surveys ("A") cost more than their towed streamer counterparts ("B" & "E" endpoints), but the cost differential will diminish as the technology matures. For seismic-time-lapse-monitoring, permanent installation approaches will be more expensive, in a cumulative sense, for a small number of repeat surveys, but as the number of repeats reaches a certain level (which will depend on the specific situation, but which seems to be around 10-15), then the total cost will be less than that of a series of conventional surveys.

SUMMARY

This paper has attempted to provide a brief overview of some of the continued improvements and recent advances being made in the acquisition and use of deepwater 3D seismic data. A constant

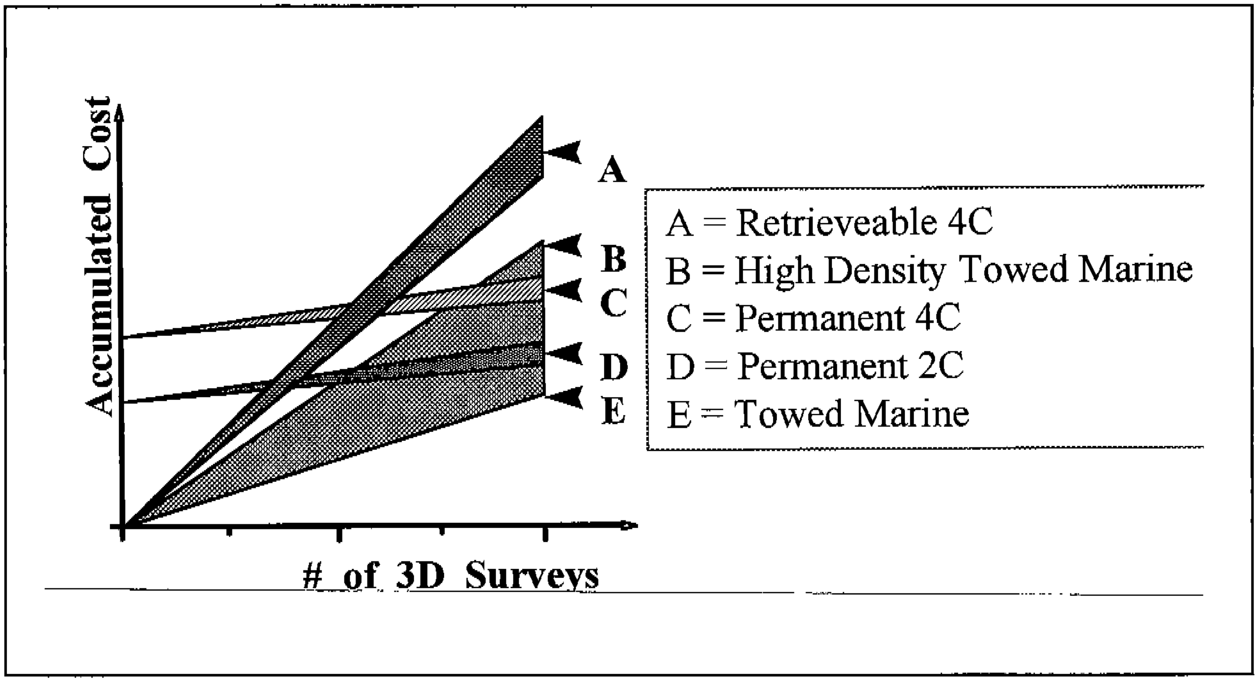

Figure 1G.16. A summary representation of the present cost of seabed cable surveys.

stream of new developments has been ongoing for some time, and it does not look to abate soon. Conventional towed streamer 3D surveys will continue to be done more efficiently and to deliver higher data quality. The marine vibrator may shortly be a source in demand for high resolution surveys and when the environmental conditions dictate it. Time-lapse seismic monitoring, and 4-component seismic will become important technologies delivered by the seismic contractors for improved reservoir characterization and management.

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Jack Caldwell received a bachelor's degree in mathematics from Davidson College (1971), and a Ph.D. in geophysics (earthquake seismology and tectonophysics) from Cornell University (1978). He immediately entered the oil industry as a Research Geophysicist at Texaco's research lab in Houston where he worked on the overall problem of extracting lithologic information from seismic data. From 1980 until 1987, Jack held various positions in various locations in research and exploration in Marathon Oil Company. He joined Schlumberger Wireline in 1987, and moved over to sister company Geco-Prakla in 1992, and currently is Manager, Reservoir Solutions, North and

South America, a position he has held since January 1998. The common thread running through most of his assignments is that he has been involved in developing, introducing, or marketing new technologies oriented toward extracting lithologic information from seismic data. He has been involved in some of the discussions that took place between 1996 and 1998 in California with regard to the HESS (High Energy Seismic Source) workshop and recommendations.

CETACEANS AND SEISMIC EXPLORATION IN THE GULF OF MEXICO

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The Gulf of Mexico is almost precisely the size of Alaska, not large for a marine habitat, yet it is the site of the major oil source in the U.S. outside of Alaska. Not withstanding this, there is no body of water on earth with a larger diversity of dolphins: fourteen of them. This number does not include other toothed whales such as the sperm whale or the little known beaked whales. Nor does it include baleen whales such as Bryde's or humpback whales. Twenty-four cetacean species are found here. Only two of these species are found in shallow water: the well-known bottlenose dolphin and the Atlantic spotted dolphin. All others are pelagic.

Into this pelagic environment has recently come increased hydrocarbon exploration and production. Noise from these activities is in addition to heavy shipping and fishing activities. As a first step in determining the impact on cetaceans of offshore oil activities in the Gulf of Mexico, Texas A&M University and the National Marine Fisheries Service have been conducting visual and acoustic surveys since 1992 to describe cetacean distribution, abundance, and ecology. The first stage of these investigations was GulfCet I, completed in 1996. Both visual and acoustic means were used for detecting and estimating cetacean numbers. In the northwestern and central Gulf the visual survey estimated there to be 18,584 (95%CI=10,268-35,431) dolphins, while the acoustic survey estimated 36,760 (30,835-43,821) dolphins. The visual survey estimate for sperm whales was 313 (63-582), while the acoustic survey estimate was 316 (265-377). GulfCet II is only now finishing, and describes cetacean habitats in the central and eastern Gulf of Mexico.

Three aspects of the cetacean community bear on the effects of seismic exploration in the Gulf: a large and diverse dolphin community, a large and stable sperm whale population, and very few baleen whales. The dolphins are the largest component to the cetacean community. The animals most likely sensitive to low frequencies, the baleen whales, appear in small numbers, though mostly in the eastern gulf where oil exploration is greatest. There appears to be site fidelity among at least some of the sperm whales, including an area of intense oil industry activity near the mouth of the

Mississippi River. This can be taken to indicate that sperm whales continue to use areas of heavy seismic exploration. It remains, however, unclear whether this site fidelity is a product of low sensitivity to the noise or a high motivation to remain in the area.

In the 17,000 km where we recorded signals in the Gulf of Mexico, we recorded many forms of signals that could impact marine mammals. Signals can adversely effect animals by physically injuring their hearing, causing them to leave important habitats, or masking their own communication and food finding signals. The form of the signal therefore has an impact on whether it will affect an animal. For example, a loud pulsed explosion may deafen an animal, whereas a continuous signal, rain or shrieking bearings on poorly maintained vessels, for example, may result in the animal's not hearing conspecifics calling or interfere with reception of their sonar signals. Seismic signals are thought to be strictly low frequency signals, with energies below 1 kHz. However, we have recorded loud pulsed signals associated with seismic exploration with center frequencies at 2.5 kHz, with little energy below 1 kHz. These signals are similar in frequency to sperm whale clicks, and assuming that the whale can hear its own vocalizations, are entirely audible to the whale. Additionally, other signals such as array locators are also used, at higher frequencies (up to 60 kHz). Lastly, the U.S. Navy is considering a series of ship shock trials in the eastern Gulf, which result in the demolition of thousands of pounds of high explosives.

Beyond simple descriptions of cetacean distribution and abundance, we have begun preliminary investigations into the impacts on marine mammals of oil exploration. Most importantly we have found that in the north central and eastern Gulf cetaceans are regularly exposed to seismic signals, where seismic signals were audible during 34% of the acoustic censusing effort. In the western Gulf this figure is smaller, where these signals were apparent 10% of the time. Controlling for different hydrographic regions, there was no significant difference in the cetacean sighting frequency for five acoustic zones which differed in signal-to-noise as a result of seismics. Further, for each hydrographic region, the observed cetacean distribution associated with seismic sounds does not significantly differ from that expected by chance. This study, however, does not present any information regarding smaller scale behavioral impacts.

In explaining the possible responses to seismic signals, it is necessary to understand both how and why cetaceans react. It is likely that the results noted to date are due to both cetacean hearing and the seismic signal's frequency and temporal characteristics. We know the auditory thresholds of a few dolphin species, but little about either sperm whale or baleen whale hearing. However, because of their low frequency vocalizations and auditory morphology, it is thought that baleen whales have good low frequency hearing. We suggest that because of their large size and use of relatively low frequency pulsing, sperm whales also have good low frequency hearing. It is likely that dolphins can hear the higher components of seismic pulses, though the thresholds are relatively poor at those low frequencies. Additionally, pulse configuration may effect how seismic signals influence some cetaceans. Both dolphins and sperm whales produce high amplitude transient pulses. Like most animals, they have mechanisms to protect their hearing against loud signals. Speculatively, if the rise time of a pulse is slower than their own signals, it is likely that pulsing cetaceans are particularly well suited to protect their hearing against loud pulses. There would still be a limit beyond which their hearing could still be damaged by sufficiently loud transients, but this level may be higher than for animals, such as baleen whales, that do not produce transients. Designing seismic signals relative to cetacean pulses may reduce their impact on some cetaceans. Lastly, some signals used in seismic exploration may mimic some signals used by sperm whales.

MARINE MAMMALS AND SEISMIC: THE LONDON WORKSHOP

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Joint Nature Conservation Committee
Scotland

INTRODUCTION

There has been much recent controversy in the United Kingdom on the effects of seismic exploration on cetaceans. An increase in sperm whale strandings in the North Sea has been attributed by some to an increase in seismic surveys in deeper water to the north and west of Scotland. The leading cetacean conservation organization in UK issued a tape of seismic noise with the clear message that UK's cetacean population was imperiled by this activity.

At a more official level, the United Kingdom is party to the Agreement on the Conservation of Small Cetaceans in the Baltic and North Seas (ASCOBANS). This Agreement was concluded under the auspices of the UN's Convention on Migratory Species and is legally binding on its parties. One of the objectives of this Agreement is to "work towards...the prevention of...significant disturbance, especially of an acoustic nature." As a result of this Agreement, the Joint Nature Conservation Committee, with others, drew up a set of guidelines for the seismic industry in 1994. These guidelines contained some practical approaches that were thought would reduce disturbance and minimize the risk of physical damage to cetaceans. These guidelines were attached as mandatory conditions on all new licenses issued by the UK government for hydrocarbon exploration. They were not universally acclaimed: non-governmental organizations felt that they did not go far enough, while industry felt they were too onerous in the absence of proven effects.

The guidelines were revised after one year in operation to clarify them, with a commitment to keep them under review in the light of experience and research findings. In late 1997, industry approached the Joint Nature Conservation Committee with an offer to sponsor a workshop to examine the whole issue of seismic and marine mammals. There was still controversy around the issue and it was felt a fully open workshop would shed light on issues and remove some of the heat. A steering committee was sought which would involve industry (both hydrocarbons and seismic contractors), governmental advisors, non-governmental organizations and academics. In the end, NGO participation on the steering committee was limited.

THE WORKSHOP

The steering committee decided to split the workshop into five inter-related topics and commission a paper on each topic to generate discussion in a structured fashion. These topics were:

- Marine seismic overview
- Physics of sound in water
- Biology of marine mammals
- Seismic and marine mammal interaction
- Mitigation of potential effects

These topics focused where necessary on the northeast Atlantic and on features relevant to the interaction between seismic and marine mammals. The first three topics were as far as possible based on fact, while some speculation and suggestion were encouraged also in the reviews of the last two topics to engender discussion. Authors were selected to as far as possible be known experts in each subject, and co-authorship was encouraged to incorporate a range of opinion. At the meeting, sessions were organized around each topic, followed by breakout groups and conclusion sessions. A lively poster session added much information to the proceedings.

MARINE SEISMIC OVERVIEW

The paper described how seismic surveys attempt to map sub-surface geological structures. The move from 2D surveys to 3D surveys has required closer line spacing, but this has been offset by the ability to tow more cables behind each vessel. The amount of sound required per unit area of sea has nevertheless increased. The current standard air-gun array was described and other possible sound sources discussed. Some information on the geographic changes in areas of interest in the northeast Atlantic were presented. To understand this issue better, the workshop concluded that

- more measurements of the broad band spectrum of airgun sources were required. Industry is usually only interested in the lowest frequency sounds, whereas cetaceans can hear and react to higher frequencies.
- a critical evaluation of alternative energy sources would be useful in order to determine if any of these were "cleaner" from the point of view of unwanted sound.
- a historical database of seismic activity would be useful in indicating if any broad-scale changes in cetacean distribution had occurred as a result of changes in seismic surveying

PHYSICS OF SOUND IN WATER

The propagation of sound through water theoretically follows a set of fundamental principles. However, in real life, these principles interact in a complex fashion to produce results that are often not predictable. Modeling of the propagation of seismic sounds is thus difficult without *in situ* measurements at the time that testing is to take place. This is particularly the case in relatively variable shelf seas. The literature on this topic has also become confused by a plethora of measurement techniques and units. The usual unit for measuring output level, the decibel, is a relative unit, and confusion over the reference level used also abounds. The review considered also other sources of marine sound, pointing out that levels of sound produced at some frequencies by shipping exceed those produced at those frequencies by seismic testing. The workshop concluded that better understanding in this area would

- help define a propagation model that would enable "safe" limits to be set on the proximity of marine mammals to seismic sources,
- better define possible impacts when making environmental assessments are made, and
- help in studies of the reactions of marine mammals to sound

This could be achieved by further modeling of known situations and by making new measurements with a dedicated system. These approaches could usefully be combined to examine variability in propagation and specific situations. A further review of anthropogenic noises and studies prior to seismic exploration would provide useful information on the range at which seismic testing would be masked, and on the relative levels between seismic noise and background noise.

BIOLOGY OF MARINE MAMMALS

Knowledge of the biology of cetaceans and seals in the northeast Atlantic was reviewed. Relevant biological features include the following:

- the numbers and migration of species occurring in the region,
- their breeding cycle (are there particularly sensitive times of year when any potential effects should be particularly avoided?),
- their feeding regime (surface feeders vs. deep divers),
- their ability to hear or sense sound and
- their reaction to disturbance

The deep waters to the north and west of Britain are known from a variety of studies, not least sightings from seismic survey vessels, to be important (in a NE Atlantic context) for the larger whale species and for deep diving species such as the beaked whales. A certain amount is known about breeding cycle, both from records made during the whaling era and from sightings since then. Rather little is known about ability to hear and sense sound, or precisely how cetaceans use and process that sound. There have been a few observational studies of disturbance reactions (see next section).

The meeting agreed that the disparate sources of information on the distribution of marine mammals in NW European waters should be bought together as far as possible to enable a "gap" analysis. A library of audiograms should be compiled, using the little available information and by creating a "rapid-reaction team" in NW Europe to collect information on stranded or trapped mammals. To form this team, experience from the United States could usefully be acquired and a formal protocol developed. There was discussion of the need to study and record "natural" behaviors of marine mammals, so that any changes in behavior might be more easily identified.

SEISMIC AND MARINE MAMMAL INTERACTION

The range of potential direct impact of seismic sound on marine mammals could run from severe injury to body tissue through permanent or temporary reductions in auditory sensitivity (threshold shifts). In addition, disturbance could result in behavioral alteration or sound could mask communication or other uses of sound. Indirectly, food stocks might be affected, leading to a reduction in foraging opportunities. Over a long period, such effects may accumulate to cause other problems. There have been few direct studies worldwide of these effects. John Richardson presented a summary of one of the best of these studies: on bowhead whales off Alaska. On a related topic, it was noted that disturbance might also lead to a reduction of economic opportunity in the form of whale-watching.

The methods by which effects might be detected were discussed. Population dynamics might be examined, but results would be available only in the long-term, be expensive and difficult to obtain and likely to lack in statistical power. Studies of body condition would be difficult, especially in ascribing cause and effect. Behavioral studies appear to offer the best way forward with visual and acoustic observations from seismic "chase" boats and from other platforms of opportunity likely to be useful and comparatively cheap. The definition of "significant effect" presents some difficulty. If "critical habitat" can be defined for relevant cetacean species, perhaps by the use of population gradients, then the evasion range could be compared with the spatial scale of the critical region to give an indication of the likely significance of any disturbance. Studies on physical and hearing damage presently under way in the United States would be informative.

MITIGATION OF POTENTIAL EFFECTS

Current potential mitigation measures include

- seasonal and geographic limitations on surveys,
- soft-start (ramp-up) procedures,
- safety-zones around noise sources,
- use of minimal source power compatible with imaging subsurface targets

The degree to which these are implemented varies world-wide. In the United States, legally-binding legislation is used. The UK's guidelines have been used in several other areas worldwide. The various mitigation measures are limited by knowledge. The application of proper limitations on surveys relies on sufficient accurate information on marine mammal distribution. The effectiveness of soft-start has not been critically evaluated. In the United States, safety zones have been defined as the distance at which sound levels are above 180 dB (re 1 μPa (rms)), although even these distances have proved controversial. In the UK, a blanket 500m is recommended in the guidelines. The difficulty of seeing marine mammals within and outside the safety zone can be addressed with the use of acoustic monitoring devices or by dedicated ship or aerial survey.

The workshop suggested that in addition to the above, the industry should

- strive to design sources that minimize the output outside the usable bandwidth,
- review the effectiveness of soft-start
- better define safety zones
- develop a more transparent administrative procedure to re-assure third parties,
- develop strategic EIA for seismic operations to help guide regional activities

CONCLUSION AND THE FUTURE

The workshop was successful in reviewing current knowledge and procedure and in identifying areas where we are presently deficient in information. In terms of wider involvement in the issue, most participants went away happy. It is likely that a further workshop will be convened in two or three years.

ACKNOWLEDGMENTS

The "seismic and marine mammal" workshop was organized by Joe Karwatowski, Chris Walker, Ingebret Gausland, Dave Thompson, Jonathan Gordon, Anne Walls, George Chisholm, Jim Gulland and me. The workshop was sponsored by 29 hydrocarbon or geophysical companies. The authors of the main topics were Jim Gulland, Chris Walker, Ingebret Gausland, Dave Thompson, Peter Evans, Jonathan Gordon, Doug Gillespie, John Potter, Alexandris Frantzis, Mark Simmonds, Rene Swift, Pat Birnie, Jay Wagner, Vance Langford and Mark Pierson. I thank them and all others who attended for making the workshop a success.

Mark Tasker has worked on the conservation of offshore animals for the UK government since 1979. In early years this was primarily as a researcher on the marine distribution of seabirds, but since 1987 Mark has progressively moved into information and advice provision. Such advice is targeted primarily at offshore industry and fisheries managers. Mark was a member of the organizing committee of a workshop on seismic and marine mammals held in London in June 1998.

OFFICE OF NAVAL RESEARCH CONCERNS AND RESEARCH INITIATIVES FOR ACOUSTIC/EXPLOSIVES EFFECTS

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INTRODUCTION

The U.S. Navy is deeply committed to operating in an environmentally safe manner (see Navy website at *http://206.5.146.100/n45/branch/n454/*). To foster better understanding of the potential effects from impulse sound, and to develop the means to better assess and mitigate such effects, the Office of Naval Research has initiated research to shed light on this issue. It is our hope that the information thus obtained will not only facilitate the U.S. Navy's requirements to meet its commitment to environmentally safe operation, but will be of use to other federal, state and local agencies, as well as to relevant industry and other nongovernment parties, and to the general public.

The ONR program is one of scientific data-gathering and dissemination. While it is typically considered desirable that legal guidelines and policy rely heavily on science-based information, it is important to remember that the two processes are independent, and that one should not draw premature conclusions from this presentation about implications for Navy or national policy, guidelines or regulations. In some cases I will be describing experimental designs that have not yet produced data. In other cases I will describe work so recently completed that there has not been sufficient time for full peer review and incorporation into an accepted body of knowledge upon which to base legal and policy decisions. In all the projects I will be discussing, the concept, execution, interpretation, and dissemination of the work is considered to be the property of the researcher. For example, the determination of temporary threshold shift effects (TTS) from impulse sound is a scientifically feasible project, and one that is currently being undertaken by investigators under ONR sponsorship. However, the ultimate use of such information in policy or guidelines is still very unclear and hinges on discussions as far-reaching as the relationship between permanent and temporary hearing loss, the legal definition of "harassment" under the Marine Mammal Protection Act, and the ability of organisms to cope with decreased auditory function in both the short and long term. It would be beyond the scope of this discussion (and the author's expertise) to speculate on the significance of such information for Navy or national policy and procedures.

BACKGROUND ON THE OFFICE OF NAVAL RESEARCH AND ITS ROLE

The Office of Naval Research was created in 1946 to continue the successful interaction between universities, government and industry that emerged during World War II. ONR was the first formal, large-scale government program to foster basic research outside the government and was a model for other federal research funding agencies, such as the National Science Foundation (Vest 1996). The role of the current ONR remains much the same, over 50 years later. Success, for ONR programs, is as much about metrics of academic achievement such as peer-reviewed publications and Nobel prizes as it is about delivering new science and technology products to the Navy. As you will see, the ONR research program into the effects of impulsive sound on marine organisms takes advantage of ONR scientific leadership in such areas as underwater acoustics and marine mammal biology to provide cutting edge science that is not only useful to the Navy but contributes to a generally accessible knowledge base with a wide range of potential uses. The work involves expertise and facilities at universities, Navy research laboratories, National Marine Fisheries Service and the Army. All work from the program is unclassified and will be published in scientific journals or other publicly accessible sources under academic peer review.

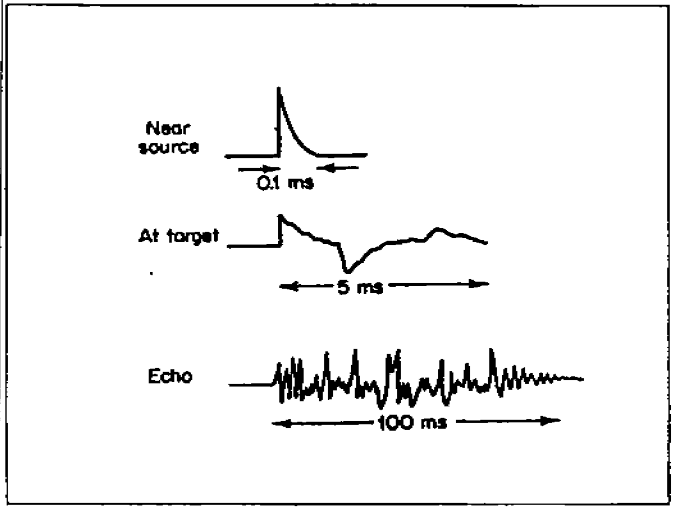
BACKGROUND ON IMPULSE SOUND AND ITS EFFECTS

Impulse sound is generally defined as sound with an irregular and sharp waveform (rapid pressure oscillations), as opposed to sounds produced by regular oscillation of some mechanical device or material which produces a sinusoidal pattern of pressure change (see Figure 1G.17 for some examples). Some sources of impulse sound, explosives and airguns for example, show obvious differences from a tonal sound source like a loudspeaker or rotary machinery noise (e.g. see Richardson *et al.* 1995). But many other sources of sound may not be so easy to categorize, such as sonars which are capable of producing a loud tonal signal with very rapid onset. A recent meeting of technical experts convened by National Marine Fisheries Service was unable to arrive at a satisfactory "simple" definition for separating impulse or transient sounds from tonal or continuous sounds, so no definition will be attempted in this presentation. What is important is that clearly impulsive and clearly tonal sounds be compared to look for differences in effects on hearing, comparable to the differences observed for airborne impulse and tonal sounds. In air, impulse sounds tend to produce more variable effects than tonal sounds, in part because it is difficult to measure the exact characteristics of an impulse such as peak pressure or frequency composition, and in part because features of biological response such as structural failures, protective reflexes and effects of orientation can result in widely varying outcomes for different individuals exposed to the same impulsive sound (Kryter 1985).

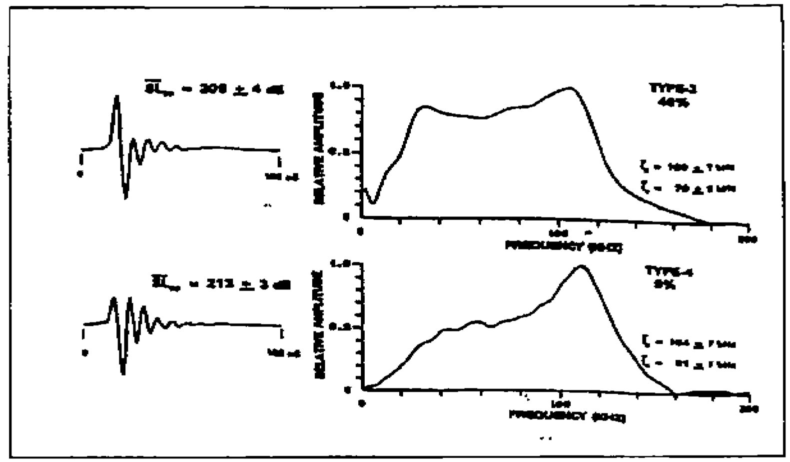
Also, the sound energy from impulse sources comes to resemble a tonal or continuous sound at increasing range due to frequency spreading and multi-path transmission between source and receiver. If one were to imagine this effect visually, the waveform would appear to become smoothed or "mushy" and spread out in time. Acoustically, an impulse would be perceived as a "pop" or "click" near the source and would sound like a more prolonged rumble at greater distance due to the time-delayed arrival of sound energy along several paths, and the tendency of lower frequencies to propagate further than high frequencies (Urick 1975). Thus the same sound heard at one mile and six miles might not only differ in loudness, but in features of frequency structure and duration as well.

The major differences of interest between impulse and tonal sounds are

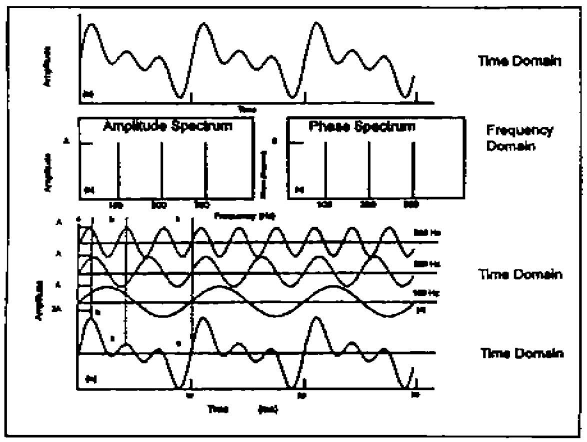
1. many impulse sound sources produce greater peak over- or under-pressures than tonal sources. For example, a loud explosion may produce peak pressures 100 or more times



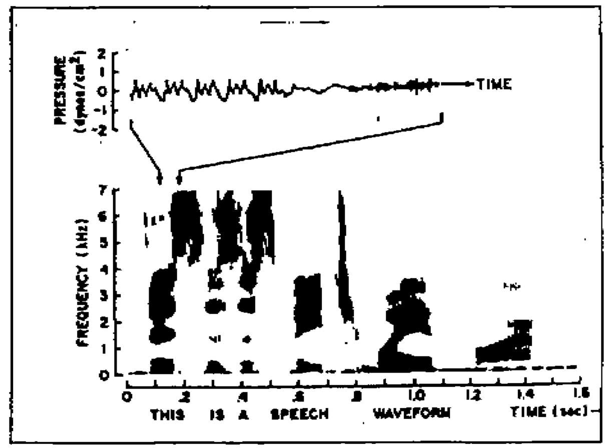
Impulse from an explosion(from Urick, 1975)



Impulse from a dolphin (from Au, 1993)



From pure tones to complex sounds



A complex tonal sound (speech)

Figure 1G.17. Examples of impulse and tonal sounds.

greater than the loudest tonal sources (e.g. 270-280 dB re 1 μPa for a large explosion versus 220-230 dB re 1 μPa for a sonar).

2. the rise time to peak pressure, or the time between peak over- and under-pressure may be so short (microseconds) that physical structures cannot flex over the course of the pressure change, and they break or are displaced. The result can be damage to hearing or other structures at sound pressure levels that might produce little or no effect from a tonal source.

These accelerative effects are greatest where there is a difference in the medium transmitting the sound with a resulting change in sound speed. Soft-bodied organisms like jellyfish or sea cucumbers may be unaffected by even very loud sounds because the pressure wave passes through their bodies as through seawater. Organisms that contain gas-filled spaces, e.g. fish with swim bladders or turtles and mammals with lungs, will experience mechanical movement at the interface between two media such as air and water, resulting in rapid accelerative movement and tearing of tissues or blood leakage in lungs, middle ears, or digestive tract in proximity to gas pockets. In some cases the acceleration of denser tissues such as middle ear bones or ribs may result in damage to those structures or the tissues around them (Yelverton 1981; Young 1991).

These effects should not be confused with damage from the shock wave, which is a mechanical force generated by an explosion or by water displacement by expansion of a compressed air bubble from an airgun. In close proximity to an impulsive source, an organism may be damaged by the shock wave as it physically accelerates both the medium and the organism, but in a dense viscous medium like water the shock wave does not travel very far, usually only tens or hundreds of meters for the vast majority of impulse sources.

RATIONALE FOR THE ONR PROGRAM

Lethal and injurious effects from shock waves and sound overpressure or energy flux are well documented and will not be discussed in detail (see Yelverton 1981; Young 1991; Ketten 1995). Larger animals are likely to withstand greater peak pressures. Keep in mind that these are received values, and source levels might be much higher, depending on the range from the source.

At the other end of the spectrum are noninjurious behavioral responses to impulse sounds. Hypothetically, any sound that can be heard could elicit a behavioral reaction. In reality, the probability of eliciting a reaction, and the type of reaction elicited, can vary greatly with species, individual experience, alertness or the nature of the sound and the circumstances under which it occurs. Because of the tremendous variability of behavioral response, it will undoubtedly be very difficult to develop metrics for "harassing" sound or some other boundary between biologically significant or consequential noninjurious sound levels and inconsequential but audible sound levels. ONR and other Navy activities expect to generate data on behavioral reactions in the course of monitoring and mitigation efforts, but it will probably be some time before sufficient data accumulate to suggest any general predictive relationships between impulse events and behavioral reactions.

In this context ONR has focused on quantifiable physiological or percept-based effects of impulse sound that can be experimentally induced, replicated and verified in statistically meaningful ways, but which bridge the region between injurious effects and more variable, less predictable behavioral responses. The two studies we have selected for funding are briefly described below.

TEMPORARY THRESHOLD SHIFT (TTS)

This study is being carried out under the leadership of Dr. Sam Ridgway at the Space and Naval Warfare Systems Center (SSC) in San Diego, using a sound source provided by the Naval Surface Warfare Center (NSWC) in Carderock, Maryland. The TTS protocol developed by Ridgway and his colleagues at SSC has been used to generate data on the levels of pure tones that induce a small (six decibel) quickly recovered hearing loss (Ridgway *et al.* 1997). Using the impulse sound simulator developed by NSWC Dr. Ridgway will employ the same protocol to determine the onset of brief temporary threshold shift to a simulated signal replicating an impulse event at some range from the source. The NSWC device uses multiple tonal transducers to produce a plane wave that replicates an impulse sound through the constructive and destructive interference of the different individual signals produced at each transducer. The simulator cannot replicate the sharp microsecond duration waveform found at or near a source, but it can replicate the more spread out signal found at ranges of thousands of meters from the source. At that range, the signal is still only a few tenths of a second long at most and, therefore, still much shorter than the tonal signals which usually last a second or longer. Ridgway's experimental protocol also allows for testing of other impulse sources such as airguns and sparkers and for testing the scaling relationship of TTS to multiple impulse exposures.

The onset of temporary threshold shift to short (one second) tonal signals at frequencies between 400 Hz and 70 kHz have been on the order of 190-200 dB, and we anticipate that responses to shorter duration impulse events will be at similar signal strengths (Figure 1G.18), but a question that is best resolved by the empirical data. However, we still do not know if there will be greater variability in the onset levels from test to test than we are seeing for tonal signals or if the broadband impulse events will exhibit stronger effects on certain hearing frequencies due to the mechanical properties of the ear or for other reasons. In terrestrial mammals, TTS to impulse sounds tends to be more variable than to tonal sounds, probably due to irregular reactions by ear protective mechanisms and effects of orientation. Terrestrial mammals also tend to show greater TTS effects at higher frequencies than the stimulus, probably due to the shape of the inner ear.

Ridgway employs an operantly conditioned, food-reinforced testing procedure that tends to produce the greatest and most consistent indication of hearing sensitivity. The effects of methodology on results are being assessed by independent parallel efforts undertaken by Ron Schusterman of the University of California at Santa Cruz and Paul Nachtigall and Whitlow Au at the University of Hawaii. Three species of marine mammal are being tested at SSC; California sea lions (*Zalophus californianus*), bottlenose dolphins (*Tursiops truncatus*), and beluga or white whales (*Delphinapteras leucas*). The experiment begins with a pre-test hearing check. Then, after a variable delay, the "inducing" sound stimulus is played and another hearing check is administered (Figure 1G.19). When hearing is checked after the inducing sound and a decrement of six decibels is obtained (the minimum statistically significant difference in this particular design), a temporary

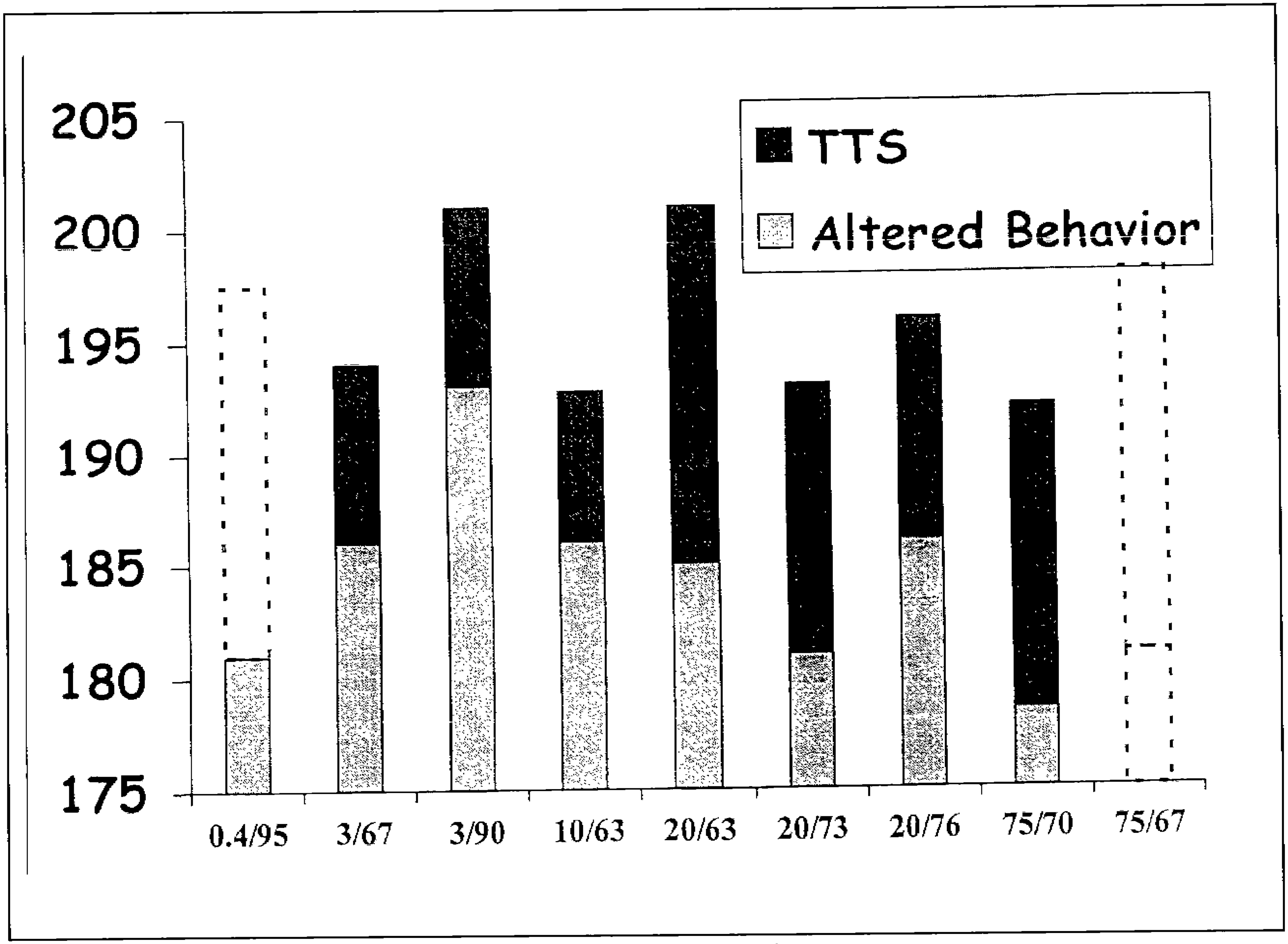


Figure 1G.18. Sample results of hearing sensitivity testing on marine mammals.

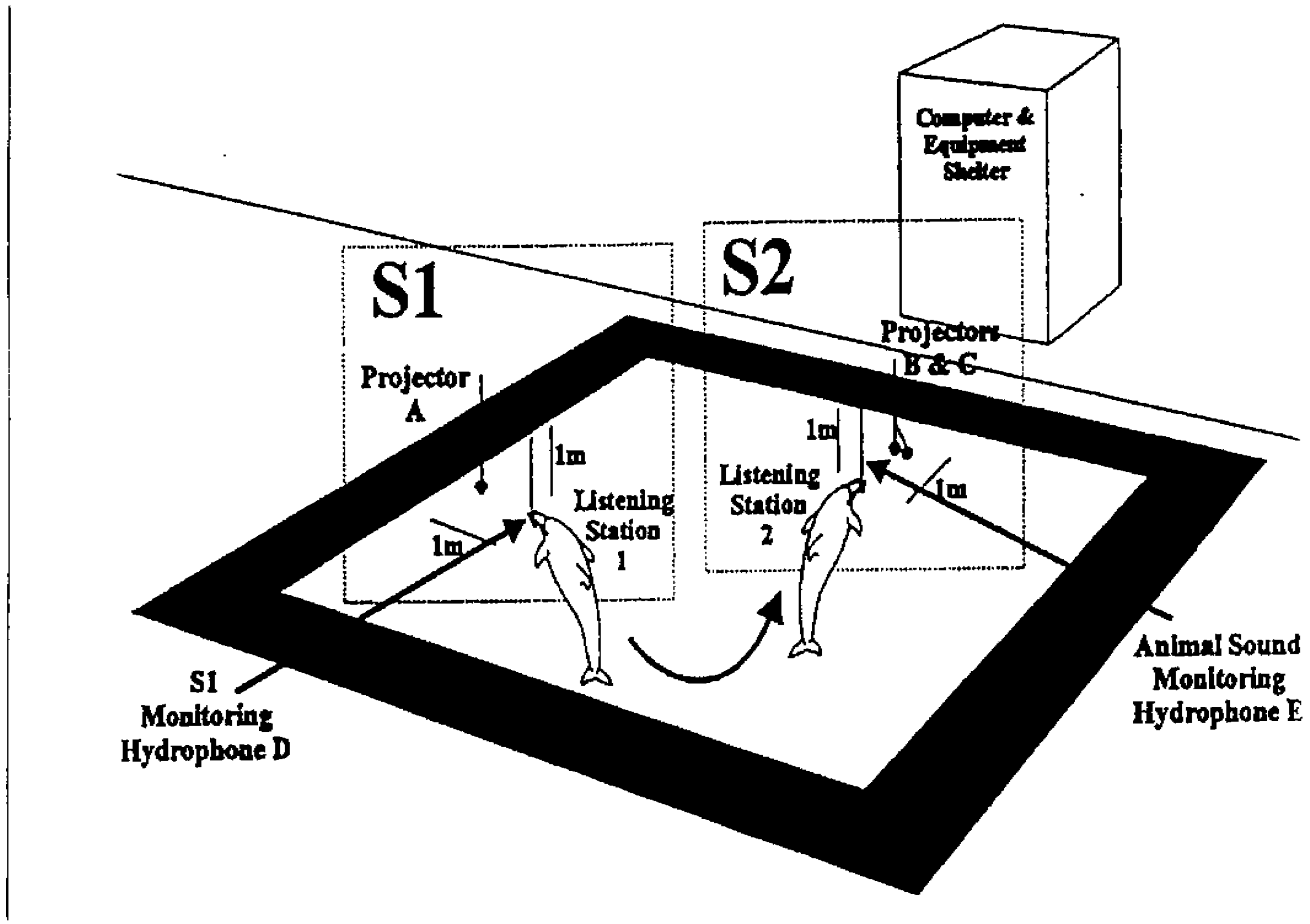


Figure 1G.19. Diagram of the TTS testing enclosure. At listening station 1, the dolphin got an S1 signal from projector A, then proceeded to listening station 2 for hearing threshold testing. Projector B delivered the S2 tones, and projector C emitted the white noise that served as level background. Monitoring hydrophone D was used to record louder S1 signals for precise determination of acoustic amplitude at the dolphin's lower jaw. Monitoring hydrohpone E recorded the dolphin whistles emitted by the animal when it heard an S2 tone.

threshold shift is said to have occurred, and the level and duration of the inducing signal is noted. For the short duration signals used thus far (most are one second long), recovery to pre-test levels generally occurs within 15-30 minutes of the TTS event. Animals must return to full pre-test levels before they are allowed to do another TTS test.

TTS is of interest for two reasons. First, it bears some relationship to Permanent Threshold Shift (PTS). Though the causal relationship is not clear, it appears that repeated TTS events can lead to PTS, and onset of TTS bears a fairly consistent relationship to onset of PTS (Kryter 1985; Ward 1991). Since it is undesirable to deliberately induce PTS to determine the actual onset of permanent hearing damage, testing for TTS at least gives us a "ballpark" number for reducing the likelihood of PTS. Second, TTS means that an individual is temporarily deprived of a specific degree of hearing acuity and for a specific duration. During that time, the individual has a reduced ability to receive environmental sensing and communicative acoustic information. The quantification of TTS effects thus enables one to make more reliable and precise risk assessments about the effects of a given sound source that has the potential to cause TTS.

MEASUREMENT OF MACRO AND MICRO SCALE DAMAGE FROM IMPULSE EVENTS

Since it is impossible to test for damage effects in live, free-ranging animals, this experiment makes use of specimen materials collected by the National Marine Fisheries Service Stranding Program. Microscopic structures such as the cilia on inner ear hair cells retain their structural mechanical properties for a considerable period post mortem and can be used to construct predictive mechanical models of the damage likely to be induced in live animals by a given impulse event, even if the effect is restricted to such microscopic effects as damage to hair cells, with no other obvious injury.

Dr. Darlene Ketten of Woods Hole Oceanographic Institution and the Harvard Medical School will use special techniques that she developed for high resolution x-ray computed tomographic scanning (CT scan) to create 3-D images of intact ears in specimens provided by the NMFS Stranding Program (see Ketten 1997). The specimens will be CT scanned before and after exposure to a controlled, measured impulse event, and then standard histological techniques will be used to further assess the nature and extent of damage induced by a given impulse event . Figure 1G.20 provides a schematic illustration of the sequence of experimental procedures. Sound output from explosives scales with charge size (Kibblewhite & Denham 1970), so small charges in test pools are sufficient to establish predictive relationships for larger at-sea impulse events without the risk of uncontrolled inadvertent exposures of marine life during testing. Likewise, effects scale with the size and robustness of the ear structures (Ketten 1995), so tests will be conducted on small specimens (harbor porpoises) and tissue blocks containing the ear structures and surrounding supportive tissues for larger species like baleen whales.

In addition to impulse waveforms from explosives, other impulse waveforms, such as those from air-guns, may be tested. Eventually the energetic correlates of damage can be merged with measured dimension, mass and resilience of auditory structures to create a predictive model of damage (Figure 1G.21), such as exists for human in-air auditory damage from guns and explosions (Price & Kalb

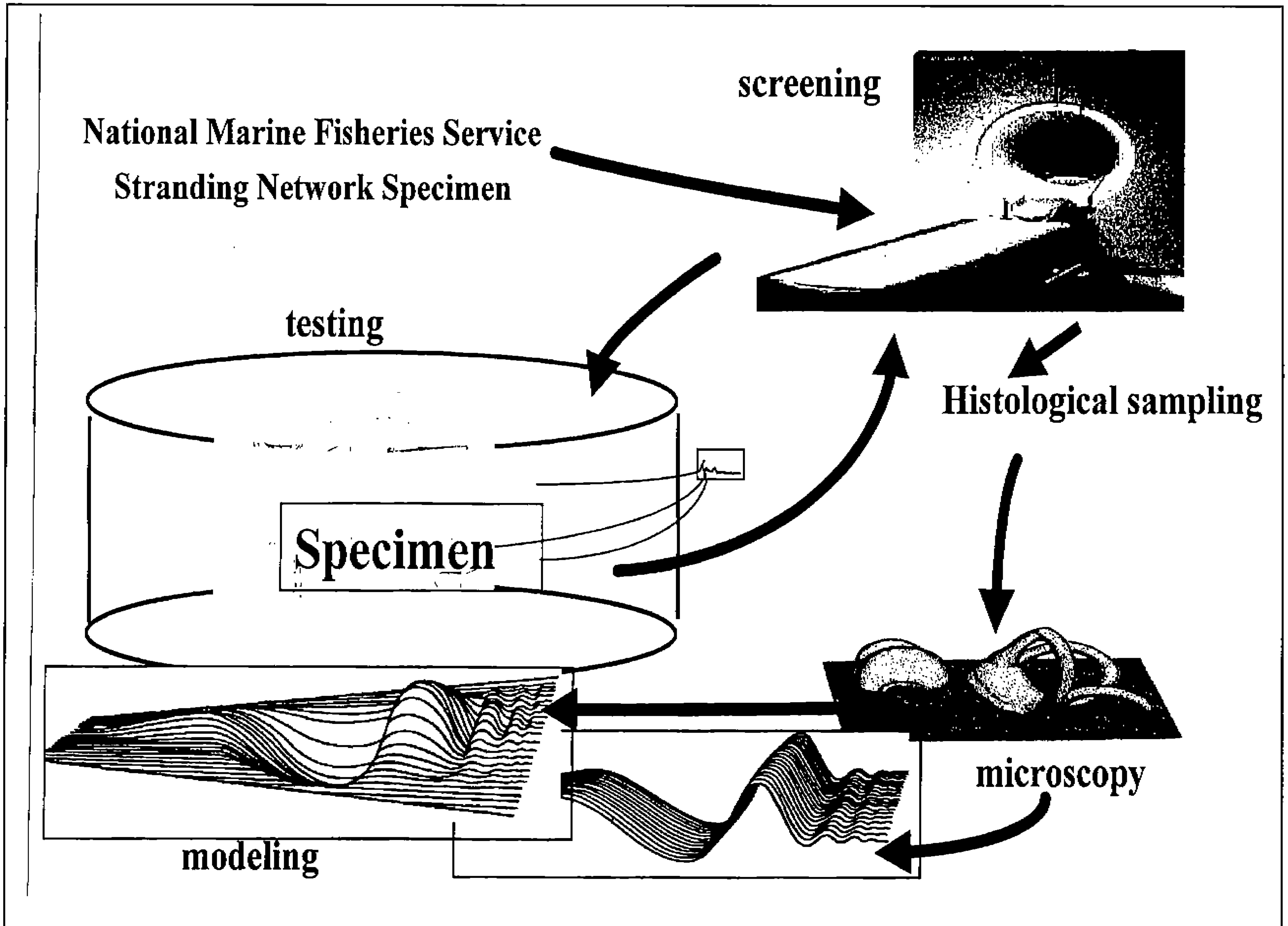


Figure 1G.20. A schematic illustration of the sequence of experimental procedures.

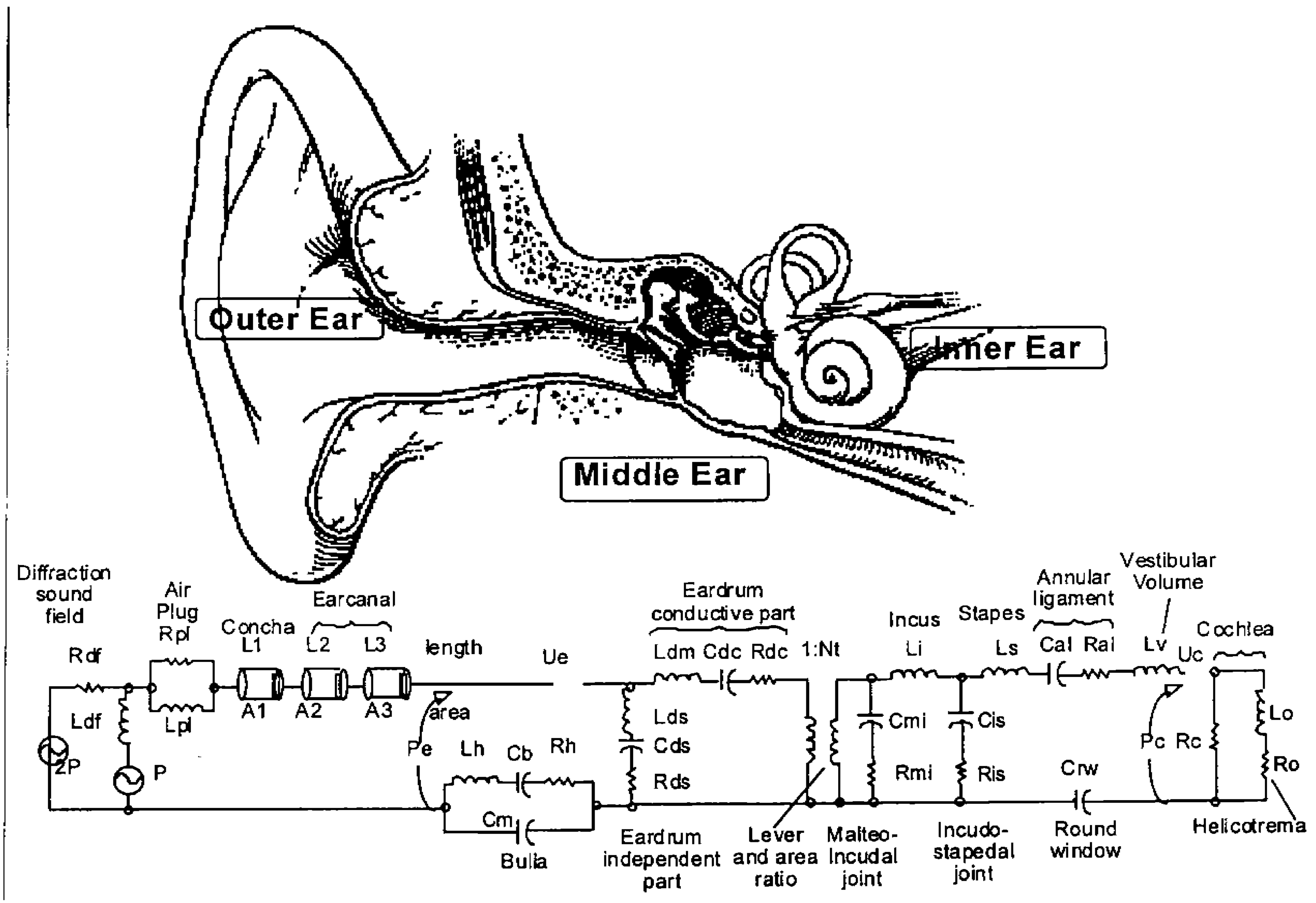


Figure 1G.21. A predictive model of damage created from the energetic correlates of damage merged with measured dimension, mass and resilience of auditory structures.

1996). The Price model is currently used to establish exposure safety standards for the U.S. Army and NATO for in-air impulsive noise. It should be relatively easy to adapt this model for marine mammal and human ears underwater to provide a similarly useful predictive model of damage from underwater impulse events.

CONCLUSION

The experiments led by Ketten and Ridgway should provide a much more detailed and statistically stronger set of metrics for risk assessment and damage prediction, even for very small damaging effects. These data can serve as cross-checks to each other and to current predictions based on human or terrestrial animal models, since the phenomena they measure overlap. Both Ketten and Ridgway's data should support predictive math models that can be used to extend their results to impulse sources of different sizes producing sounds of different frequencies and durations, and the models should scale in predictable ways for animals of different size.

These experiments, which should be completed within the next two years, are expected to enable us to establish very definite criteria concerning the potential for injury and temporary performance losses from impulse sound, ranging from lethal and serious effects to tiny recoverable effects. As indicated earlier in this paper, the potential for purely behavioral effects is much more difficult to assess and will probably produce much more variable outcomes that will be difficult to reconcile to simple models for impact assessment and prediction. At some point, NMFS and the interested community at large will probably want to make a cost-benefit analysis of the remaining risk after immediate damaging effects have been clearly defined and mitigated. While it is possible that some risk may exist from adverse behavioral or cumulative sub-threshold effects, it remains to be seen whether such effects constitute a significant threat to individual or population survival and well-being, and if so what kinds of efforts and what level of support will be required to resolve these remaining questions.

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THE MMS PACIFIC OCS REGION HIGH-ENERGY SEISMIC WORKSHOP

Dr. Mark O. Pierson
Minerals Management Service
Pacific OCS Region

THE HESS PROCESS

During this decade, several sound-producing projects off the California coast have increased concern over and public interest in the problems of underwater sound and marine mammals. These have included the U.S. Navy's plan to ship-shock test new warships using high explosives, Scripps Institution of Oceanography's ATOC experiment to detect evidence of global warming from changes in water temperature, an Exxon 3-D seismic survey m the Santa Barbara Channel, and, more recently, the Navy's low-frequency active sonar project (LFA).

The Exxon survey, conducted in the fall of 1995, was the first seismic survey in Pacific Outer Continental Shelf (OCS) waters since the late 1980s. Controversy over this project brought Exxon, MMS, NMFS, several state, and local agencies, fishermen, and environmental groups to an impasse over survey procedures and mitigation that was resolved only after several last-minute meetings. This was a very unsatisfactory process. Consequently, after completion of the Exxon survey MMS's Pacific OCS Region met in June 1996 with all interested stakeholders and agreed to establish the High-Energy Seismic Survey (HESS) Team. The purpose of the Team was to develop a standardized set of acceptable procedures for the review of seismic survey proposals off southern California. The Team also agreed to discuss the scope of environmental review necessary to conduct future surveys and possible mitigation measures. The drafted review process and mitigation guidelines were then to be presented to the Pacific OCS Regional Director for approval.

PURPOSE OF THE WORKSHOP

Given the ongoing scientific controversy over the potential effects of low-frequency sound on marine mammals, the HESS Team decided to convene a workshop. The purpose of the workshop was to provide a forum for a scientific expert panel to discuss and provide responses to scientific and technical questions. This information was intended to assist the Team in developing protocols for the review of seismic surveys and, in particular, to help develop mitigation measures and to identify needed studies.

Prior to the workshop, a series of technical questions were drafted by a subcommittee, which included representatives of MMS, NMFS, industry, the Joint Oil/Fisheries Liaison Office, and environmental groups. The Team as a whole provided input and reached consensus on the final list of questions.

The subcommittee also developed a list of possible scientific panel members, which was presented to the Team for review and approval. The panel convened was first-rate, consisting of distinguished scientists with expertise in the fields of geophysics, bioacoustics, and marine mammals (Table 1G.2).

The two-day workshop was held on 12-13 June 1997, at Pepperdine University in Malibu, California. The workshop was videotaped, and notes were taken by the facilitators and raporteurs. A written summary of the proceedings and the panel's recommendations was prepared with input from the panelists. The information presented here was abstracted from the draft final workshop report.

Table 1G.2. Scientific panel members at the MMS Pacific OCS Region High-Energy Seismic Workshop, Pepperdine University, Malibu, California, 12-13 June 1997.

John Calambokidis Cascadia Research Collective Olympia, Washington	Dr. Darlene R. Ketten Harvard Medical School Boston, Massachusetts & Woods Hole Oceanic Research Institute Woods Hole, Massachusetts
Dr. Daniel P. Costa University of California, Santa Cruz Santa Cruz, California	Dr. W. John Richardson LGL Ltd., Environmental Research Associates King City, Ontario, Canada
Dr. William T. Ellison Marine Acoustics, Inc. Middletown, Rhode Island	Dr. Samuel H. Ridgway U.S. Navy NCCOSC RDTE Division San Diego, California
Dr. Charles R. Greene Greeneridge Sciences, Inc. Santa Barbara, California	Dr. Bernd Wtirsig Texas A&M University at Galveston Galveston, Texas
Dr. Gordon M. Greve Orion Consultants Durango, Colorado	

RESULTS OF THE WORKSHOP

The panel was presented with seven major questions, each of which had a number of subparts. The panel's discussions and responses to each of the questions are summarized below.

1. What are the important factors that influence the generation and propagation of sound ft~m high-energy seismic sources in water in the study area?

   The panel concluded that estimating the acoustic field generated by an array of source elements is complicated, but possible. They agreed upon a conceptual model for describing the sound source that distinguishes four regions. The panel noted that it was easier to predict the distance from the source and decibel range for each zone than to predict actual effects. They felt that, given our current level of understanding of the effects of underwater sound on marine mammals, improving our knowledge of potential effects at the closer ranges is a better use of resources than defining the parameters of each zone more precisely.

   The four regions identified were:

   A. Very Near Field (within ~ 30 meters). Effects within this range will be dominated by the single most powerftil source in the array. Exposure in this region could cause tissue damage and, possibly, acoustic trauma.

   B. Near Field (up to ~ 100 meters). Within this zone, the beam from the array has not yet formed, and signal strength may have lost up to 30 dB. Exposure may disrupt important behavioral processes (e.g., feeding, mating).

   C. Close-in Field (100-200 meters). The beam from the array has formed at this distance. Exposed animals will experience temporary threshold shift (TTS), although the effects will be primarily behavioral.

   D. Far Field (beyond 200 meters). The signal has spread considerably at this point. While signal strength is decreasing, the sound may be audible at great distance from the source (up to 100 km for some species). The actual distance will be a function of the source spectrum, transmission loss, an animal's hearing sensitivity, and the ambient noise in the spectrum of interest. At these ranges, a response is still possible.

   The panel agreed that the modeling process is more complicated in the far fields, where ambient noise plays a much greater role and a great deal of on-site data is needed. Water temperature, bottom topography, and sediment type are also important factors in the far field.

2. Under what conditions can modeling be used as a reliable approach for determining the propagation characteristics of sound energy from a high-energy airgun array to define, for

example, areas for protection of marine mammals? How technically feasible, reliable, and cost-effective is pre-survey field verification, and when should it be considered?

The panel concluded that, given the quality of currently available models, pre-survey verification is unnecessary. They recommended that companies conducting seismic surveys employ a good, site-specific propagation model, developed in advance and incorporating the best available information on local bottom topography; add a safety buffer; make actual measurements as early as possible during the survey; and adjust accordingly. They agreed that such a model would be fairly accurate within a kilometer (but that it would be important to look at hot spots, i.e., 8 and 16 miles away). These recommendations have been incorporated into the interim HESS mitigation guidelines.

3. What is known about marine mammal physiology and behavior that would suggest potential impacts to mammals from introducing high-energy seismic sound into their environment? What might constitute an unacceptable level of impact?

The panel discussed the range of potential impacts to marine mammals that might result from the introduction of sound into the marine environment. They identified the following five categories of impacts:

A. Physical trauma - includes physiological damage and acoustic trauma.

B. Biologically relevant impacts - not acute, but disrupt important biological functions, e.g., causing animals to leave feeding areas, or disrupting reproductive behavior.

C. Harassment – it is necessary to differentiate between the legal threshold and a biologically significant threshold. In biological terms, the level at which behavior changes might be set as the threshold for harassment, but it should be noted that behavioral changes range across a continuum. NMFS is continuing this discussion while redrafting their take regulations under the Marine Mammal Protection Act (MMPA).

D. Chronic effects – long-term, e.g., adrenaline build-up (stress).

E. Infrasound – these are non-auditory physiological effects, including such barely perceived physiological effects as nausea and dizziness.

The panel members indicated that it is difficult to ascertain when a temporary threshold shift (TTS) occurs. Also, an animal might not experience discomfort until long after actual damage has occurred (the "Walkman effect"). Permanent damage can also occur from TTS over time.

The panel also discussed the importance of motivation, the phenomenon of masking, and the adequacy of current data on effects. These and subsequent discussions culminated in a series of recommendations for future research, which were presented at the end of the workshop (see below).

4. What are appropriate safety zones and zones of influence for an array in the study area, beyond which impacts, as defined above, decrease to an acceptable level?

   Asked to define appropriate safety zones to protect marine mammals, the panel began by criticizing NMFS' interim acoustic criteria to determine whether marine mammals are being "taken" under the MMPA. They felt that not enough was known about marine mammal hearing processes and structures to use these criteria to evaluate marine mammal harassment. A recent NMFS workshop focused on the problems of take criteria (Gentry, this volume).

   However, the panel did conclude that, given what is known from other systems and until additional information can be obtained, they were "apprehensive" about received levels above 180 dB re 1 μ Pa (rms) with respect to overt behavioral, physiological, and hearing effects.

   A majority of the panel concurred that the 180-dB statement should be applied to all marine mammals. Several panel members suggested adopting a slightly higher level for groups that have poor low frequency hearing (small odontocetes and pinniped), but his suggestion was not accepted. The final consensus was to add a second sentence indicating that they were "aware of the rationale for suspecting that the threshold of hearing or physiological damage might be higher for some groups of marine mammals," but that "the available data did not allow any firm conclusion."

   To obtain this information, the panel strongly recommended experiments to test overt effects on the hearing, behavior, and physiology of pinniped and small cetaceans. They felt it was less likely that large shales would be exposed to close-range sound, but, considering their expected greater sensitivity to low-frequency sound and their levels of population endangerment, that there was a need for guidelines on incidental exposure of these whales.

   Although discussion of these criteria is continuing, the interim HESS mitigation guidelines do define safety zones for all marine mammals as the area around the airgun array within which received levels of sound are at or above 180 dB re 1 μ Pa (rms).

   Effects below 180 dB. The panel agreed that studies are needed to determihe the occurrence and nature of behavioral reactions to sounds at levels below 180 dB re 1 μ Pa (rms). They recognized that there might be responses at or near ambient noise levels, but felt that the most likely response range is above 140 dB re 1 μ Pa (rms). They did stress, however, that a measurable response does not necessarily signify a biological concern.

5. What changes in survey operational design might result in reduced impacts?

Since animals are always present, the panel felt that seasonally based prohibitions should be provided for species most sensitive to sound and/or at the highest levels of endangerment. Because this is not always practical, they recommended that surveys be designed using criteria based on distance to the most sensitive and/or endangered animals.

The panel prioritized marine mammal species in the southern California study area according to the following factors: 1) sensitivity to low-frequency airgun sounds, and 2) level of species or population endangerment. They identified the following three priority levels:

First Priority: blue, humpback, fifi, and gray whale.
Second Priority: sperm whale, elephant seal, other mysticetes.
Third Priority: other odontocetes, other pinnipeds.

Priority species have been taken into consideration in the design of monitoring protocols for the interim HESS mitigation guidelines.

Since continuous (24-hour) operations would complete a survey as quickly as possible, the panel agreed that they generally would be preferable to longer, intermittent surveys. However, continuous surveys require night operations, which involve a trade-off regarding the ability to visually detect animals vs. the advantages of continuous operation. The panel concluded that night operations require case-by-case evaluation, considering factors such as seasonality (hours of daylight, weather, migration patterns), priority of animals of concern, and economics. The use of continuous operations is an issue that is still unresolved in Team discussions of the interim HESS mitigation guidelines format.

The panel stated that, although unproven, ramp-up is a desirable mitigation measure, pending further research into its effectiveness. Ramp-up is in use worldwide as a mitigation measure for seismic survey operations and has been incorporated into the interim HESS mitigation guidelines.

6. What approaches for monitoring or mitigation efforts in the zone of influence are most effective?

The panel responded to this question by first establishing the following objectives for a monitoring program: 1) to implement mitigation, 2) to estimate take, and 3) to monitor species for potential far-field effects.

Shipboard observers. The use of shipboard observers is, along with ramp-up, the mitigation and monitoring measure most widely employed for seismic surveys. The panel felt that, at minimum, there should be observers on the seismic vessel, and recommended having multiple observers on d~y at one time. They felt that observers aboard the scout boat are also useful, since they can see farther ahead of the seismic vessel.

The panel emphasized that, while data collection is important for future planning and permitting, it is important to distinguish the behavioral observation roles of observers from their mitigation roles. The interim HESS mitigation guidelines call for observers to be aboard the seismic vessel during all surveys.

Aerial surveys. The panel considered aerial surveys to be a valuable tool for examining an area broader than near-field and useful for identifying concentrations of animals. Pre-survey aerial surveys may provide information necessary for the implementation of mitigation measures, such as delaying the start of a seismic survey. Survey information could also be used to estimate harassment during a seismic survey, although multiple replicates over the area are necessary to clarify whether such an effect is occurring. The interim HESS mitigation guidelines call for aerial surveys under some circumstances when high-priority marine mammal species are known to be present in the survey area.

Passive acoustic monitoring. The panel considered this approach to be worth exploring and evaluating as a mitigation measure. They felt that, if feasible, detection of animals in the safety zone by this method should be a criterion for shutdown. Passive acoustic monitoring is not called for under the interim HESS mitigation guidelines.

7. Are there other approaches for reducing impacts?

   Operation at reduced levels. The panel recommended that seismic surveys be conducted at the minimum sound level practicable.

   Bubble curtains. The panel concluded that bubble-curtain physics are theoretically sound, but that implementation is difficult with current technology.

   Acoustic deterrents. The panel felt that pingers and other active acoustic deterrents added additional noise and did not clearly provide an additional deterrent effect.

   Additional mitigation measures. The panel felt that combining passive acoustic arrays with aerial surveys would maximize knowledge of the marine mammals present in the survey area, although such a methodology is expensive. They suggested that "enhanced" visual techniques also be considered.

STUDY RECOMMENDATIONS

Finally, the panel made several recommendations for future research:

- Studies on overt hearing, behavioral, and physiological effects relating to sounds at or above the 180-dB + 10 dB level for different species (with focus on pinnipeds and small cetaceans).
- Studies on potential effects in the 140-180 dB range.
- Studies on the effectiveness of ramp-up procedures.

- Research into new techniques (e.g., passive acoustic) and their effectiveness as monitoring tools.
- A baseline study to compile information (matrix) on species, animals, distribution, population status, and sensitivity to sound in California waters.

SESSION 1H

PHYSICAL OCEANOGRAPHY SESSION

Co-Chairs: Dr. Alexis Lugo-Fernández and Dr. Mary Boatman

Date: December 10, 1998

Presentation	Author/Affiliation
Meteorology of the Northeastern Gulf of Mexico	Dr. Mark Hocke ENVIRON International Corp.
Northeastern Gulf of Mexico Physical Oceanography Program: Eddy Monitoring and Remote Sensing	Dr. Frank E. Muller-Karger Department of Marine Science University of South Florida Dr. Fred Vukovich Science Applications International Corporation Dr. Robert Leben Department of Aerospace Engineering Sciences University of Colorado Mr. Bisman Nababan University of South Florida
Nearshore Bottom Properties over the Northeastern Shelves of the Gulf of Mexico as Observed During Early May 1998	Dr. Worth D. Nowlin, Jr. Dr. Ann E. Jochens, Dr. Matthew K. Howard Dr. Steven F. DiMarco Department of Oceanography Texas A&M University
De Soto Canyon Physical Oceanography	Dr. Peter Hamilton Science Applications International Corporation Raleigh, North Carolina
Modeling Currents in Northeastern Gulf of Mexico: An Evaluation	Dr. Y. Hsueh Dr. Yury Golubev Department of Oceanography Florida State University
Preliminary Report on Coastal Upwelling and Mass Mortalities in the Northeastern Gulf of Mexico During Spring and Summer 1998	Dr. Sneed B. Collard University of West Florida

Presentation	Author/Affiliation
Physical Oceanography/Biological Integration Document Not Submitted	Dr. Harriet Perry Gulf Coast Research Laboratory Dr. Donald R. Johnson Naval Reserach Laboratory

METEOROLOGY OF THE NORTHEASTERN GULF OF MEXICO

Dr. Mark Yocke
ENVIRON International Corp.

STUDY TEAM

Prime Contractor:	ENVIRON International Corp.
Subcontractors:	Sonoma Technology Inc.
	Aerovironment Environmental Services
	Evans Hamilton Inc.
Consultant:	Dr. S.A. Hsu, Louisiana State University
Expert Advisory Group:	Dr. Richard McNider, University of Alabama, Huntsville
	Dr. Allan Clarke, Florida State University

STUDY OBJECTIVES

- Base Effort
  - Identify and acquire available meteorological data in the Northeastern Gulf of Mexico region for a two-year period, 1996 and 1997
  - Design and populate a relational data base containing all collected data
  - Develop an expert computer system to allow rapid access to the data base, data analysis products, and air trajectory analyses
- Add-on Work
  - Archive ETA model output for 1996 and 1997
  - Add ETA model output to relational data base and expert system

CURRENT STATUS

• Completed:	Phase 1	Collect and archive 1995–1997
	(Year 1)	Meteorological data
	Phase 2	Analyze data
	(Year 2)	Develop expert system
• In Progress:	Phase 3	Acquire ETA model output for 1996 and 1997
	(Add-on)	Add ETA model output to data archive and expert system

DATA SOURCES
(Table 1H.1 and Figure 1H.1)

- National Climatic Data Center (NCDC)
- National Data Buoy Center (NDBC)
- Breton Island
- USGS Center for Coastal Geology

Table 1H.1. Data inventory in MMS database.

Station ID	Station Name	Station Type	Range of Data
00013858	ELGIN AFB/VALPARAIS	Upper Air	95-97
00013861	WAYCROSS/WARE CO.	Upper Air	1/95
00013889		Upper Air	95-97
00053813	SLIDELL MUNICIPAL	Upper Air	95-97
00093805	TALLAHASSEE RGNL	Upper Air	95-97
42001	MID GULF	Buoy	95-97
42002	W. GULF	Buoy	95-97
42003	E. GULF	Buoy	95-9/96
42007	OTP	Buoy	95-97
42036	W. TAMPA	Buoy	95-97
42039	PENSACOLA	Buoy	95-97
42040	MOBILE SOUTH	Buoy	95-97
722055	OCALA MUNI (AWOS)	Land Based	95-97
722120	CROSS CITY	Land Based	95-6/96
722130	WAYCROSS/CARE CO.	Land Based	95-96
722135	ALMA/BACON	Land Based	95-97
722140	TALLAHASSEE RGNL	Land Based	95-97
722146	GAINESVILLE RGNL	Land Based	95-97
722160	ALBANY MUNICIPAL	Land Based	95-97
722166	VALDOSTA REGIONAL	Land Based	95-97
722210	ELGIN AFB/VALPARAIS	Land Based	95-97
722215	CRESTVIEW/BOB SIKES	Land Based	95-97
722223	PENSACOLA REGIONAL	Land Based	95-97
722225	PENSACOLA NAS	Land Based	95-97
722226	WHITING FLD NAS-N	Land Based	95-97
722230	MOBILE/BATAES FIELD	Land Based	95-97
722235	MOBILE DOWNTOWN	Land Based	95-97
722245	PANAMA CITY/BAY CO	Land Based	95-97
722246	DUKE FLD/ELGIN AUX	Land Based	95-97
722267	TROY MUNICIPAL	Land Based	95-97
722268	DOTHAN MUNICIPAL	Land Based	95-97
722269	CAIRNS AAF/OZARK	Land Based	95-97
722275	ANDALUSIA/OPP ARPT	Land Based	95-97
722276	SCHELL AHP	Land Based	95
722307	GOLDEN TRI	Land Based	95-97
722309	GRANDE ISLE	Land Based	95-97
722210	NEW ORLEANS INTERNATIONAL AIRPORT	Land Based	95-97
722316	NEW ORLEANS NAVAL AIR	Land Based	95-97
722348	PINE BELT RGNL AWOS	Land Based	95-97
747685	GULFPORT-BILOXI	Land Based	95-97
747686	KEESLER AFB/BILOXI	Land Based	95-97
747750	TYNDALL AFB	Land Based	95-97
747770	HURLBURT FIELD	Land Based	95-97
747810	MOODY AFB/VALDOSTA	Land Based	95-97
BURL1	SOUTHWEST PASS, LA	C-Man	95-97
BUSL1	BULLWINKLE BLOCK 65	C-Man	8/95-10/96
CDRF1	CEDAR KEY, FL	C-Man	95-97
CSBF1	CAPE SAN BLAS, FL	C-Man	95-97
DPIA1	DAUPHIN ISLAND, AL	C-Man	95-97
GDIL1	GRAND ISLE, LA	C-Man	95-97
KTNF1	KEATON BEACH, FL	C-Man	95-97

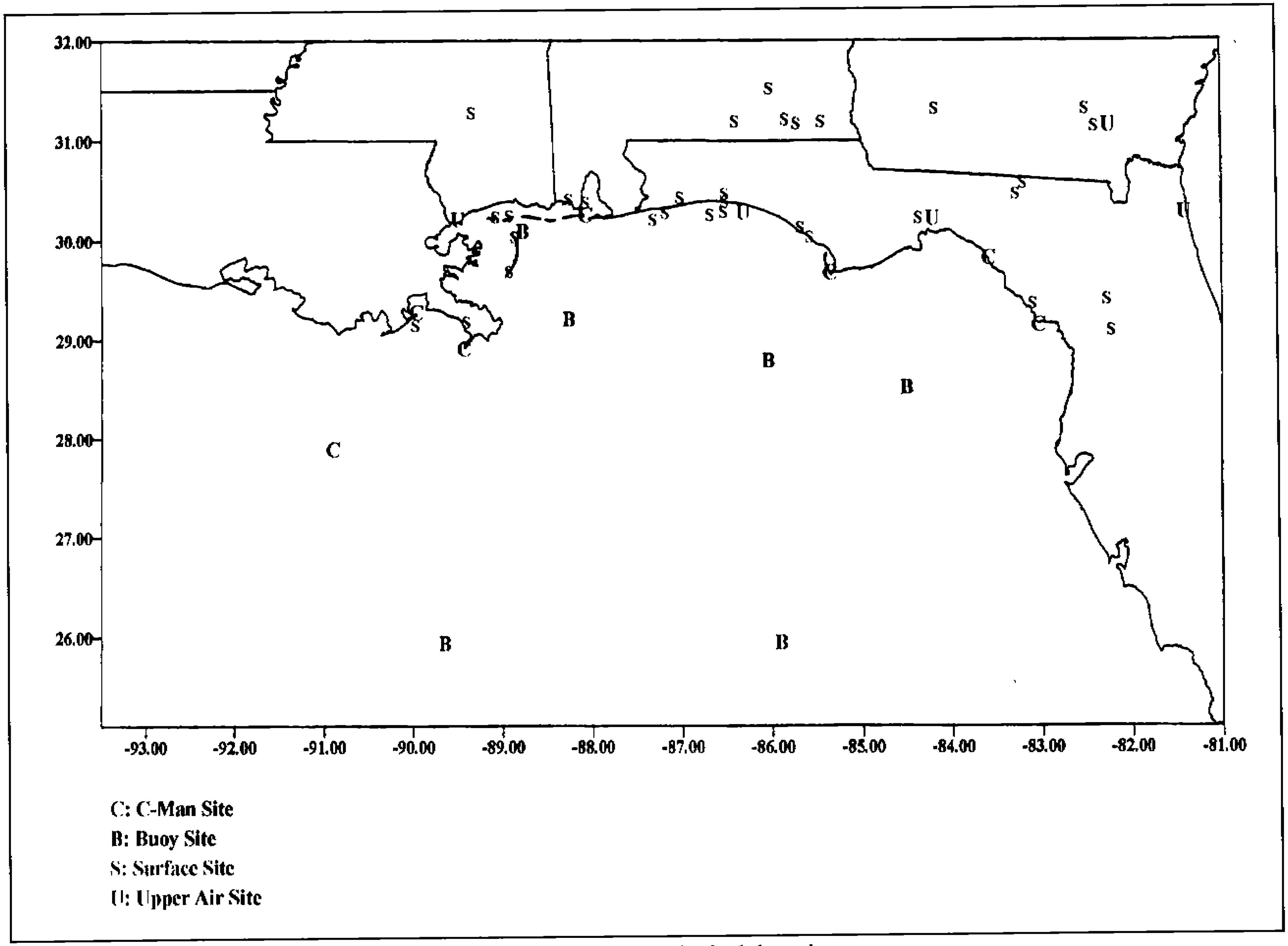

Figure 1H.1. Location of MMS Northeast Gulf of Mexico meteorological data sites.

DATA SEARCH (NO DATA)

- Oil companies
- Universities
- National Weather Service
- Government laboratories, agencies, and programs
- Private sources

DATABASE STRUCTURE AND DATA ARCHIVING

- Database hardware and software
  - PC network
  - Windows NT (servers)
  - Windsow95 (computers)
  - Microsoft ACCESS
- Station information tables
  - Station ID
  - Station name
  - Station type
  - Latitude
  - Longitude
  - Elevation
  - Call letters
- Parameter tables
  - Sfc. winds
  - Gusts
  - Temp. and press.
  - Precipitation
  - Visibility
  - Sky conditions
  - Upper air data
  - Sea sfc. temp.
  - Wave data
- Spatial interpolation of mean and std. dev. values
- Time-series analyses
- Data transfer
  - Internet file transfer protocol (FTP)
  - Individual user upload and download folders
  - User passwords for access to individual user upload and download areas
  - Database status folder (in FTP area)
- Database security
  - Database on AVES network

- Daily system backups
- Off-site copies of daily system backups

DATA HANDLING

- Data screening
  - Run add data through screening routines to verify accuracy
  - Criteria for maximum values
  - Criteria for minimum values
  - Criteria for rates of change
- Data validation
  - Verify maximum values
  - Verify minimum values
  - Verify rates of change that exceed criteria
  - Make comparisons with NOAA Monthly Weather Summaries

STATISTICAL ANALYSES

- Mean and standard deviation of all measured parameters at all stations (Figure 1H.2)
  - annual
  - by season
  - by met-type
- Calculate derived parameters
  - PBL parameters
  - Vertical vorticity
  - Stress, stress curl
  - Heat flux

SYNOPTIC WEATHER TYPING

- Objective: Classify days by consistent weather types; use classifications for basis to calculate statistical summaries of data. Surface winds and pressure gradients are critical variables.
- Preliminary review and refinement of classifications
- Weather classifications and examples (Figure 1H.3)

REFINEMENT OF CLASSIFICATIONS

- Reviewed eight synoptic weather types for New Orleans (Muller *et al.*)
- Performed preliminary classification of 1994 days using 12Z (0700 EST) daily weather maps
- Refined synoptic types to address NE Gulf surface winds and pressure gradients
- Applied refined classification of 1996-1997 12Z daily weather maps to evaluate process

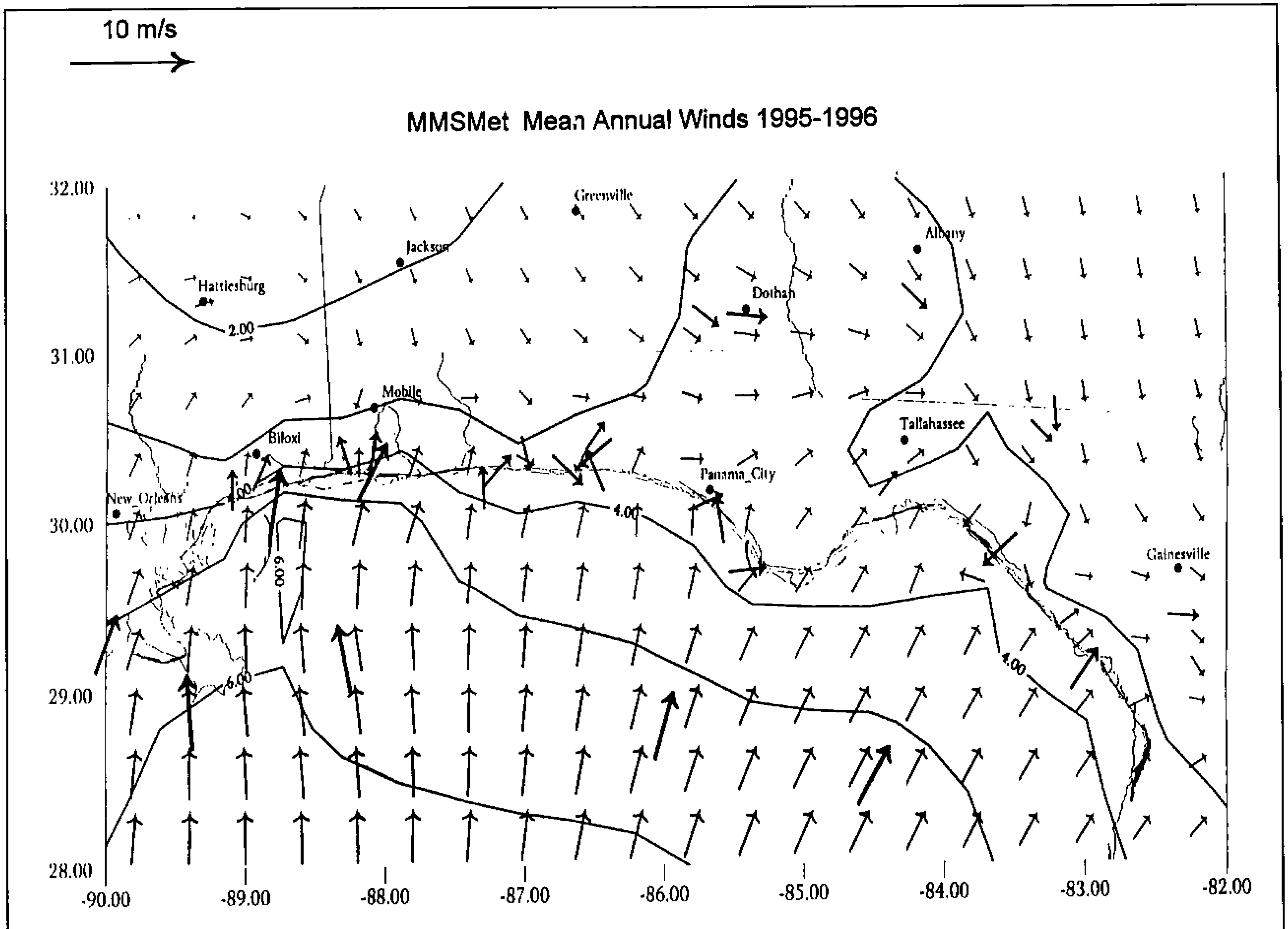

Figure 1H.2. MMSMet mean annual winds 1995-1996.

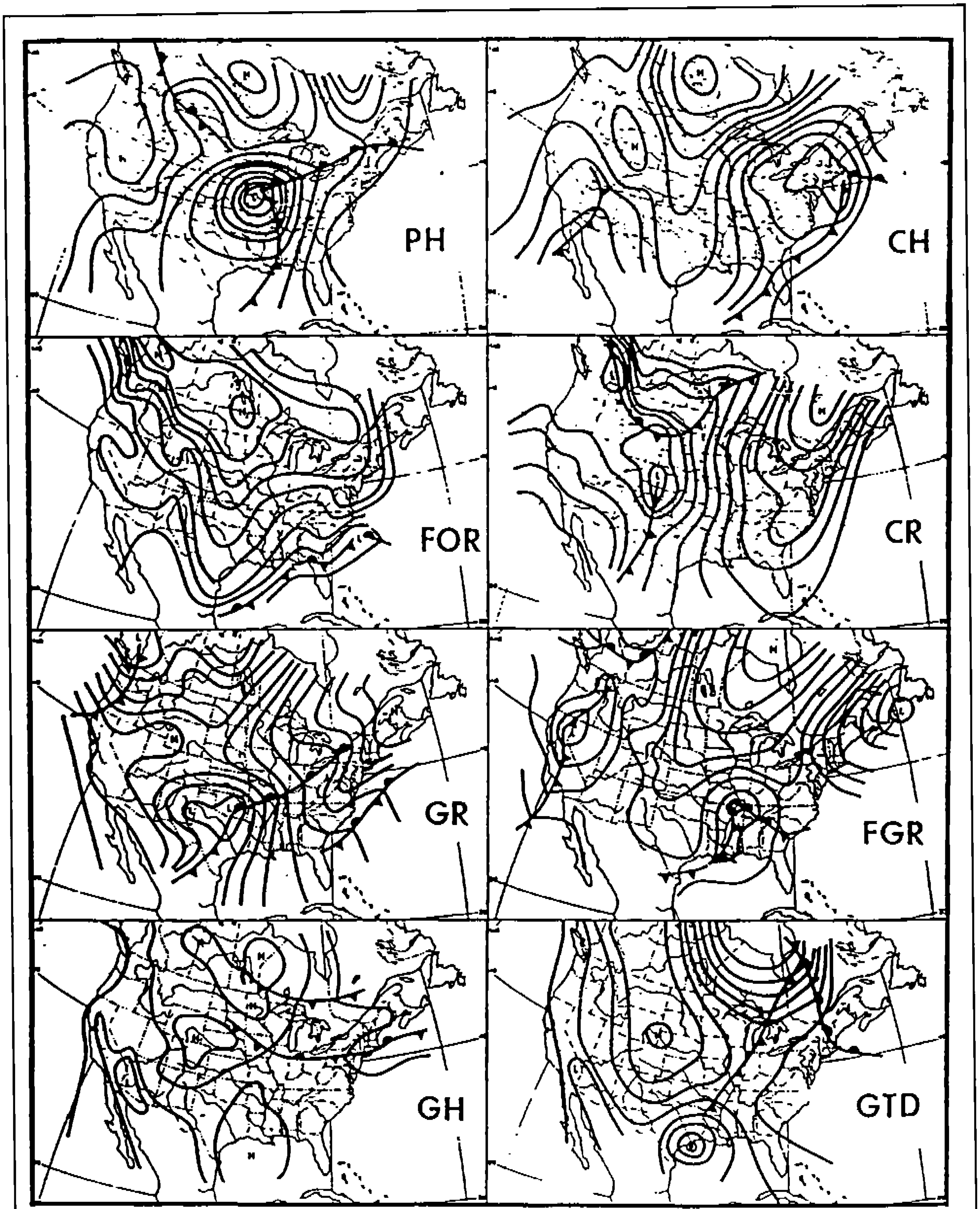

Figure 1H.3. Representative examples of eight synoptic weather types for New Orleans, Louisiana (from Muller and Wax 1977).

PROJECT ADD-ON—ETA MODEL OUTPUT

- Offshore meteorological data sites are widely spaced and limited in number; therefore, calculations of spatial gradients for wind stress, wind stress curl, and vertical vorticity are difficult and suspect.
- Archival of NWS ETA meteorological model results was proposed to add spatial resolution afforded by solution of the governing primitive equations:
  - NCEP routinely runs the ETA model several times each day for numerical weather prediction
  - recently NCAR began archiving ETA model output
  - NCAR is also creating an archive of historical ETA model output back to October 1985
- The ETA model assimilates large volumes of observational data for initialization. Therefore,
  - initial and analysis fields are relatively faithful to observed conditions
  - these can be viewed as interpolation between observation points based solutions of the governing physics
- ETA model output could substantially improve the information available from this NEGOM study.

ETA MODEL—ADD-ON TASKS

- Investigate of available ETA model output products (completed)
- Acquire appropriate ETA model outputs for 1996-1997
  - 1997 data ordered and received
  - 1996 data available from NCAR in early 1999
- Decompress ETA data files and parse for NEGOM region
- Add ETA output to data archive
- Extend to expert system to access ETA model output files

NEXT STEPS

- Complete acquisition (i.e., 1996) of ETA model output
- Develop software to decompress and parse ETA model output for NEGOM domain
- Calculate derived parameters from ETA model output
- Add NEGOM ETA model output to NEGOM data archive
- Extend expert system to include access to ETA model output
- Complete conceptual model of regional meteorology and circulations based on observational data and ETA model output
- Final report

NORTHEASTERN GULF OF MEXICO PHYSICAL OCEANOGRAPHY PROGRAM: EDDY MONITORING AND REMOTE SENSING

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Dr. Fred Vukovich
Science Applications International Corporation

Dr. Robert Leben
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INTRODUCTION

The continental shelf off Florida in the northeastern Gulf of Mexico has unique fisheries and environmental characteristics that could be affected by oil and gas development. There is, however, a general lack of historical information on the oceanography of the region, and particularly on the effect that large scale ocean circulation features like the Loop Current and its associated eddies may have on the oceanography of this shelf region. It is critical to understand the motion of waters within a region to assess the potential consequences of possible spills derived from oceanic, shelf, and coastal mining industries. This study is being conducted to help assess the value of merged satellite data and specific oceanographic field data in determining the circulation and biological productivity of waters within the NE Gulf of Mexico. The primary objective of this effort centers on collecting, processing, and merging historical and concurrent infrared, radar-altimetry, and ocean color satellite data as well as selected *in situ* information like drifting buoy trajectories obtained in collaboration with other Gulf of Mexico MMS programs.

METHODS

Satellite Data Compilation

We collect and process selected satellite time series data to identify and track major circulation features in the Gulf of Mexico. Specifically, we developed a set of software tools to generate daily AVHRR Sea Surface Temperature distribution fields, TOPEX and ERS-1 Radar Altimetry Sea Surface Height fields, and Coastal Zone Color Scanner and SeaWiFS ocean color-derived pigment concentrations. We collect the AVHRR and SeaWiFS data with an antenna installed in St. Petersburg, FL. We have operated this antenna since late 1993 and are able to cover the Gulf of Mexico with the AVHRR up to 2-3 times per day and with SeaWiFS at least 1-2 times per day. We have also processed the CZCS data for the Gulf of Mexico (1978-1986) to examine historical circulation patterns. We are still working with NASA on the calibration and algorithms to be used with SeaWiFS, as products still do not match field data. The TOPEX and ERS data have been merged and interpolated at the University of Colorado to render one image per day.

We have collected approximately 3,500 AVHRR images since April 1997 and about 420 SeaWiFS images since September 1997 (the date of first SeaWiFS data) over the Gulf of Mexico. The historical CZCS data were processed at USF to show pigment concentration, and then averaged to derive a series of 92 monthly concentration means. We have also computed monthly mean sea surface temperatures for the Gulf of Mexico for 1996-1998 (present; data located at *http://paria.marine.usf.edu*), and merged the corresponding average sea surface dynamic height with each of the SST monthly means, in the form of overlayed contours. These data were remapped to cover only the NEGOM region for purposes of overlaying drifting buoy tracks. All the software to overlay these various data sets and to analyze the image fields in terms of geophysical values (SST, pigment, altimetry) were developed in house using the IDL programming environment.

Field Program

We teamed up with Dr. Worth Nowlin and Dr. Douglas Biggs of Texas A&M University (TAMU) to participate in MMS-sponsored oceanographic cruises to the NEGOM (Chemical Oceanography/Hydrography Program). To date we have participated in three NEGOM cruises: May, July-August, and November 1998. Each cruise provides about 12 days shiptime. The cruises provide an extensive, high quality hydrography and chemical oceanographic background against which we collect detailed phytoplankton pigment and bio-optical observations. This will serve to characterize regional waters and validate the regional SeaWiFS products that we processed systematically.

We complement the TAMU field measurements with along-track dissolved organic matter (DOM) fluorescence measurements and total absorption/c-beam attenuation coefficient observations in seven spectral bands. At specific stations we also measure water-leaving radiance (Lw), downwelling irradiance (Ed), diffuse attenuation coefficient (K), and PAR (Kpar) measurements using above-water and in-water instrumentation. These measurements allow an estimate of Remote Sensing Reflectance (Rrs). At these stations we also obtain water samples for laboratory analyses of the color of particulate and dissolved material (specific absorption coefficients).

Drifting Buoys

Both Walter Johnson (MMS) and Peter Niiler (Scripps Institute of Oceanography) provided buoy data for the Big Bend region of Florida. These data cover February 1996 through May 1997. Buoys were deployed every two weeks for 24 deployments in the Big Bend region over the period above. A total of about 335 drifters were used in the experiment. We also obtained the monthly mean averaged velocity vectors derived from the buoy trajectories. We developed a set of software tools to overlay drifting buoy tracks over the satellite-derived SST and altimeter maps. We further mapped and overlayed the monthly-mean velocity vectors on SST/altimeter merged fields. Currently the mean drifter tracks representing January, February, and March include data from drifters deployed both in 1996 and 1997.

RESULTS

The AVHRR data provides substantial information on circulation patterns during the winter (October-May), when temperature gradients are strong. However, during summer (June-September), AVHRR data for the most part shows uniform sea surface temperature patterns over the NEGOM (Muller-Karger *et al.* 1991). The AVHRR can provide some information on the position of the Loop Current during summers after images are contrast-stretched. Also, significant upwelling events can be seen during summer along the periphery of the NEGOM, specifically in coasts of the Big Bend region and in the region off Pinellas and Manatee Counties (near the mouth of Tampa Bay). The historical ocean color data obtained from the CZCS shows that the pigment concentration patterns are an effective tool for tracing small scale as well as large scale circulation patterns in the GOM, pasrticularly during summers. The altimeter data, while providing sampling at roughly 10-day intervals, provides all-weather sampling. Therefore the combination of AVHRR, TOPEX/ERS, and CZCS/SeaWiFS is very robust for outlining the position of the Loop Current, eddies, and various instability waves visible along fronts in the region.

General Circulation in the NEGOM

Upon merging the AVHRR sea surface temperature data with the altimeter fields, we found extremely good correlation between warm areas and elevated dynamic heights, and cool areas and low dynamic heights. Low SST and low dynamic sea level indicate a cyclonic circulation, whereas the high SST and high dynamic sea level indicate anticyclonic circulation. Such features are particularly pronounced along the Loop Current.

Most individual drifter tracks were very close to the shore (<50 km) where the altimeter data are questionable. However, farther offshore, both the individual drifter tracks and the monthly-mean velocities derived from these drifters help in interpreting the direction of flow within specific features observed in the images. Features in the images are stable enough so that over the period of several weeks to a month, there is correspondence between what can be observed in the ephemeral drifter tracks and the time-averaged satellite data.

In January-March, flow immediately to the east of the Mississippi delta seems to be erratic or turbulent, with vectors in adjacent 25-km cells having either northward or southward components. However, flow in the eastern portion of the NEGOM and over the west Florida shelf is distinctly and strongly (> 10 m s^{-1}) southward (Figure 1H.4). Waters here are much colder (>5 C) than Loop Current waters. The Loop Current extended about halfway north into the GOM from Yucatan Straight, and a cyclonic eddy sat between the northern extension of the Loop Current and the NEGOM shelf. In April 1996, drifter vectors over the shelf reversed, showing a slow (< 10 m s^{-1}) drift to the north. However, along the shelf break of the West Florida shelf proper, current vectors remained strongly southward. The cyclone north of the LC drifted somewhat to the West in May but

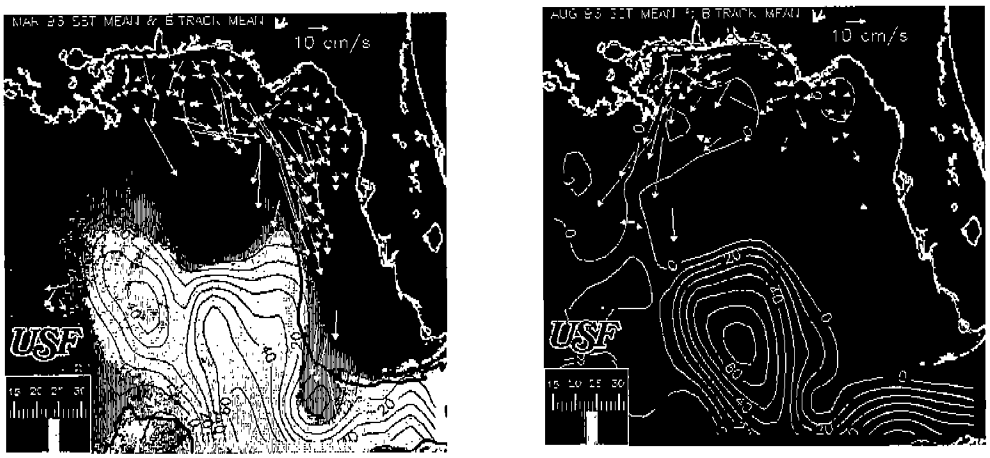

Figure 1H.4. Monthly mean Sea Surface Temperature images (Left: March 1996; Right: August 1996). SST is shaded according to the color bar insert. Contours represent altimeter-derived sea surface topography rendered for the 15th day of each corresponding month. Contour labels are shown in [cm]. White contours represent high elevations and black contours represent depressions. Vectors represent monthly-mean velocities derived from drifter positions within 25x25 km boxes in the NEGOM. Vectors are colored black if they have a northward component and white if they have a southward component.

drifted back East over the summer. By August, currents over the shelf aligned themselves to flow northward at speeds exceeding 10 m s^{-1}. In September, currents over the shelf were to the south again (~10 m s^{-1}), and an eddy was shed from the Loop Current. The southward flow over the shelf intensified in October. In November, while southward flow was observed over the shelf, northward flow was observed along the shelf break. In December 1996, southward flow prevailed over the West Florida shelf. This general description of flow over the West Florida Shelf agrees very well with conclusions derived from current meter data (R. Weisberg, USF, pers. comm.).

Anomalous Summer Coastal Upwelling

During winter months (December-April), it is quite usual to observe cold SST near the coasts of the NEGOM and over the adjacent shelf. In May, SST in these coastal areas tends to be as warm as waters within the interior of the GOM. In 1998, the AVHRR satellite imagery provided the first indications of an anomalous coastal upwelling event in the NEGOM in that lasted from about May through June 1998. In May 1998 we noticed cool SST's (23-24 C) immediately off Cape San Blas, in a strip that extended along the coast of the Florida panhandle to Mobile Bay. This event was notable because SST in the interior of the GOM reached extremely high values compared to other years. We estimated temperatures in the interior of the Gulf reached 28-30 C in early July, but in large portions of the Gulf and in Florida Bay SSTs soared past 30-32 C in June. The colder SST strip grew offshore, and then shrank again over a period of a few days. For example, in early June this strip reached order of 20-30 km in width at temperatures less than 24 C (almost 23 C near the coast). The width decreased after that, but the strip then grew again toward the second half of June. On June 28/29, warm SST were observed along the coast, but the first week in July cold patches were seen off Cape San Blas and to the east, and the strip was re-established. On 13 July, the cold waters seemed to extend offshore well over 50 km south of Cape San Blas, but this cold patch seems to have receded by 14 July. While we are still unclear as to what SeaWiFS data shows us in this area, we can definitely see high "pigment concentration" plumes extending south of Cape San Blas and the coast to the east.

In a 7 July 1998 SeaWiFS picture, we could see the northern boundary of the Loop Current was located approximately at the latitude of Florida Bay. A counter-clockwise eddy, however, was located just north of the Loop Current, and a clockwise eddy immediately to the north of this cyclone. The existence of this cyclone/anticyclone pair was verified in altimeter data.

We propose that this northernmost anticyclonic eddy is the likely cause for the upwelling in the northeastern Gulf of Mexico. In a SeaWiFS image for the 16 July, the discharge of the Mississippi River can be seen wrapped around the anticyclone, and was advected away from the delta toward the southeast, toward the DeSoto Canyon region and further offshore, partially masking the eddies. We would propose that the major low-O2 zones found in the region, however, are associated with high discharge from the Apalachicola or Mobile Rivers in spring 1998.

By 22 July, the AVHRR data showed that the upwelling had subsided and coastal waters were as warm as offshore waters in the NEGOM.

Hurricane Activity

Changes in sea-surface properties associated with hurricanes Earl and George were observed in the NEGOM using NOAA and SeaWiFS satellite data. In each case, a region low SSTs was detected which was located, for the most part, to the right of the hurricane's track. The lowest SSTs were found near or at the shelf break. These features were most likely associated with the intense upwelling produced by hurricane winds. For Earl, SSTs were as much as 3-4 C lower and for George, as much as 5-6 C lower than those for the surrounding water. The fact that the lowest SSTs were located near the shelf break suggested that the shelf slope may have acted to intensify the upwelling produced by the hurricanes.

SeaWiFS also detected a region with higher pigment concentrations at the surface immediately south of the shelf break near the Mississippi Delta region after the passage of Georges. However, the feature was principally to the left of the hurricane's path and west of the region where the most intense SST changes were found in the AVHRR data. This feature was probably shelf water that was advected southward into the deep GOM by the hurricane's cyclonic circulation.

For Georges, both the SST and the pigment features drifted to the southwest and decreased in size over a 19 day period. Over the period of about 19 days, the average speed of the low SST feature

(~18 cm/s) and the high biomass feature (~19 cm/s) was about the same. The temperature in the cold lens developed by hurricane George increased by 2.2 C in 3 days reaching a relative steady-state value of about 25 °C at that time, reflecting the rapid dilution of this feature.

REFERENCES

Muller-Karger, F.E., J.J. Walsh, R.H. Evans, and M.B. Meyers. 1991. On the seasonal phytoplankton concentration and sea surface temperature cycles of the Gulf of Mexico as determined by satellites. Journal of Geophysical Research. 96(C7). 12645-12665.

Frank E. Muller-Karger uses ocean color and infrared satellite imagery to assess physical and biological variability in the Gulf of Mexico and Caribbean Sea. He is also studying the role of oceanic waters along continental margins in the global carbon cycle. Dr. Muller-Karger served at NASA Headquarters as Program Scientist for Ocean Biogeochemistry between 1992 and 1994, and is a member of NASA Science Teams for various satellite missions. He is Associate Professor at the University of South Florida, Department of Marine Science. Dr. Muller-Karger obtained a Ph.D. from the University of Maryland, an M.S. from the University of Alaska, and a B.S. from the Florida Institute of Technology.

Fred Vukovich is Chief Scientist for Science Applications International Corporation. He has been involved in oceanographic studies using satellite data for thirty years, focusing primarily on the Gulf of Mexico (GOM). Dr. Vukovich has studied and developed statistics on the characteristics of the Loop Current, including eddy shedding periods, the behavior of cold-core eddies on the boundary of the Loop Current, the intrusion of Loop Current water onto the West Florida Shelf associated with the eddies on the boundary of the Loop Current, the structure of the large cold-core eddies off the Dry Tortugas, and the behavior of warm rings in the western GOM.
Dr. Vukovich also collaborates with the National Marine Fisheries Service, Beaufort, NC, on the potential transport of *G. breve* from the GOM to the North Carolina shelf and the subsequent initiation of a red tide boom.

Robert Leben's primary expertise is in satellite altimetry and its application to ocean circulation monitoring. He is also interested in computational fluid dynamics and digital signal processing techniques and their application to problems in geophysical fluid dynamics and aerodynamics. Dr. Leben is Research Associate Professor at the Department of Aerospace Engineering Sciences, Colorado Center for Astrodynamics Research, University of Colorado, Boulder.

Bisman Nababan is a Ph.D. student at the University of South Florida under Frank Muller-Karger. He has an M.S. from Nova University and is interested in remote sensing applications to address general ecosystem issues in marine science.

NEARSHORE BOTTOM PROPERTIES OVER THE NORTHEASTERN SHELVES OF THE GULF OF MEXICO AS OBSERVED DURING EARLY MAY 1998

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Texas A&M University

INTRODUCTION

Texas A&M University is carrying out the Northeastern Gulf of Mexico Physical Oceanography Program: Chemical Oceanography and Hydrography study sponsored by the Minerals Management Service (MMS) of the U.S. Department of the Interior under MMS OCS contract No. 1435-01-97-CT-30851. As part of this program we are conducting seasonal sampling for physical and chemical oceanographic properties of the northeastern Gulf shelves between 89°W and 27.5°N.

The second cruise of that program, N2, took place from 5 through 16 May 1998. This report briefly describes the results of this May 1998 NEGOM cruise, with a focus on nearshore bottom properties.

BACKGROUND

Figure 1H.5 shows the locations of CTD/bottle stations occupied during cruise N2. Numbers are in sequence of occupation. Lines are referred to as 1 through 11 from west to southeast. Lines 4-11 were occupied in reverse order beginning with 11, after which, lines 1-3 were occupied in that order.

Surface meteorological observations are generally available from 16 locations including coastal and offshore stations. We examined surface winds from ten of those locations for the period April through August 1998. There was good spatial coherence of the wind field for this period. During the month of May surface winds were generally toward the east with weak speeds averaging near 4 $m \cdot s^{-1}$. Such winds are favorable for near coastal upwelling, but are weak.

Figure 1H.6 shows the sea surface height anomaly (SSHA) from satellite altimeter data averaged over the period 21 April - 4 May 1998, just prior to the beginning of cruise N2. Seen are two anticyclonic features impinging on the shelf edge in the region of DeSoto Canyon and west of Tampa. In the final section of this paper we present a description of the changing circulation off the shelf for the period April through August of 1998 based on study of weekly SSHA fields.

PROPERTIES OBSERVED ON CRUISE N2

The distribution of geopotential anomaly for the sea surface (3 m) relative to 800 m (Figure 1H.7) shows an anticyclonic feature over the DeSoto Canyon and a second anticyclone encroaching over

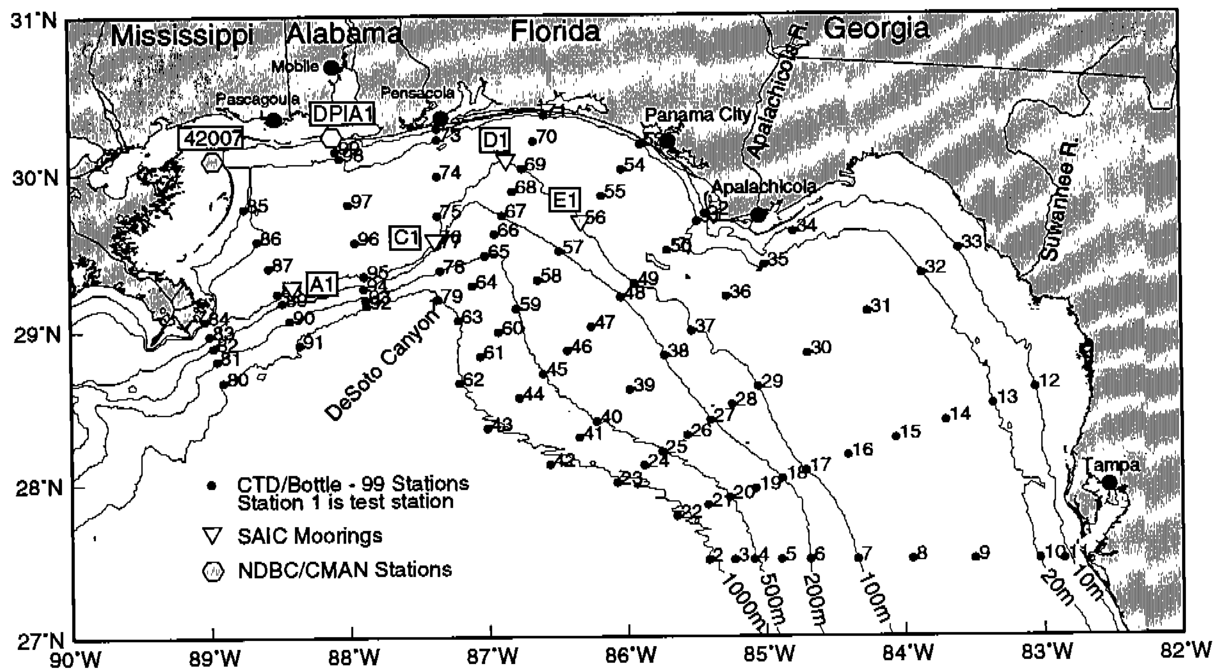

Figure 1H.5. Station numbers for CTD/bottle stations on cruise N2 conducted during 5-16 May 1998; locations of four SAIC moorings on 100-m isobath along northwestern wall of DeSoto Canyon; and locations of two nearshore meteorological stations.

the outer shelf edge west of Tampa. The circulation indicated by these features is substantiated by shipboard ADCP measurements, also shown in Figure 1H.8. The gridded ADCP vector field at 50 m is representative of other levels as well. An anticyclonic feature is seen located over the upper canyon (centered near 29°N, 87°W). There is evidence for along-isobath flow along the northern edge of the canyon and cross-isobath flow, directed inshore, at the canyon axis. This results in inshore penetration of deep water along the canyon sides. Such a flow will lead to transport in a bottom Ekman layer that is to the left of the flow—leading to even more penetration of bottom waters upslope in the canyon. Upwelling is clearly seen in the bottom distribution of temperature (Figure 1H.8), showing maximum inshore penetration of cool bottom water near the head of DeSoto Canyon (lines 5 and 6).

Vertical sections of hydrographic properties provide clear evidence that onshore, near-bottom flow, extending in most cases to the innermost stations (10-m isobath), had occurred prior to the cruise. Figure 1H.9 upper shows temperature in vertical section on line 5. This is characteristic of the situation observed on lines 1-7 west of Cape San Blas. Apparently, upwelling had been strong prior to the time of the cruise, as evidenced by cooler water at the bottom at the innermost stations. Southeast of Cape San Blas (lines 8-11) this onshore upwelling generally did not extend to the shallowest stations, as can be seen from the distribution of bottom temperature (Figure 1H.8).

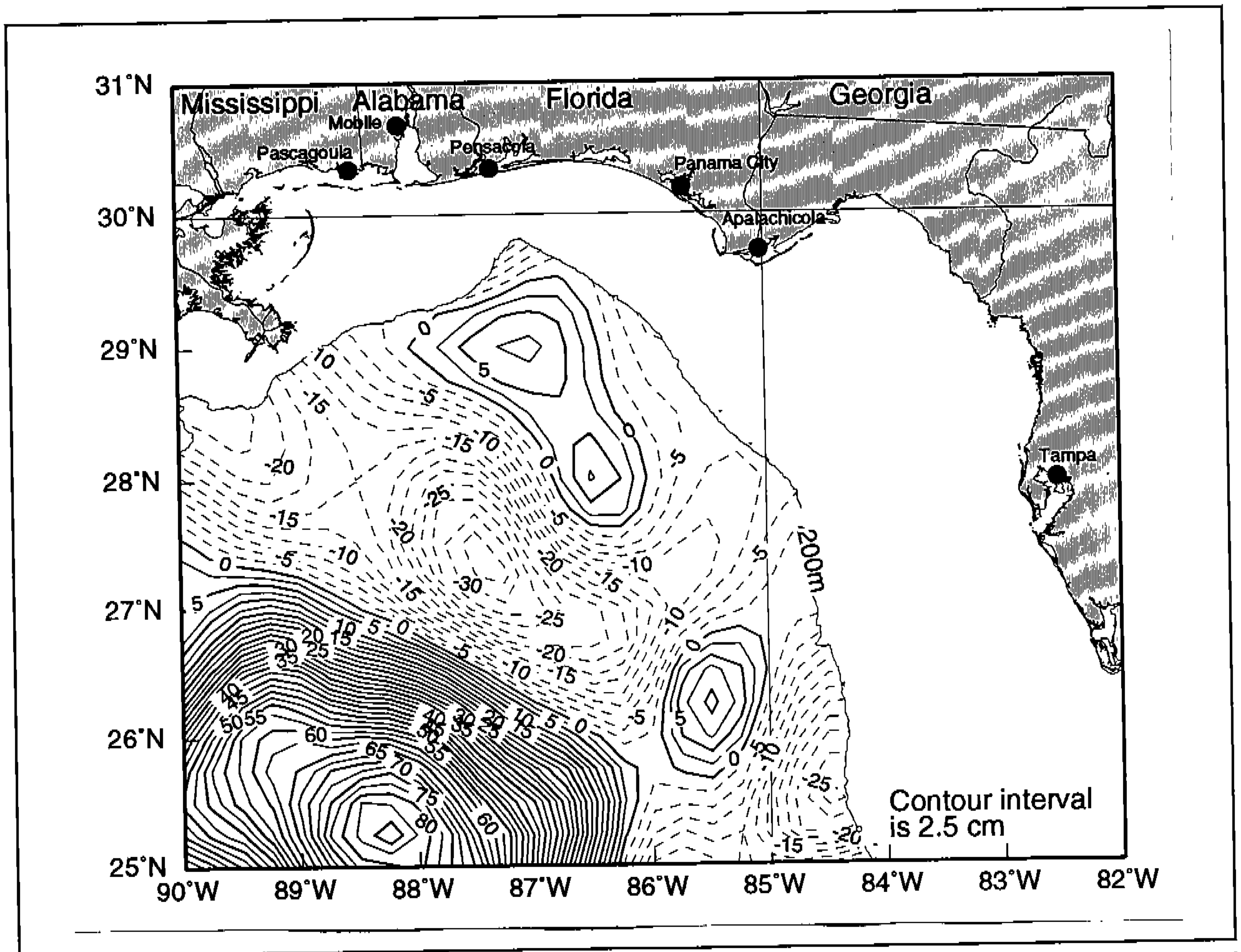

Figure 1H.6. Sea surface height anomaly from satellite altimeter data showing study area averaged for 21 April-4 May 1998 (courtesy of Robert Leben, University of Colorado).

The high vertical stability associated with the temperature distribution is enhanced west of Cape San Blas by a layer of relatively fresh surface water. On lines 3-7 the freshest surface water was found offshore; Figure 1H.9 (lower) shows the distribution on line 5. This could have been caused by nearshore upwelling moving surface water offshore or by advection from the west due to the anticyclonic circulation over DeSoto Canyon. On lines 1 and 2 the freshest surface water was observed at the inshore stations—evidence of local river sources for this water. East of Cape San Blas, the freshest water was also found in the surface layers at the inshore stations. The extent, core, and possible source of the fresh water lens may be deduced from the surface (3.5 m) salinity distribution shown in Figure 1H.10.

The combination of cool bottom water and a lens of fresh surface water produced a very strong pycnocline over the inner and mid shelf regions. West of Cape San Blas the pycnocline was much stronger than to the east; compare the distribution for line 3 with that for line 9 (Figure 1H.11). It is likely that this stability contributed to the relatively low oxygen values found at the bottom over much of the survey region (Figure 1H.12). Many values were near 3 $mL \cdot L^{-1}$ and values approached

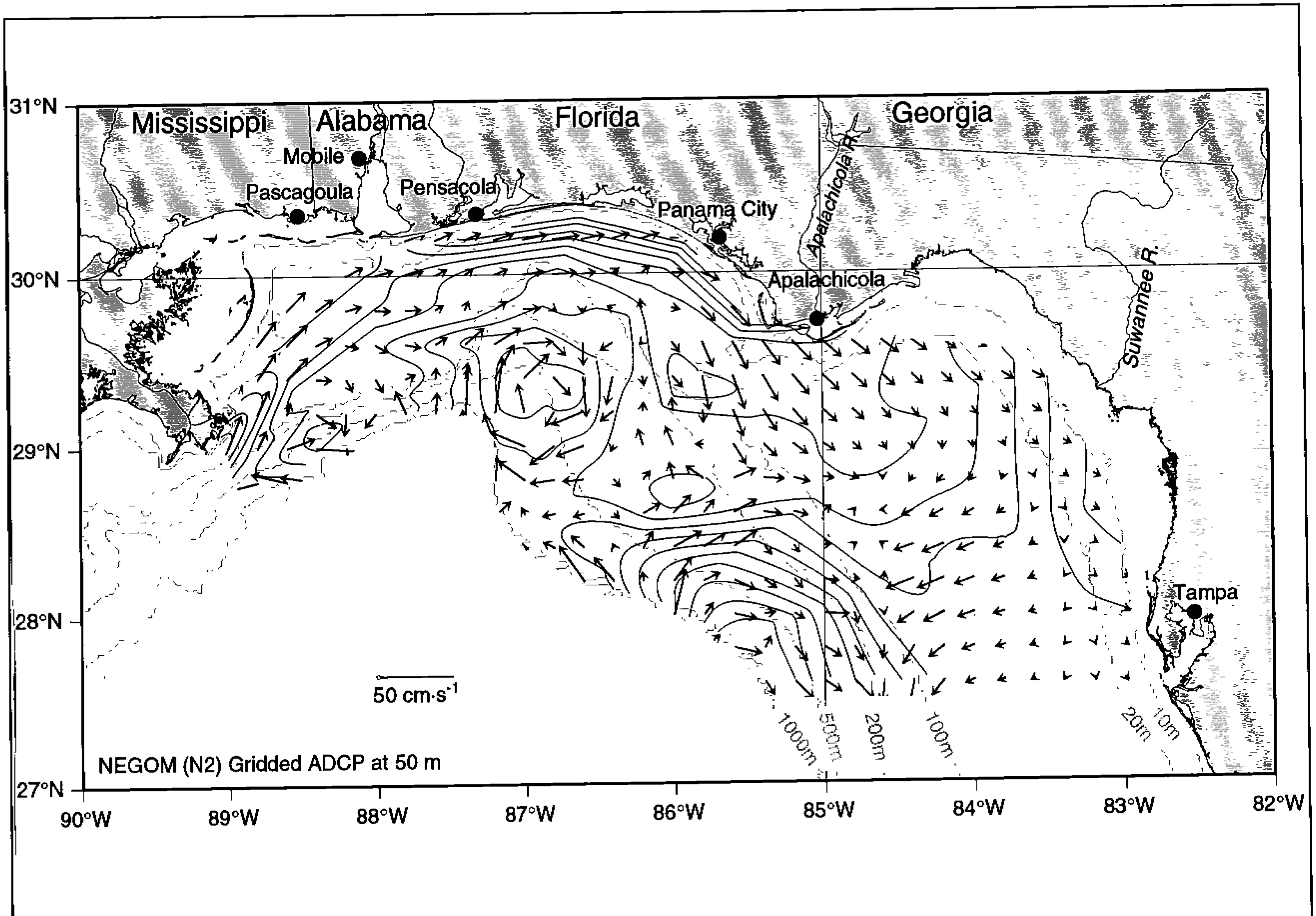

Figure 1H.7. Gridded shipboard ADCP vectors at 50 m plotted on contours of geopotential anomaly of 3-m surface relative to 800 m.

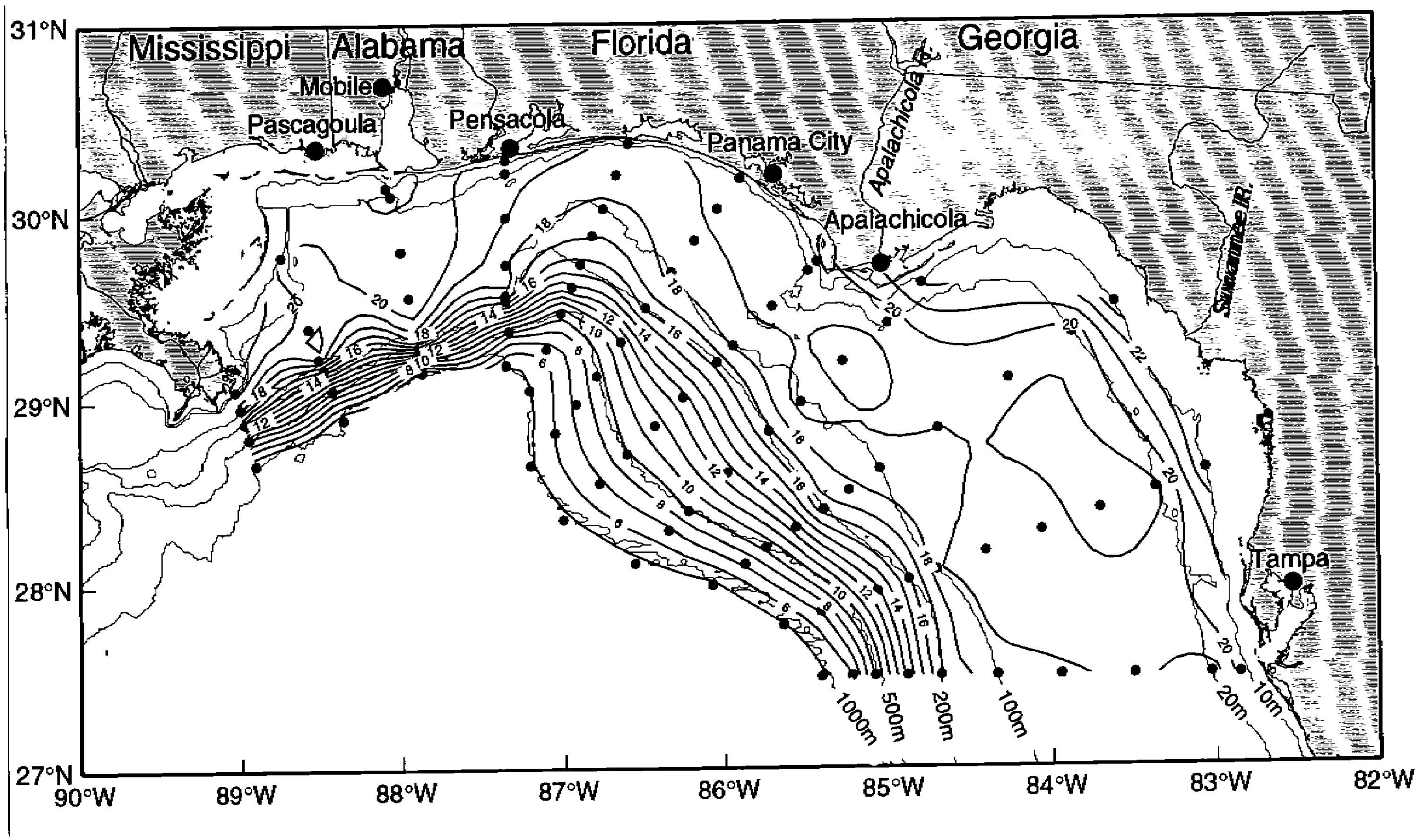

Figure 1H.8. Potential temperature (°C) near the bottom on cruise N2, 5-16 May 1998.

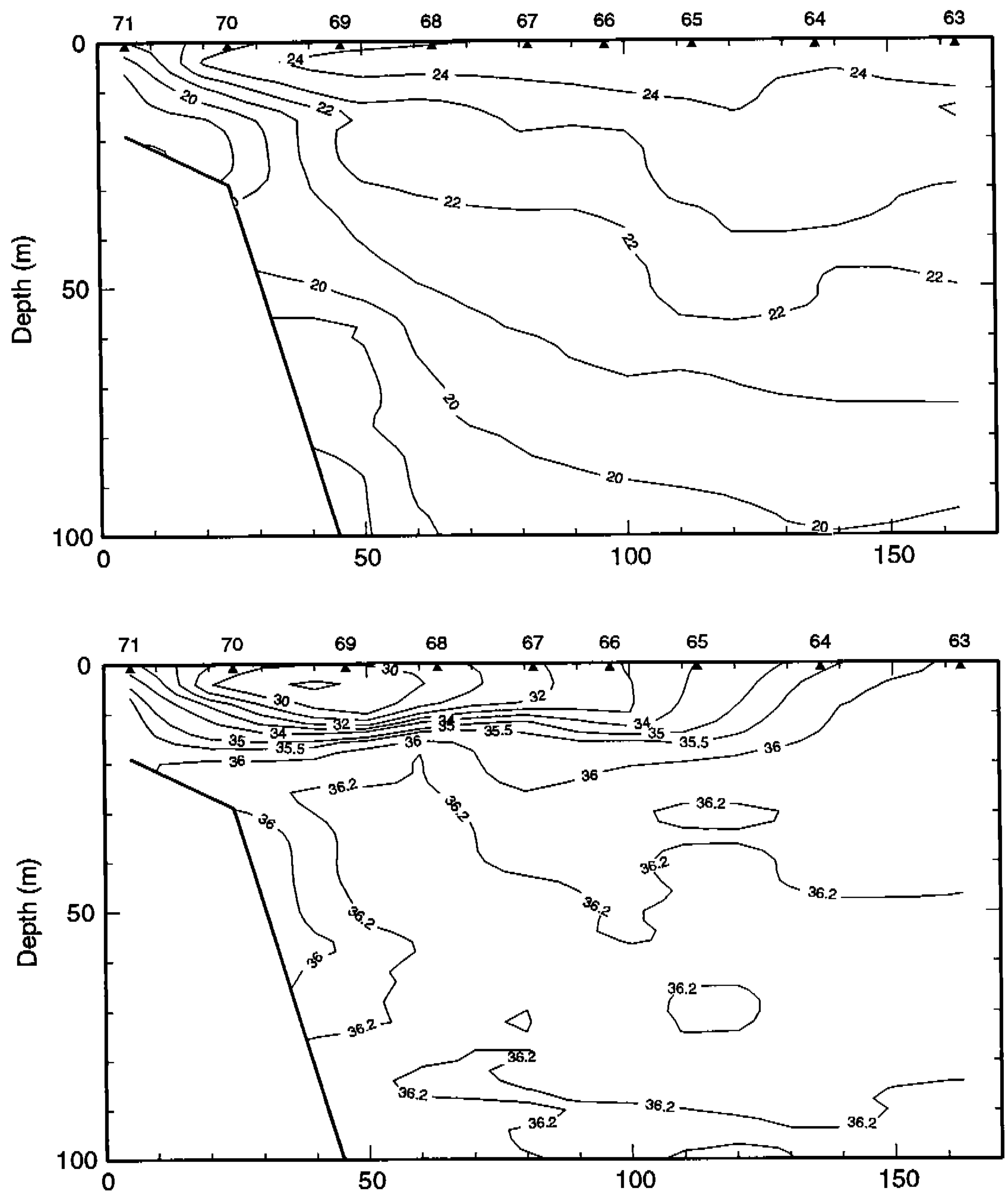

Figure 1H.9. (Upper) potential temperature (°C) and (lower) salinity on line 5 of cruise N2, 5-16 May 1998.

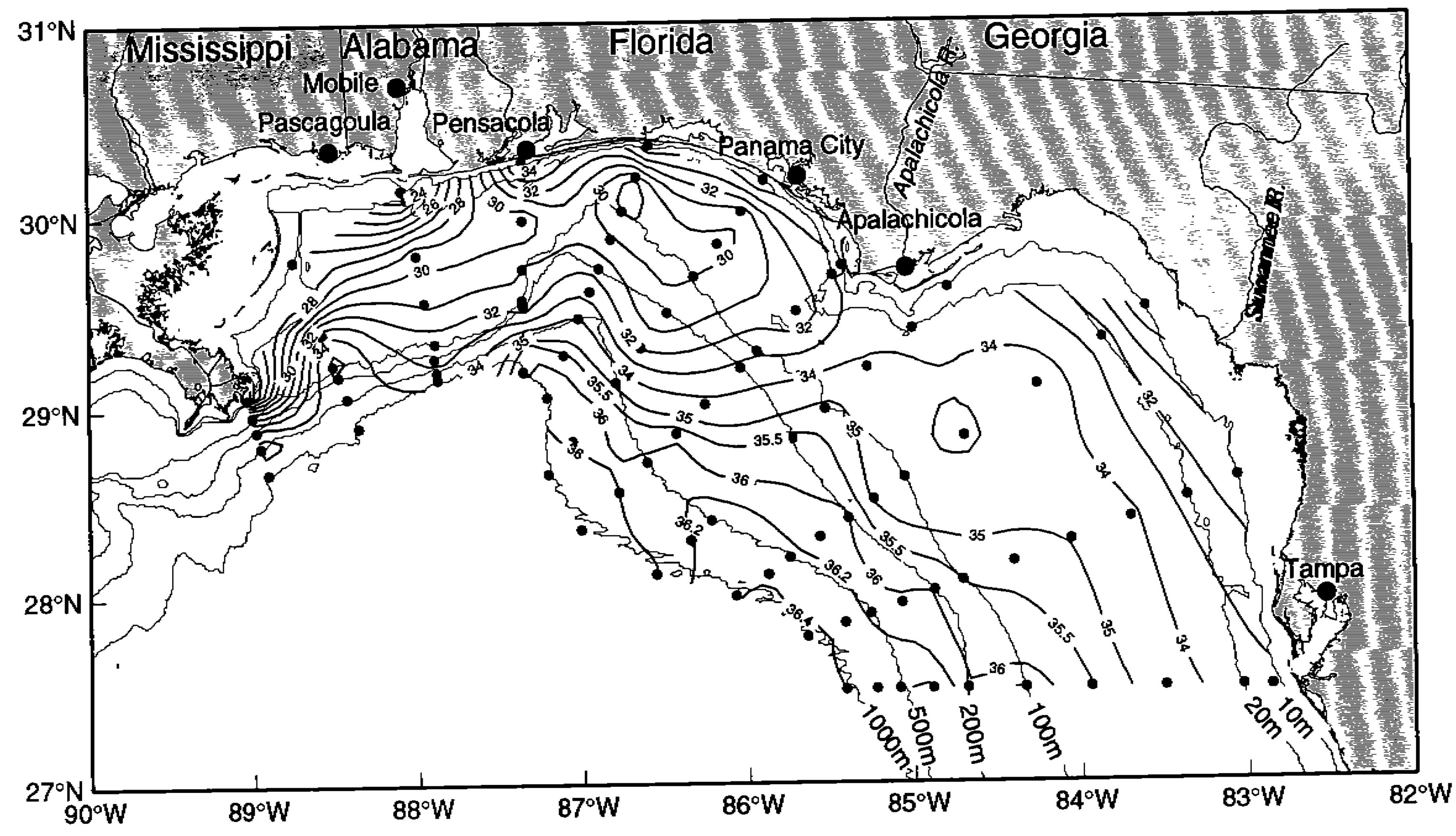

Figure 1H.10. Salinity at 3.5 m derived from CTD data collected on cruise N2, 5-16 May 1998.

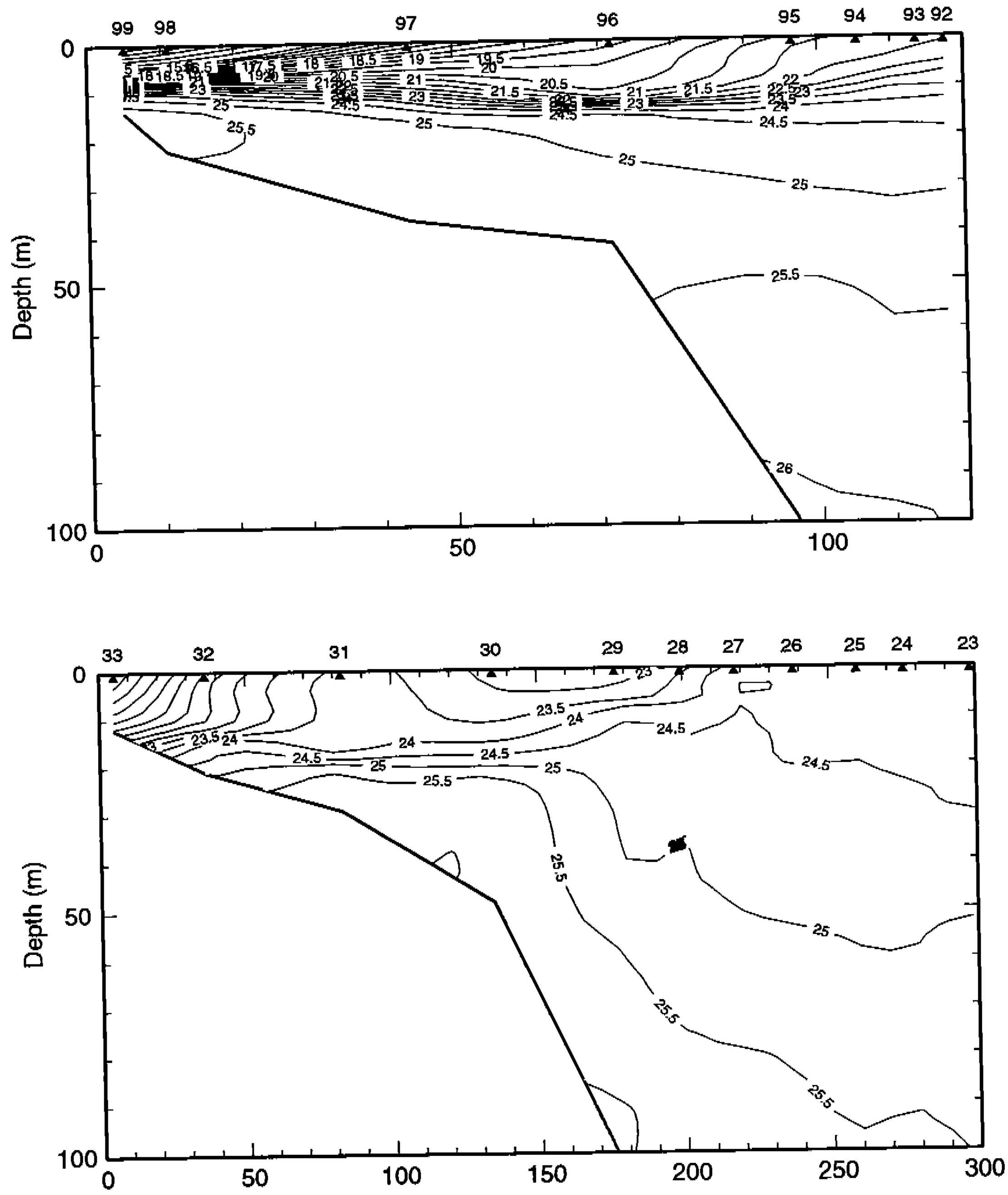

Figure 1H.11. Density anomaly (σ_θ in $kg \cdot m^{-3}$) on lines 3 and 9 on cruise N2, 5-16 May 1998.

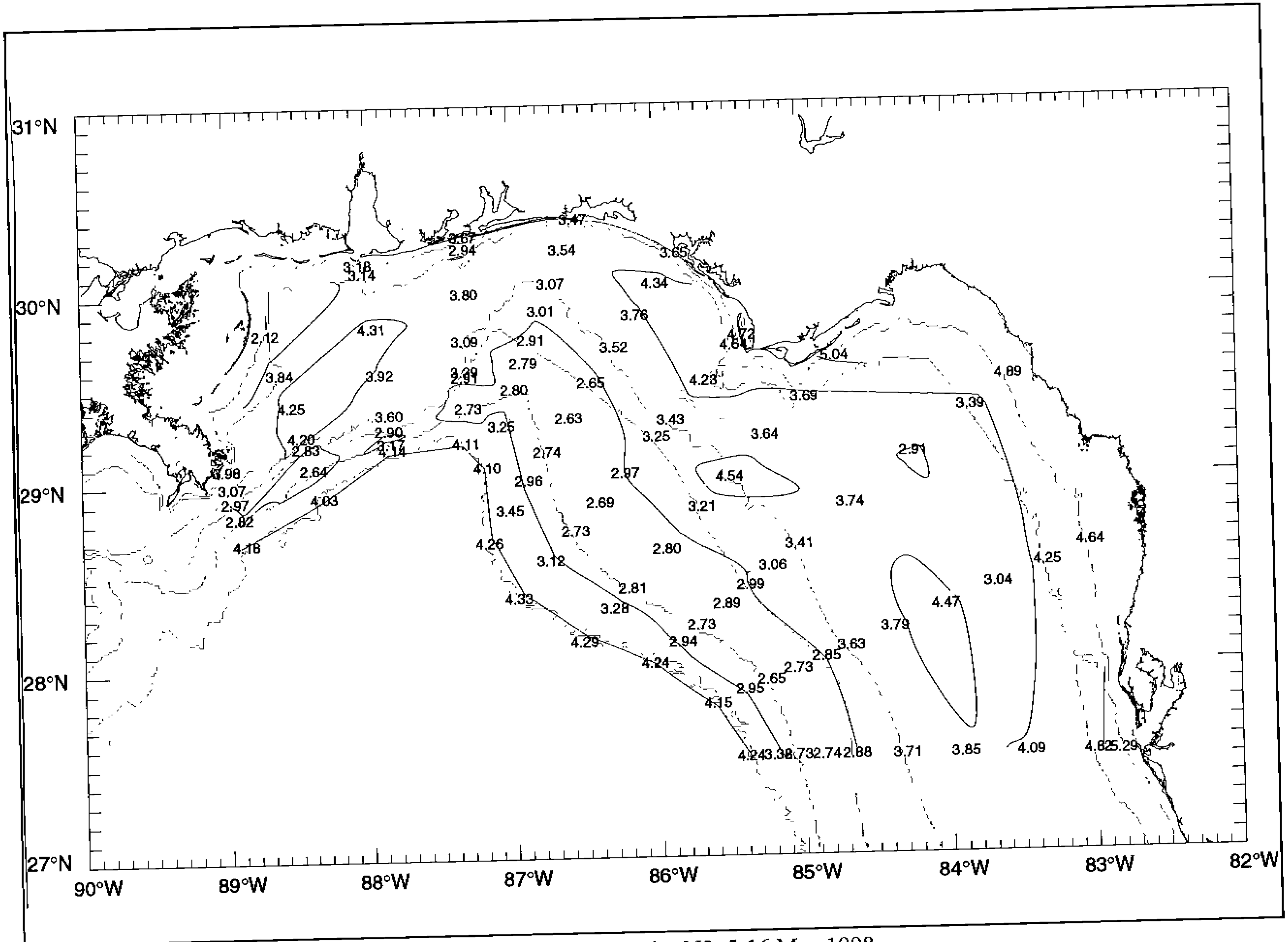

Figure 1H.12. Dissolved oxygen (mL·L^{-1}) near the bottom on cruise N2, 5-16 May 1998.

2 $mL \cdot L^{-1}$ near the Mississippi Sound. Dissolved oxygen values at the bottom were not particularly low east of Cape San Blas. That could have been due to differences in stratification or to the fact that the region east of the Cape was sampled earlier in the cruise.

Percent light transmission at the 660 nm wavelength observed during cruise N2 on lines 4 through 11 was generally at least 80% to greater than 90%. These high transmission values in the cool bottom waters nearshore give further evidence that these are upwelled offshore waters. By contrast, as we approached the Mississippi Sound, light transmission decreased inshore, toward the surface, and to the west.

Nutrient distributions over the mid-and-inner shelf appear elevated at locations corresponding to the cooler upwelled waters. High nitrate values at the bottom seem well correlated with low oxygen values. The 3.5 m and bottom distributions of nitrate observed on cruise N2 are shown in Figure 1H.13. Effects of river discharge and primary production are clear in the surface distribution. The bottom distribution shows the effects of onshore movement of nutrient rich bottom waters and may be compared with bottom oxygen distributions shown in Figure 1H.12. The distributions of silicate, phosphate, and nitrite at 3.5 m and near the bottom based on cruise N2 measurements show the expected good agreement with nitrate.

EXAMINATION OF TEMPORAL CHANGES

In search of cool upwelling events prior to cruise N2 or during the summer of 1998, we examined time series of temperatures from SAIC moorings in the DeSoto Canyon from early April to early August 1998 (SAIC 1998). We focused on near-bottom temperature observations from four moorings located along the 100-m isobath: A1, C1, D1, and E1 (see Figure 1H.5 for locations). Lower than average temperatures were recorded during periods in April and early May at C1, D1, and E1. During two periods in mid-April pulses of cool water appeared at mooring locations C1 and D1 at approximately the same time. These cool water pulses appeared at E1, at the head of DeSoto Canyon, about ten days later. This cool water penetration over the 100-m isobath was not seen at A1. (We examined temperature records at the bottom at A1 and B1 for March and early April and found no indication of such penetration.) These intrusions likely set the stage for the cool bottom water observed during cruise N2.

Another influx of cooler water over the 100-m isobath occurred in mid-July. Again its presence was noted at D1 about ten days before E1. The intensity of this intrusion was less than those in April.

We examined nearshore records from meteorological stations 42007 and Dauphin Island (see Figure 1H.5 for locations) for surface temperature. At both locations there was a pronounced warming trend during spring, as expected. A cool event lasting several weeks with a magnitude near 5 °C occurred at both locations in early June 1998.

Mean surface winds for the April–August 1998 period were generally eastward (upwelling favorable) and onshore. However, at the end of the first week in June a strong offshore wind event occurred

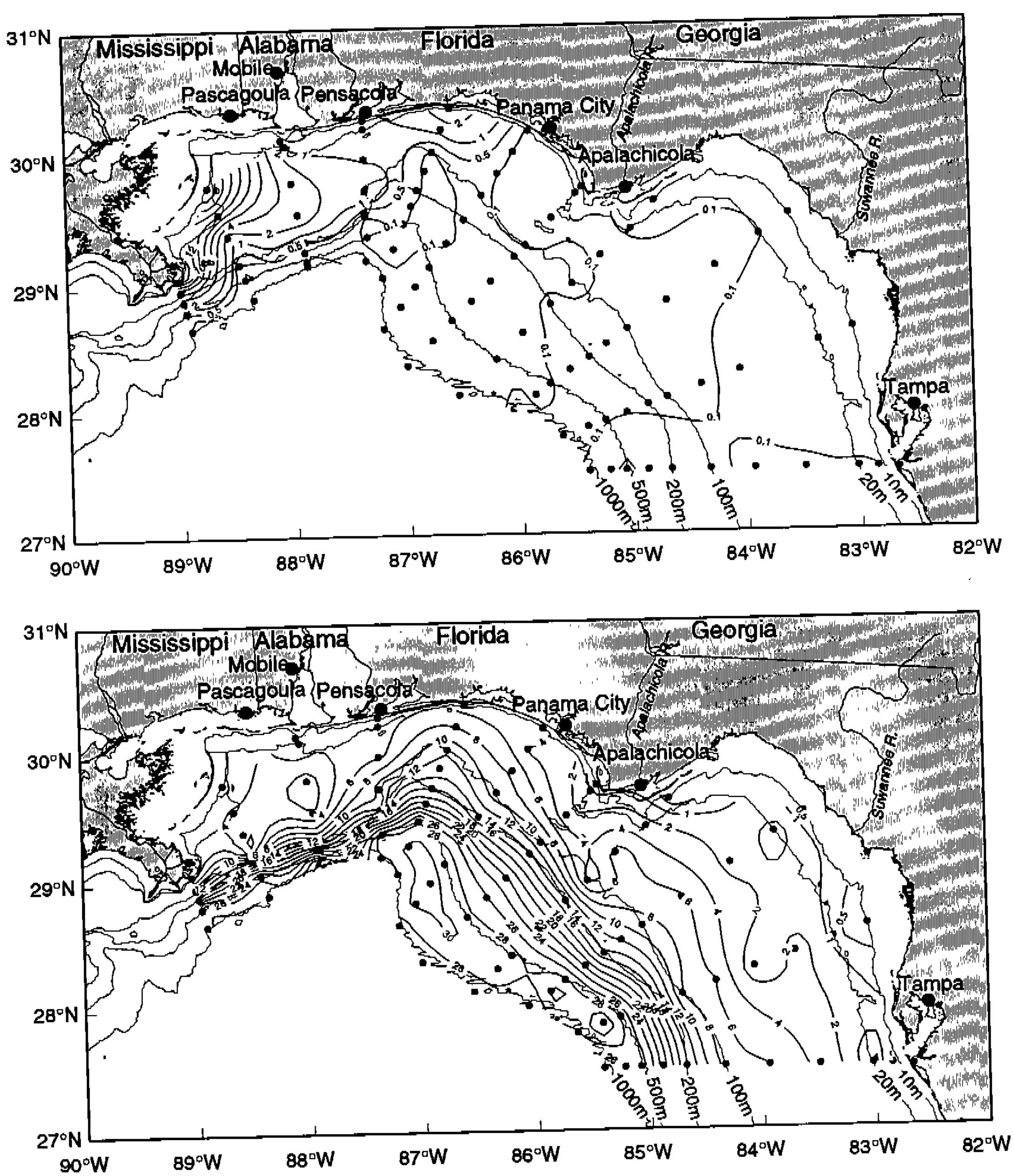

Figure 1H.13. Nitrate (μmol·L⁻¹) at 3.5 m (upper) and near the bottom (lower) on cruise N2, 5-16 May 1998.

from the Mississippi Sound to Cape San Blas. This event apparently drove offshore flow and upwelling because it corresponds with the cool event in observed surface temperatures.

Because off-shelf cyclonic and anticyclonic eddies have such profound influence on the outer shelf circulation in the northeastern Gulf, we studied the development of these features by examining the evolution of SSHA over the northeastern Gulf of Mexico (depths greater than 200 m) using a product prepared by Robert Leben (University of Colorado) based on a combination of altimeter data from TOPEX/POSEIDON and ERS-2. We looked at one SSHA distribution per week beginning 1 April 1998 and continuing through August 1998. These SSHA distributions are in fact a temporally smoothed product using data over about a ten day period centered near the day identified. The data have been temporally and spatially smoothed using decorrelation scales of 12 days and 100 km. Therefore, features may tend to be weaker than in reality, and smaller scale features may have been removed.

On 1 April most of the off-shelf area was under cyclonic flow except for one small anticyclone over DeSoto Canyon. A strong extension of a large anticyclone centered at 25.5°N, 88°W extended toward the shelf break west-southwest of Tampa. By 8 April the anticyclone off Tampa had extended to the 200-m isobath and, after separation of a weak anticyclone near the shelf edge, it subsequently withdrew offshore. By 29 April shortly before the beginning of cruise N2, the anticyclone over DeSoto Canyon had strengthened. Shortly thereafter the two anticyclonic features at the shelf edge extended toward one another, coalesced and strengthened, resulting by 30 May in a peanut-shaped feature, similar to but more intense than that seen in Figure 1H.6.

By 1 July the feature had strengthened to a height anomaly of more than 20 cm and straightened into an east-west orientation. Then, connections began to form with a larger anticyclonic feature to the south until by 22 July both ends of the anticyclone appeared to be connected to the larger anticyclone. During the next three weeks, it again separated and diminished somewhat in spatial extent. By the end of August, the feature had renewed a connection with an anticyclone to the southwest and was oriented over the axis of the DeSoto Canyon with considerable strength.

There may be some evidence for the counterclockwise movement along the continental slope of small anticyclones. However, the reality of weak features in the SSHA field near the shelf edge probably should be viewed with caution.

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DE SOTO CANYON PHYSICAL OCEANOGRAPHY

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INTRODUCTION

The De Soto canyon study is presently investigating the circulation of the northeastern Gulf of Mexico slope between the Mississippi delta and west Florida escarpment. Thirteen moorings all equipped with upward-looking acoustic Doppler profilers along with a variety of current meters, thermistors and conductivity sensors have been deployed since March 1997. Figure 1H.14 shows the he positions of the moorings, wind stations (NDBC buoys and CMAN), and the hydrographic station grid which is occupied every four months. The final retrieval and hydrographic cruise is scheduled for April 1999. Data return has been excellent, and the year-long time series from the first year of the study have had some preliminary analysis.

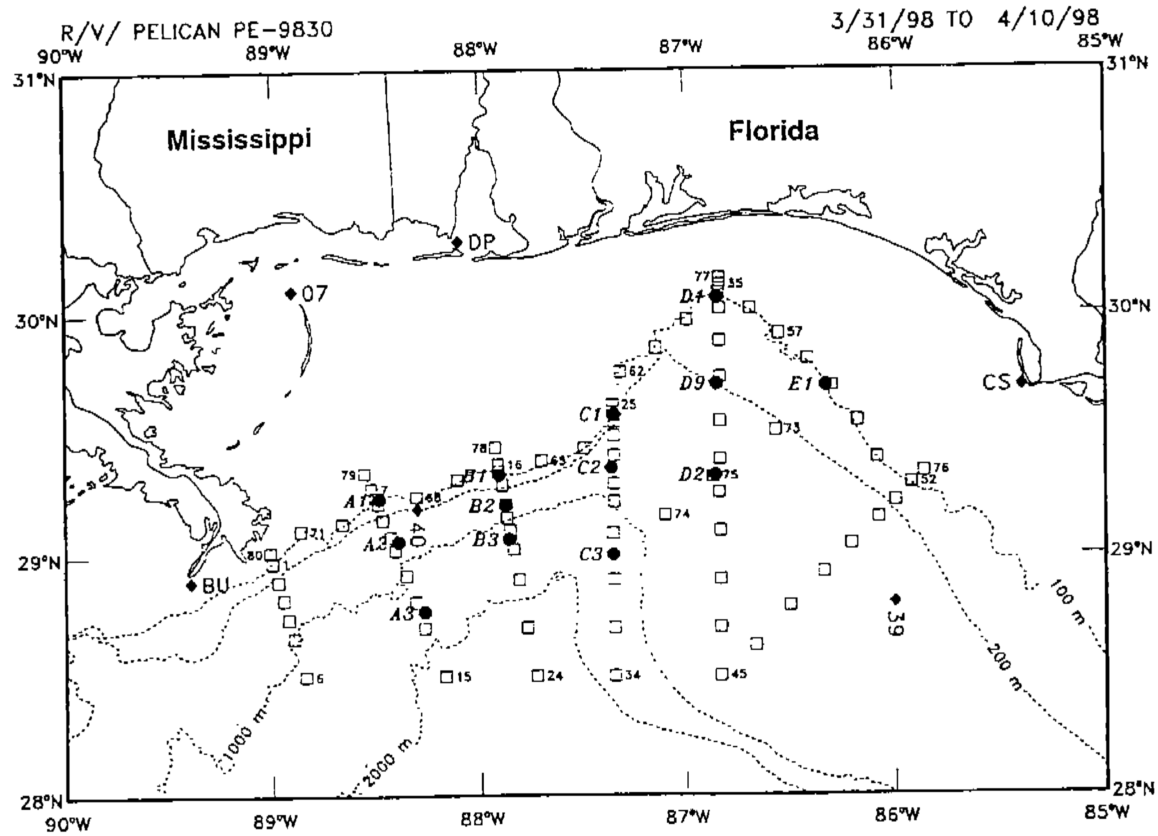

Figure 1H.14. Map of mooring positions (solid dots), standard grid hydrographic (CTD) stations (open squares), and meteorological buoys and CMAN stations (solid diamonds).

CIRCULATION CHARACTERISTICS

The slope circulation is dominated by relatively small scale (~ 50 to 100 km diameter) warm and cold eddies. Examples of near-surface, geostrophic velocity vectors, relative to 1,000 dbars, are given in Figure 1H.15 for two of the hydrograhic surveys. In March 1998, the circulation pattern showed three eddies (two cyclones and an anticyclone) on the lower slope with weaker eddy flows over the shelf break, just east of the delta and at the head of the De Soto canyon. These lower slope eddy circulations can advect warm, salty surface water from the Loop Current region to the south

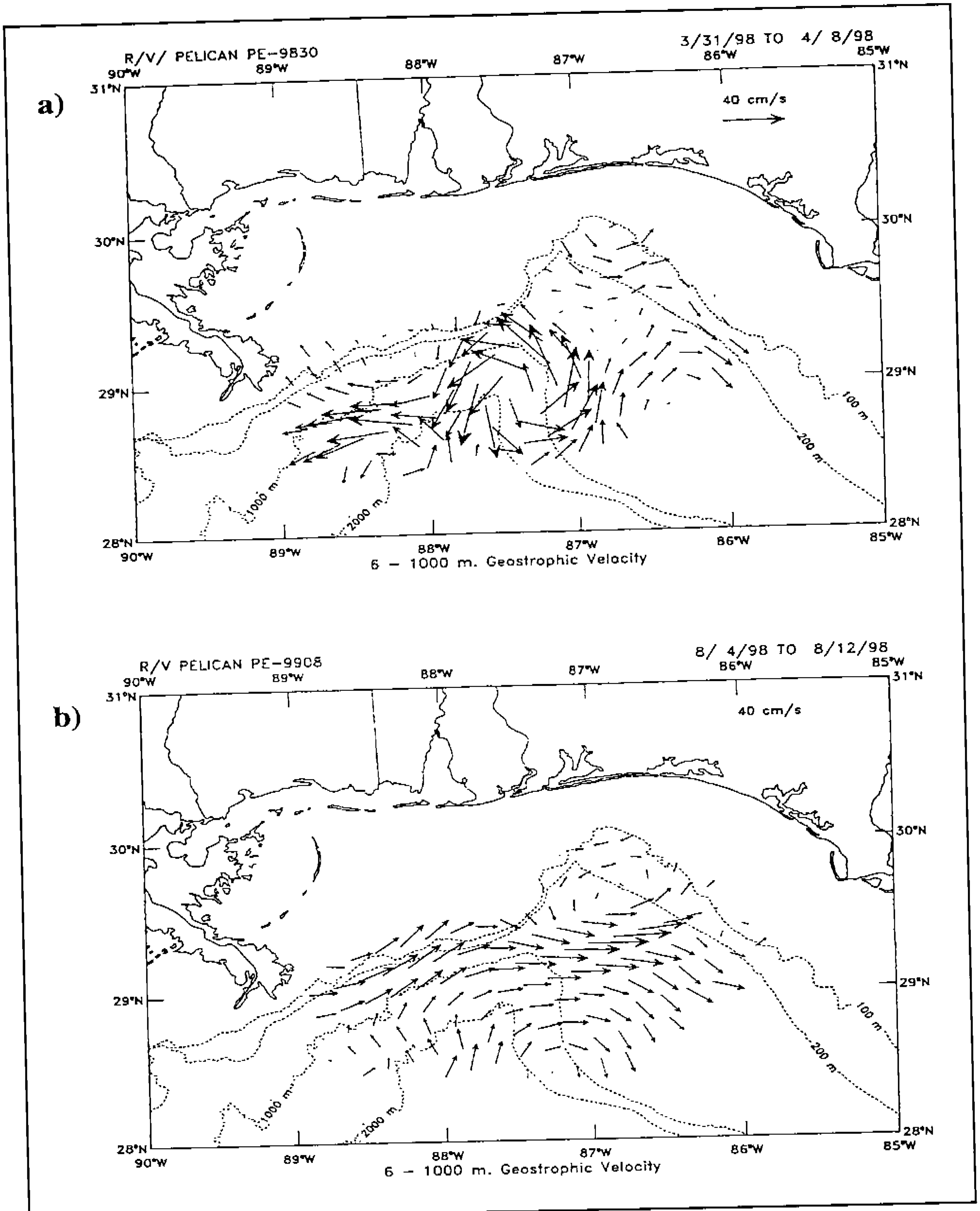

Figure 1H.15. Geostrophic velocities relative to 1,000 dbar calculated from CTD data for the March (PE-9830) and August (PE-9908) hydrographic cruises.

and also export brackish shelf and/or Mississippi plume water across the slope. The August 1998 survey (Figure 1H.15b) showed the lower slope dominated by a larger scale anticyclone that was generating strong eastward currents along the Mississippi and Alabama shelf break. This upper slope eastward jet bypasses the head of the De Soto canyon generating a cyclone in this region. The interaction between the cyclone and the jet produces a strong convergence and export of shelf water near mooring C1, and onshore flow on the other side of the canyon near mooring E1. An eastward jet-like flow along the upper slope is relatively common in these measurements and is usually accompanied by a counter-current flowing westward below about 200 m depth. The eastward and westward flows above and below about 200 m, respectively, are also apparent in the year-long mean current statistics for the upper slope.

The subtidal current velocity, temperature and salinity time series show quite different characteristics between the summer and fall of 1997 and the winter and spring of 1998. In the summer of 1997, flow events along the shelf break were sustained over several weeks and apparently dominated by slow moving eddies over the slope. In the following winter, events were short-lived with periods of 10 days or less and considerably more energetic. One of the strongest current events that were not related to passage of a hurricane, occurred at the beginning of February 1998. This event generated westward currents at C1 that exceeded 80 cm/s over a large portion of the 90 m water column and lasted about one day. Time series of temperatures (Figure 1H.16), from near the bottom at the shelf break moorings, illustrate the many short-lived cold events that occurred from December to April. There is evidence that the events are propagating westward along the slope from E1 around to A1. Deeper current and temperature fluctuations were also more energetic in winter than in summer and showed evidence of westward propagation of wave-like signals. The reasons for the change in character of the circulation are not clear but may not be a result of seasonal changes in forcings such as the wind. The winter period in offshore waters to the south was dominated by the formation and detachment of a major Loop Current anticyclone (eddy Fourchon). This could have had indirect effects on flows over the northeastern Gulf slope.

Figure 1H.16 also shows that cold water was present at the head of the canyon (D1 and E1) in June and July of 1997 but not in the summer of 1998. Thus, the coastal upwelling along the Florida Panhandle coast that was reported during the summer of 1998, and is discussed elsewhere in this session, did not have exceptionally cold bottom water as a source at the shelf break. However, the water column in July is highly stratified with top to bottom differences of 8 to 10 °C at the shelf break. Thus, shelf-edge bottom temperatures of less than 20 °C would show up as being relatively cold in satellite imagery if they were upwelled at the coast.

CONCLUSIONS

This ongoing physical oceanographic study of circulation in the De Soto canyon region has been designed to resolve eddy flows and shelf-break exchanges with short horizontal length scales of order 25 to 50 km. Preliminary results indicate that over the limited region of the study, the measurements are resolving the important energetic small scale eddies that dominate the circulation. The experiment has also shown some dominant patterns of upper slope flows and eddies that were previously unknown.

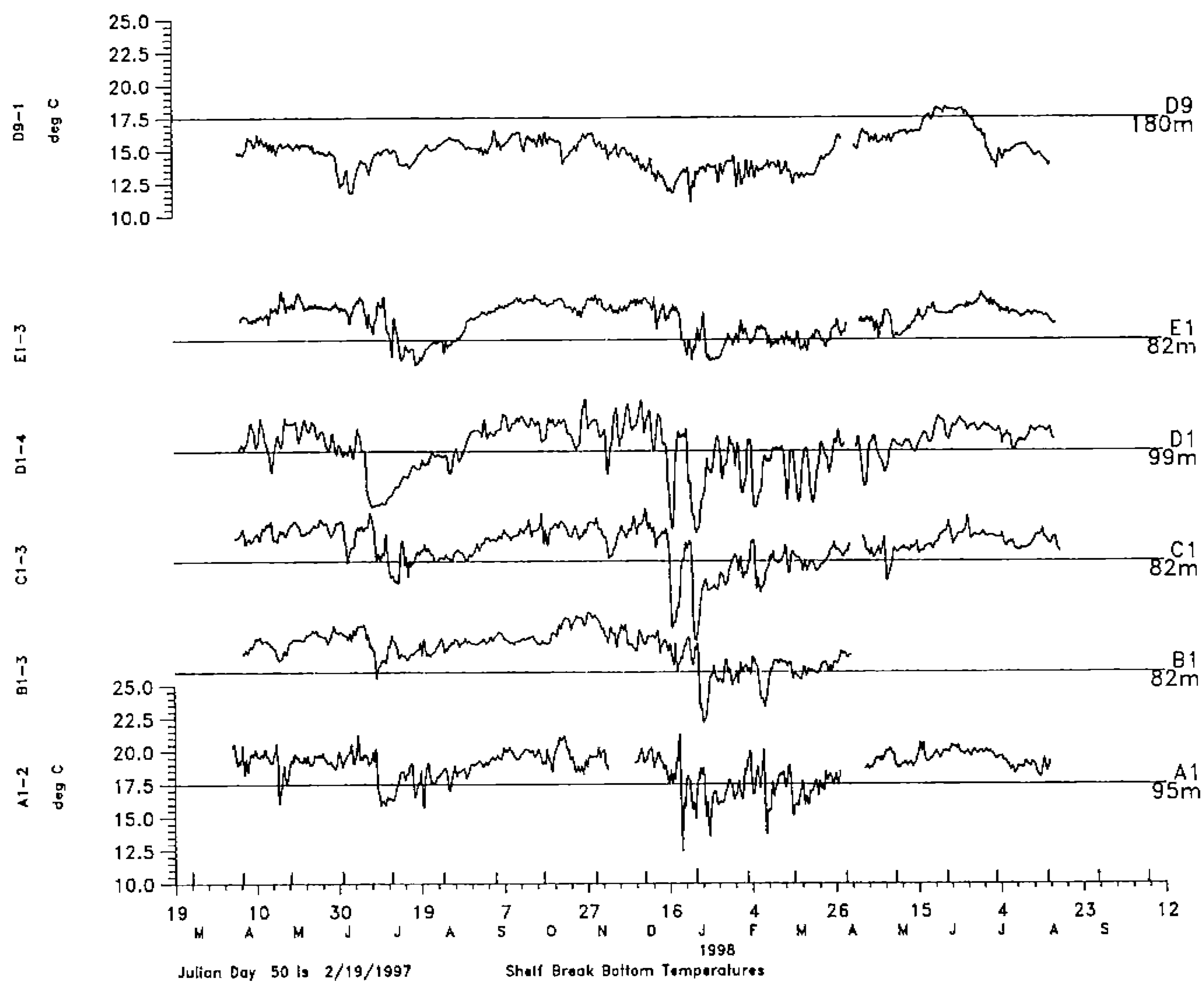

Figure 1H.16. 40-hour low-passed filtered temperature time series from the near-bottom instruments at the shelf-break moorings (A1 through E1). Top plot is from the 180 m level of the D9 mooring in the canyon. Plots without ordinate axes have the same temperature scale as the A1 time series.

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MODELING CURRENTS IN NORTHEASTERN GULF OF MEXICO: AN EVALUATION

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INTRODUCTION

The main goals of this paper are (1) to simulate currents in the Northeastern Gulf of Mexico (NEGOM) using an ocean circulation model, and (2) to make an evaluation of the model ability in reproducing the observed patterns of surface velocity.

To simulate the flow, a limited-area, primitive-equation model is developed, based upon the Bryan-Cox code (Cox 1984), originally designed for modeling the general circulation of a closed ocean basin. The model has sufficient resolution for the simulation of mesoscale dynamics involved in the interaction between the Loop Current, the main circulation feature in NEGOM, and the continental margin topography.

To assess the model's ability in reproducing observed flow features. we make use of two sources of data. The first one is the average surface velocity calculated from the distance traveled by surface drifters between successive position fixes. Drifters were tracked in NEGOM during February 1996–May 1997 (P. P. Niiler, pers. comm. 1998). The second data source is the current meter measurements on moorings in DeSoto Canyon during March 1997 - April 1998 (SAIC 1998). These data sources allow us to make an objective evaluation of model results. We base our evaluation on statistical estimation as well as on inspection.

METHODS AND RESULTS

Numerical Experiments

A relevant model for the Gulf of Mexico circulation driven both by the inflow through the Yucatan Straits and by the wind stress must resolve dynamic processes at the shelf and over the sharply changing topography in NEGOM. The eddy-resolved circulation model employed to meet this requirement is the rigid-lid, primitive-equation model of Bryan and Cox (Bryan 1969; Cox 1984).

A uniform grid with a 1/6 degree grid spacing is used that covers the domain between 18 N and 31 N and between 80 W and 100 W. The vertical grid is stretched with 8 levels in the top 200 m, a total of 16 levels in upper 1,000m, and 14 remaining levels spanning the water column the rest of the way to a maximum depth 5,500 m. With this grid, both the continental shelf and the continental slope topography are reasonably resolved.

Bathymetry for the modeled region is formed from selecting depth values from every second point in the 5-minute ETOPO global relief model, which is based on Digital Bathymetric Database 5(DBDB5) created by the U.S. Naval Oceanographic Office. All values greater than 5,500m are assigned to level 30, the deepest level of the model. The entire depth field is then smoothed with a nine-point smoothing scheme and then truncated at 20m at the edge of land masses to produce the model bathymetry.

Temperature and salinity at open boundaries are relaxed to climatological values. Horizontal velocities are relaxed to values calculated from the thermal wind relation on the basis of the climatological temperature and salinity. The relaxation is reduced in strength gradually in a buffer zone spanning 6 grid points inward from the open boundary. No relaxation is present further inward. No diffusive fluxes are allowed normal to the open boundaries. Finally, along the outflow boundary through the Straits of Florida, a radiation condition is implemented (Carmelengo and O'Brien 1980). At lateral solid boundaries, no-slip velocity and no-normal-flux tracer conditions are impossed. At the rigid-lid surface where the vertical velocity vanishes, the heat and salt fluxes are provided through a relaxation to climatological temperature and salinity values on a 50-day time scale. At the ocean bottom where the flow is constrained to be parallel to the sea floor, a bottom stress quadratic in bottom velocity is applied. There is no flux of heat or salt through the sea floor.

Two sets of numerical experiments were conducted. The first one covers the time from February 1996 to March 1997 and is for comparison with the drifter data. The second set covers the period of March 1997 to April 1998 to allow comparisons with the mooring data. In all experiments, 6-hourly 10 m surface winds from the NCEP/NCAR 40-year reanalysis data set (Kalney *et al.* 1995) were used to calculate the wind stress.

Results of Analysis

Figure 1H.17 shows the horizontal distribution of correlation coefficient (CC) for both components of velocity. In this case, CC at each point of domain was calculated for velocity components (model and drifters) at the time when drifter velocities are available. Maximum correlation is found on the shelf of NEGOM and CC decreases seaward. The main difference is that CC in the zonal component has high values (more than 0.7) along the northern shelf between 86 and 88 W whereas CC in the meridianal component has minimum values there. So, in this region the model simulates much better east-west component than south-north component. Figure 1H.18 presents the time series of CC. In this case, CC was obtained for each day from velocities at the points where drifter velocities are

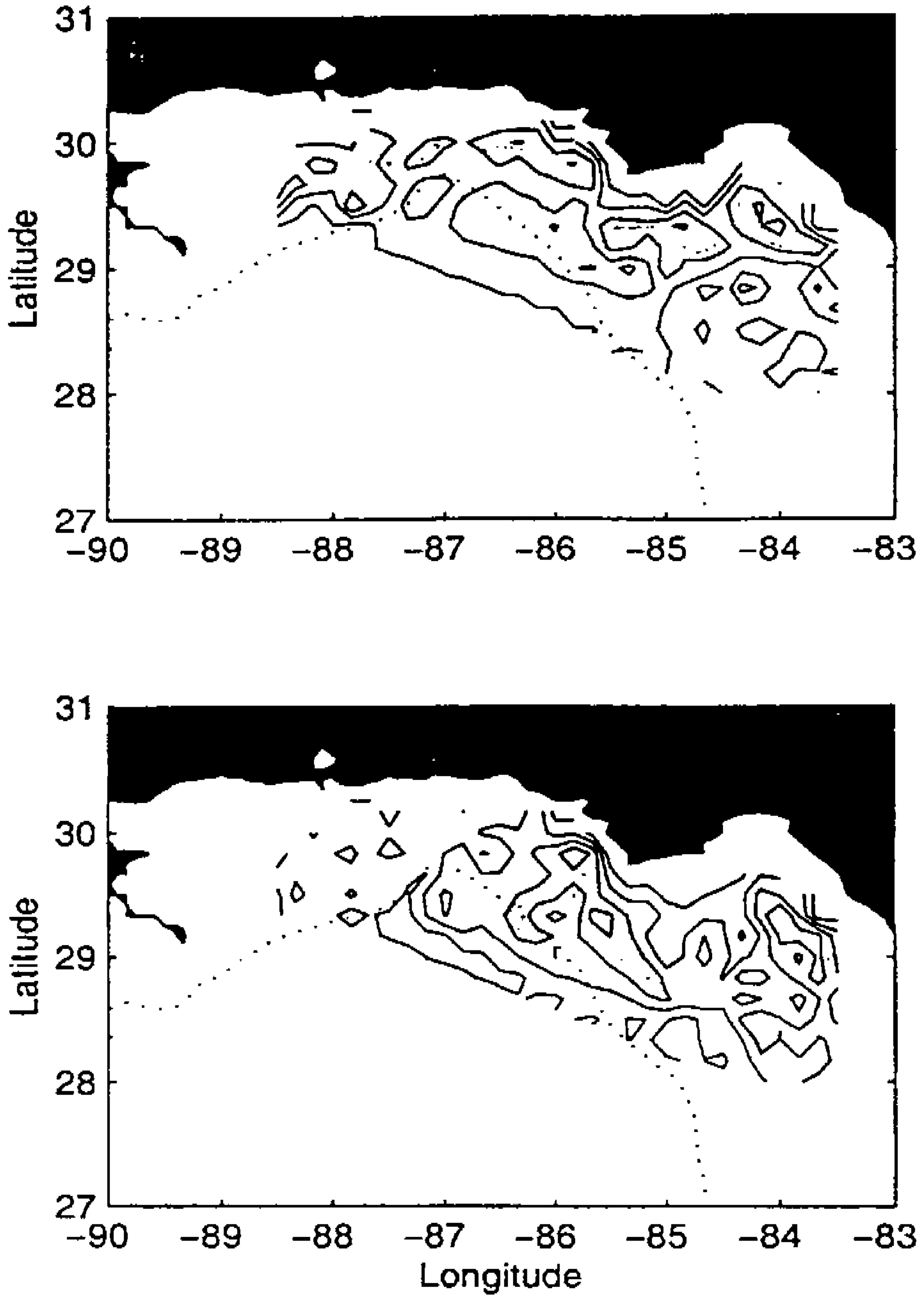

Figure 1H.17. Correlation coefficient between velocities derived from position fixes of surface drifters tracked during February 1996 and April 1997 and model velocities at 5 m as a function of horizontal coordinates for Northeastern Gulf of Mexico. The upper panel is for the east-west velocity component and the lower panel is for the south-north velocity.

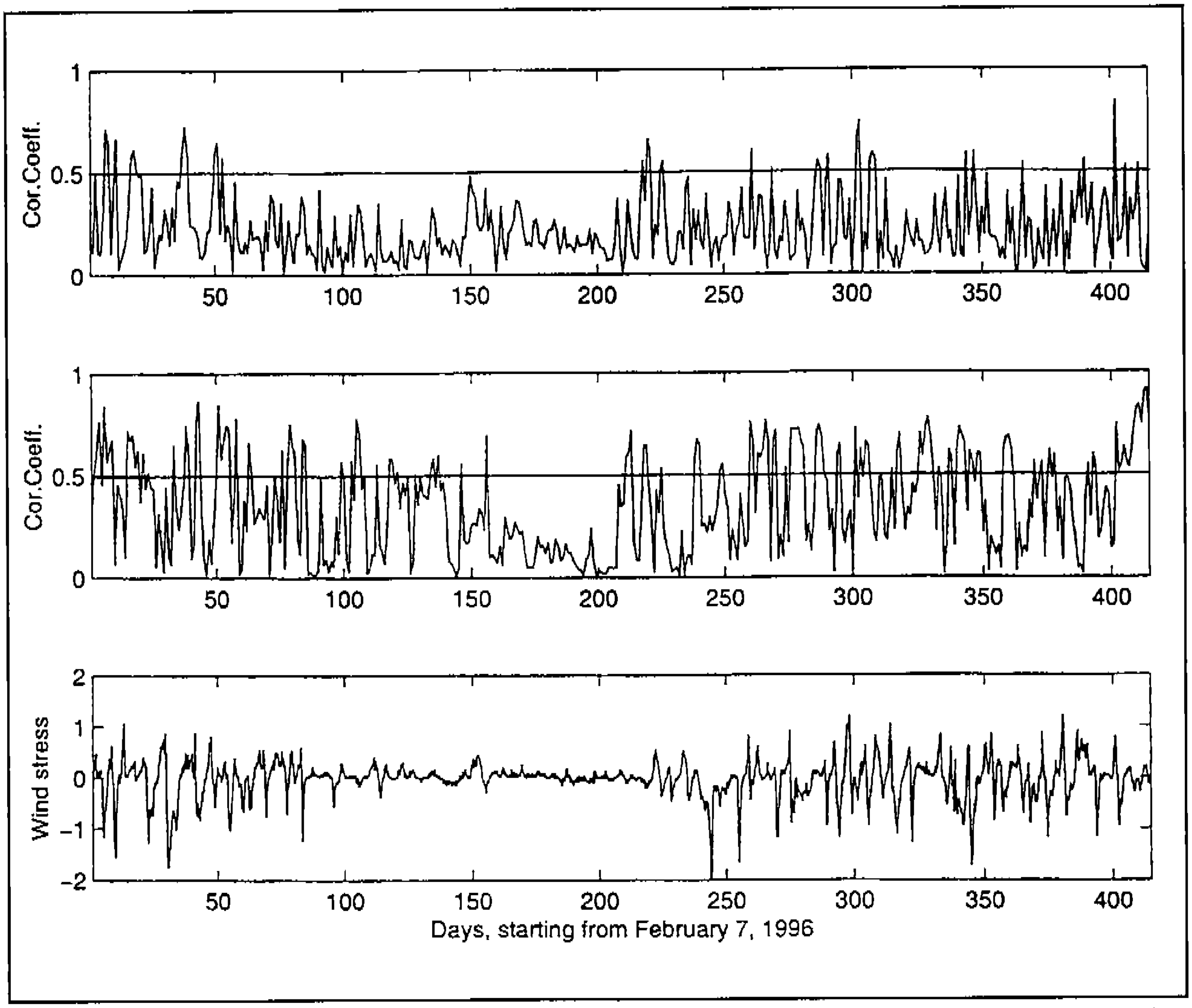

Figure 1H.18. Time series of correlation coefficient as in Fig. 1 but area-averaged daily during February 1996 - April 1997 for the east-west velocity component (upper panel) and south-north velocity component (middle panel). The time series of south-north wind stress component at Pensacola is shown in the lower panel.

available. We note the relatively small values of CC approximately between the 70th and 200th day, especially for the east-west component of velocity. This time (summer time of the year) is characterized by weak winds in NEGOM (bottom of Figure 1H.18). In contrast, the model seems to simulate drifters velocity in cases of moderate to strong winds. Two examples are presented in Figure 1H.19. The first example (left panel of Figure 1H.19) shows that strong winds from the northwest on 20 March 1996 produces strong model flows to the southeast along the edge of the Western Florida Shelf (WFS) with maximum velocity of 0.7 m/s. The drifter velocity (bottom panel) shows qualitatively the same. The second example shows that winds from the east on 6 October 1996 produces model flow to the west along the coast with velocities as large as 1.1 m/s near the

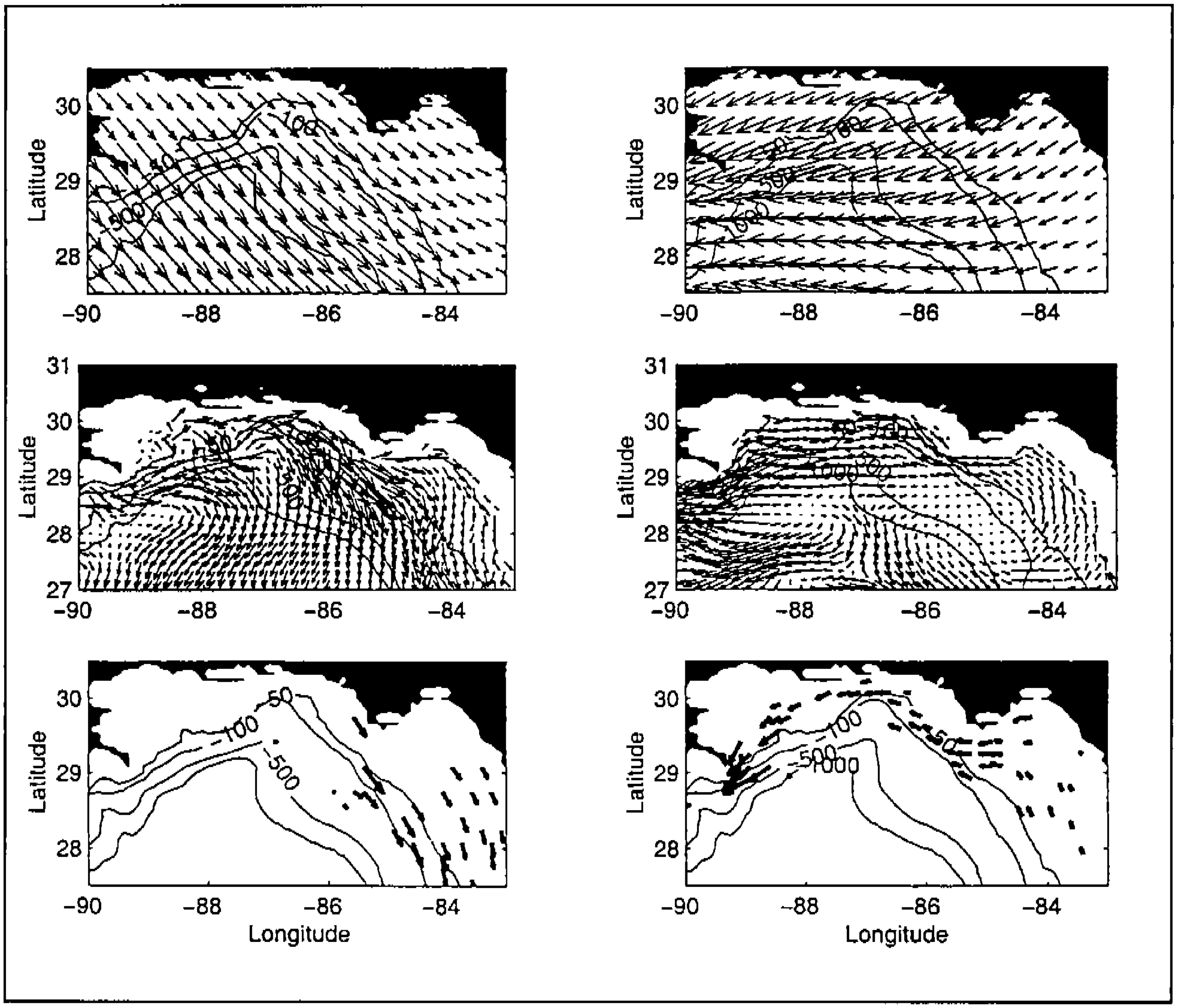

Figure 1H.19. Vector plots, in the DeSoto Canyon area, for 20 March 1996 (left column) and 6 October 1996 (right column) of wind stress (upper panel), model velocity at 5 m (middle panel), and velocity derived from satellite-tracked surface drifters (lower panel).

Mississippi river mouth. The drifter velocity shows about the same. So, the model simulates well the wind-driven currents in NEGOM.

Following Holloway and Sou,1996 (refered hereafter as HS) we consider the skill of the model in reproducing currents in NEGOM. For skill estimation, we use data from current meter moorings in DeSoto Canyon. At each current meter position, time mean (u1,v1) of velocity is calculated for the entire record length. The same is done with model velocity (u2,v2) at that position. The kinetic energy of the difference f=(u2-u1,v2-v1) is the error kinetic energy, eKE = .5*f*(1/V)*f where V is the diagonal matrix of total variance for each current meter position. We compare eKE with the kinetic energy of data themselves dKE and consider the following quantity:

$$skillE=(dKE - eKE)/(dKE + eKE)$$

With an error-free model with eKE = 0, we have skillE = 1. Whereas with a model with large error, we have skillE = -1. We consider also the skill of a completely skill-less model which gives flows randomly unrelated with observation. Denote the weighted kinetic energy of the model at the current meter locations by mKE. The skillE for this skill-less model is called skillF (for "floor"):

$$skillF = -mKE/(2dKE + mKE)$$

The difference between skillE and skillF gives an energetic skill of the model, i.e., the excess of skillE over skillF.

A second measure of model skill is the direction skill (skillD) which shows if the model has any skill in reproducing the flow direction, regardless of the speed. From unit vectors of velocity d=D/|D|(data) and m=M/|M|(model) we form the weighted inner product:

$$skillD = d*(1/V)*m$$

The values of SkillD also fall within the bounds $-1<skillD<1$.

Results of skill calculations are presented in Table 1H.2 for 12, 32, 52 and 72m. Both skillE-F and skillD have high values, especially if we compare them with estimations made by HS for the world ocean. The highest estimations obtained by Holloway and Sou are 0.191(+/-0.046) for skillE-F and 0.292(+/-0.081) for skillD. The main reason of the difference between these estimations and our values is 1) we used horizontal resolution in the model 1/6 degree comparatively with 1.856 in HS; 2) we used NCEP wind to drive the model which is more close to reality than mean Hellerman-Rosenstein fields used by HS.

As the table shows, all skills decrease systematically with depth. It allows us to conclude that the model gives reliable result in the upper layer where the current is basicaly wind-driven. The last line in the table represents estimations made with drifter data. SkillE-F now is less than in the case of mooring data but direction skill even a bit higher. The low skill here might be due to the fact that the time mean of drifter velocity contains large variability.

SUMMARY

Now we can make the following brief summary of the obtained results. We judge the ability of the model to reproduce observed surface velocity as quite satisfactory. Basically the currents on the shelf are wind-driven. That is why the model works well in the fall, winter and spring when winds in NEGOM are relatively strong. In summer when the winds are weak, the correspondence between the model results and the observations deteriorates.

Table 1H.2. Evaluation of the skill of the model to reproduce observed events.

Depth(m)	skill E	skill F	skill E-F	skill D
12	0.088	-0.516	0.603	0.712
32	0.067	-0.479	0.547	0.702
52	0.015	-0.417	0.431	0.529
72	0.024	-0.343	0.367	0.422
Drifters	-0.230	-0.433	0.203	0.748
Holloway & Sou, 1996			0.191 (+/-0.046)	0.292 (+/-0.081)

The model results are close to observations on the NEGOM shelf. In the vicinity of DeSoto Canyon the model reproduces the observed east-west component of velocity better than the observed south-north component of velocity. In regions seaward of the shelf, the correlation between model results and observations deteriorates.

In terms of mean velocities, the model appears to have high skills for both the current kinetic energy and current direction for the upper layer. Model skills declines with increasing depth.

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PRELIMINARY REPORT ON COASTAL UPWELLING AND MASS MORTALITIES IN THE NORTHEASTERN GULF OF MEXICO DURING SPRING AND SUMMER 1998

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INTRODUCTION

A widespread, protracted period of coastal upwelling occurred in the northeastern Gulf of Mexico (NEGOM) during spring and summer 1998. During the upwelling event, dense algal blooms and mass mortalities of fishes and invertebrates occurred from shore to depths of about 35 m in the central Florida Panhandle. This report briefly summarizes climate and ocean conditions during the period, and suggests possible causes and proximate biological consequences of upwelling in the affected area.

BIOLOGICAL OBSERVATIONS

From mid to late May, coincident and apparently associated with upwelling, commercial divers reported mass mortalities of fishes and invertebrates on wrecks and reefs at depths of 10-35 m (the limit of diver excursions) in a region approximately 20 km east and west of Panama City and 3-7 km offshore (Fitzhugh pers. comm.). At about the same time, fishermen reported blue runners (*Caranx fusus* or *C. crysos*) and vermillion snappers (*Rhomboplites aurorubens*) floating on the surface offshore Panama City. According to commercial divers, fishermen and professional biologists, the areal and depth distribution of dead marine animals closely approximated the distribution of cool water which moved on and offshore on the surface, or beneath a strong thermocline reported to occur at depths of 3-12 m.

On 8 June, following a period of offshore winds and nearshore upwelling (Nowlin *et al.* 1998), a dense population of a cool water-tolerant filamentous red alga, *Heterosiphonia* cf. *gibbesii* (Moncreiff *via* Shaffer pers. comm.) was reported along and offshore Panama City beaches. Concentrations of *Heterosiphonia* appeared to move on- and offshore with cool water at irregular intervals, and reports of thick mats of algae in the water column and on the bottom continued until 12 July. After 12 July concentrations of *Heterosiphonia* markedly decreased when the population died off or was cleared from the area by winds and currents. Accumulations of algae in St. Andrew Pass, on area beaches, and in coastal waters were usually associated with dead fish and invertebrates (Shaffer pers. comm.).

On 25 June, large numbers of dead fishes and invertebrates were reported on reefs off Destin in water depths of 18-21 m. At a depth of about 12 m "colder than normal" water was encountered, and currents were reported to be eastward. On 1 July, National Marine Fisheries Service divers reported a strong thermocline at 5-6 m in St. Andrew Pass, and reported that all of the organisms seen below 6 m were dead except for crabs, which were moribund. Above the thermocline, fishes generally associated with deeper water or bottom habitats were seen (Table 1H.3). At 14 m depth, bottom water temperature, salinity, and dissolved oxygen concentration were, respectively, 19° C, 35.3 psu and 0.37 $mg \cdot l^{-1}$.

During low tides on 1-2 July, NMFS biologists observed distressed fish in St. Andrew State Recreation Area tidal pools; dead juvenile flounders, crabs and lethargic fishes inside the St. Andrew Pass jetties; and dead eels, burrfish, cowfish, crabs, starfish and sea cucumbers outside the pass, and on area beaches (Table 1H.3). Water at the beaches was characterized as green and thick with algae. Mass mortalities did not recur (or were not reported) in the Panama City-Destin area during 3-6 July, and nearshore Gulf waters were reported to be clear and well mixed, with reduced algal densities. While fishkills were not reported during this four-day period, large schools of lethargic fish (Spanish mackerel, "baitfish," and stingrays) were seen in the shallows at Destin Pass.

During the period 26 June-12 July, distressed, moribund and dead fishes and invertebrates were observed from the intertidal zone to about 30 m depth in the St. Andrew Bay-Destin region. Deepwater animals were observed at the surface offshore, and in shallow water near shore during this period, and algal densities were observed to be much higher than usual. From 7-14 July, water temperatures at Panama City beaches varied between 18-20° C. Cool water and mass mortalities — similar in magnitude and species composition to those of 1-2 July, recurred in the Destin-Panama City area from 7-9 July, and fishermen reported that highly stratified water, with currents setting to the east, extended 24 km offshore. On 10 July, the water column was weakly stratified (21 °C on the surface, and 19° C on the bottom at 12-13 m) in St. Andrew Pass, and strongly stratified 1.6 km offshore (25° C on the surface and 19° C at 12-13 m). Fishermen reported that bottom currents were

Table 1H.3. Fishes and invertebrate groups reported by various observers to be either dead (D) or obviously distressed (S). No systematic collections were made, and the list is conservative. Common names are used when identification of the species was not verified.

Fishes	
Astroscopus y-graecum (D)	*Syacium papillosum* (D)
French grunts (D)	*Centropristus striata* (D)
white grunts (D)	spottail pinfish (D)
pigfish (D)	soapfish (D)
brotulas (D)	sennets (D)
Opsanus beta (D/S)	rays (S)
redfish (S)	black seabass (S)
Hemipteronotus novicula (D)	*Paralichthys albigutta* (D)
Citharichthys spilopterus (D)	*Etropus crossutus* (D)
blue runners (D)	cigarminnows (D)
wrasses (D)	electric rays (S)
parrotfish (S)	snake mackerel (S)
Rhomboplites aurorubens (D)	leatherjackets (D)
juvenile and adult flounders (D/S)	burrfish (D)
eels (D)	baitfish (S)
cowfish (D)	Spanish mackerel (S)
stingrays (S)	sharks (D)
grouper (D)	batfish (D)
scorpionfish (S)	gag (S)
skates (D/S)	flatfish (D)
Invertebrates	
snails (D)	*Hepatus* (D)
sea slugs (D)	sea urchins (D)
sponges (D)	starfish (D)
tunicates (D)	polychaetes (D)
deepwater crabs (S)	'regular shrimp'(D/S)
rock shrimp (S)	clams (D)
jellyfish (D)	sea cucumbers (D)
crabs "many species" (D/S)	nudibranchs

from west-to-east 16-64 km offshore. On 10 July, dead crabs, jellyfish and sharks washed up on Pensacola beaches, but correlation between the deaths of these organisms and upwelling is uncertain.

On 11-12 July a diver reported surface conditions over the wreck *Elvira* located 6.4 km south of Destin in water 26 m deep, to be relatively warm (~ 24 °C) with 12 m visibility. At about 9 m depth a strong thermocline was encountered, and the water was turbid, with visibility reduced to about two meters. At a depth of about 14 m, water temperatures 'evened out' near 18 °C, and visibility increased to about 8 m. Numerous fishes were seen at 24 m, but these appeared to be sluggish. Similar conditions were encountered at the wreck, *Louise* in 17 m of water, but "everything was dead — crabs, snails, clams, grouper, batfish, everything... ."

On 12 July, fishermen reported thousands of small flounder, rock shrimp, 'regular shrimp' and crabs swimming on the surface in the New Pass area at St. Andrew Bay, and at Destin, live, deepwater crabs were observed to be coming ashore in large numbers. Water temperatures during this time were reported to be about 6.5-8.5 °C colder than surrounding water in a 24-40 km wide band of water extending from the Ochlockonee River to Pensacola. Cold water extended from a depth of 6 m beneath the surface to the bottom, and was reported to be "black and murky."

From 13-16 July, charter boat captains and divers reported cool water inshore and warmer water offshore, with dense algae extending 9-10 km offshore. Surface temperatures were 21.7° C at Panama City, and 25° C at Pensacola. On a line from 8 km south of Panama City to the St. Joe sea buoy, surface and bottom (15 m) temperatures were 29.0° C and 20.5° C, respectively (FDEP pers. comm.). On 17 July a commercial diver reported that large milky clouds of unknown composition were seen about 9-10 km off Destin Pass, and that similar substances were observed in the pass on 4 July.

From 20-22 July, nearshore water became clearer, and surface temperatures increased to 27° C in the Panama City area. Satellite images indicated that cool water had moved to the west, and on 19 July, large numbers of lesser electric rays were observed in clear, cool water along a 1.6 km-long stretch of beach at Gulf Shores, Alabama, (Vittor pers. comm.). On 23 July NMFS reported that the cold water event was dissipating and that water clarity was improving. Coastal winds in the Panama City-Pensacola area shifted to the southeast on 24 July, sea surface temperatures increased to 29 °C, and fishers reported good catches of sharks, Spanish and king mackerel, grouper, snapper and redfish from Panama City to St. Joe Bay.

From information collected by National Marine Fisheries Service, biologists and marine scientists from other state and federal agencies (Fitzhugh *et al.* pers. comm.), mass mortalities on reefs appeared to be catastrophic. Offshore areas were apparently affected at different times, as cool water moved from east to west. For example, mortalities on reefs 20 km east of Panama City occurred in May, while reefs west of Destin, but not as far west as Pensacola, apparently experienced mortalities in June-mid July. Reports of dead fish floating on the surface offshore were received throughout the ten-week period, while dead organisms washed up on beaches in the Panama City area were most frequently observed between 27 June and 12 July.

In addition to reports of dead animals, numerous observations were made of fishes and invertebrates exhibiting symptoms associated with low oxygen stress. Benthic species (e.g., shrimp, crabs, some fishes) were seen swimming on the surface; lethargic fishes were observed below the thermocline; and shrimp and crabs were reported to be "crawling out of the water" — similar to "jubilees" that occur periodically in Mobile Bay due to low dissolved oxygen concentrations.

CLIMATE

Unusual climatic conditions in the NEGOM from winter 1997 through mid-summer 1998 were attributable to complex interactions between a strong 1997-1998 ENSO and a persistent negative phase North Pacific Oscillation (NP) teleconnection pattern (U.S. Department of Commerce 1997). According to the U.S. Department of Commerce (1998 a), from January to mid-March 1998, the southeastern U.S. experienced warm, stormy weather and heavy rainfall in advance of a pronounced, ENSO-related high pressure ridge that extended over the tropics and subtropics. Rainfall amounts increased as the ridge moved north, and large volumes of fresh water associated with floods in southern Alabama, Georgia and Florida entered the northeastern Gulf of Mexico from Mobile Bay to the Big Bend region of the Florida Panhandle during the second and third weeks of March (U.S. Department of Commerce 1998 a, b). Peak discharge volumes of the Mississippi River (30,583 $m^3 \cdot sec^{-1}$) did not reach the Gulf until the third week of May, due to the northward reach of its much larger watershed (Miller, U.S. Army Corps of Engineers pers. comm.). In late March, as the high pressure ridge moved northward into the south-central United States, warm, wet weather in the southeast was replaced by record-setting hot, dry conditions that persisted through late July, when the residual effects of the 1997-1998 El Niño on NEGOM climatic conditions dissipated (U.S. Department of Commerce 1998 a, b, c). Coupled with atypical temperature and precipitation patterns, regional winds were also influenced by the ENSO-ridge system and, after its movement to the north, by a large atmospheric high pressure cell that dominated the Gulf of Mexico through most of July.

It is useful to compare descriptions of average (i.e., non-ENSO) winds in the NEGOM with those observed during spring-summer 1998. According to Blaha and Sturges (1981) winds are westward and relatively calm during spring, and without a dominant east-west component from May-July. Wolfe *et al.* (1988) and Tanner (1992) characterized prevailing spring-summer winds as northwestward or northeastward; and SAIC (1997) described late spring and summer winds as relatively calm and onshore, in agreement with Blaha and Sturges (1981).

Unlike these patterns, upper level and surface winds in the NEGOM were predominantly eastward and northeastward under the influence of the northern arm of a large atmospheric high pressure cell during spring-summer 1998 (Purdue University 1998). Nowlin *et al.* (1998) described regional surface winds from April-August 1998 as generally eastward and onshore, with a strong offshore wind event at the end of the first week in June. Sturges (pers. comm.) found that U-component mean winds were predominantly eastward from January-mid-July, except for a month-long period of weak westward flow from mid-March through mid-April. Price (pers. comm.) analyzed NEGOM surface winds and demonstrated that May-June 1998 winds were more northeastward and eastward than in May-June 1997.

OCEANOGRAPHY

Information presented here was extracted from the results of an extensive investigation of hydrographic conditions and their evolution in the NEGOM from early April to early August 1998 (Nowlin *et al.* 1998). A complete dataset and detailed analyses may be found in in the source document.

In a search for evidence of upwelling prior to cruise N2 in May, Nowlin *et al.* examined a time series of near-bottom temperature records from five moorings located along the 100 m isobath in the NEGOM. From west to east, mooring locations A-E were located, respectively, southeast of the Chandeleur Islands, south of Mobile Bay, south of Pensacola Bay, southwest of Choctawhatchee Bay, and southwest of St. Andrew Bay, at the head of DeSoto Canyon (SAIC 1998). Temperature records indicated that two pulses of cool bottom water in April at moorings C and D were followed some ten days later by a cool water intrusion at mooring E. There was no evidence of cool water at 100 m depths at moorings A or B during March or April. Cool water at moorings C, D, and E in April apparently "set the stage" for more extensive upwelling observed during cruise N2 in May.

The SSHA field from April-August indicated the presence of a small anticyclone over DeSoto Canyon on 1 April. By 29 April this feature had strengthened, and by 30 May had coalesced with a second anticyclone that translated northwest from its earlier position west of Tampa (see Nowlin *et al.*, Figure 1H.6). By 1 July the anticyclone over DeSoto Canyon strengthed to a dynamic height > 20 cm, assumed an east-west orientation and by 22 July connected with a larger anticyclone to the south. After 22 July (at about the time when upwelling, mortalities and algal blooms off Panama City stopped), connections between the northern and southern anticyclones weakened and diminshed in size.

ADCP measurements during cruise N2 confirmed SSHA observations, and established that currents associated with the anticyclone located over DeSoto Canyon were along-isobath along the northern edge of the canyon, while the flow of deep water was shoreward along the sides of the canyon and in the bottom Ekman layer. Cool water penetrated closest to shore near the head of the canyon.

While cool water was not observed over SAIC's 100 m isobath moorings A or B in April, clear evidence was found that onshore, near-bottom flow reached the 10 m isobath at most stations west of Cape San Blas prior to the N2 cruise in May (see Nowlin *et al.* Figures 1H.5, 1H.8, and 1H.9). Bottom water did not penetrate to these shallow depths at stations southeast of Cape San Blas. It is of interest to note that the presence of cool bottom water on the innershelf west of Cape San Blas occurred as much as a month before the first reports of mass mortalities in the region, and prior to the time AVHRR imagery detected cool water on the surface.

Warm temperatures in spring, enhanced by fresh water from local river sources on the surface and cool water near the bottom resulted in a stable water column with the strongest pycnocline west of Cape San Blas and east of Mobile Bay — in the region generally corresponding to the distribution of depressed dissolved oxygen concentrations (see Nowlin *et al.* Figures 1H.11 and 1H.12).

Nowlin *et al.* observed that the distribution of fresh surface water in May occurred inshore on N2 transect lines 1 and 2 west of Moble Bay (see Nowlin *et al.*, Figure 1H.5), and offshore on transects 3-7, in the region south southeast of Mobile Bay - southwest of Cape San Blas. Local rivers were suggested to be the source of fresh water observed at western, inshore stations, while the presence of fresh water on the surface offshore, "could have been caused by nearshore upwelling moving surface water offshore or by advection from the west due to the anticyclonic circulation over DeSoto Canyon." (Nowlin *et al.* 1998). In early June, a cool event lasting several weeks was observed at meteorological stations located in Mississippi Sound and at Dauphin Island. The presence of cool water (~5 °C) observed at these locations by Nowlin *et al.* occurred soon after peak discharges from the Mississippi River, as noted earlier. The maximum eastward extent of the Mississippi River plume occurs during eastward winds (Walker 1994), suggesting that the source of cool water observed in June may have also had a riverine source.

Nowlin *et al.* reported transmissivity at 660 nm wavelength was at least 80 to greater than 90% in nearshore bottom water from Pensacola to Tampa — evidence that offshore water low in chlorophyll upwelled onto the shallow shelf east of Mobile Bay. West of transect line 4, off Pensacola, percent light transmission decreased inshore and toward the surface.

According to Nowlin *et al.*, nutrient concentrations appeared to be elevated at inner and midshelf locations where cooler upwelled water was observed. High nitrate concentrations were associated with depressed oxygen concentrations at these locations (see Nowlin *et al.* Figure 1H.13), and provide evidence of the onshore movement of nutrient-rich bottom water.

DISCUSSION AND SPECULATION

The seasonal evolution of environmental features in northern portions of the NEGOM from spring through mid-summer are, with some variation in timing due to interannual variation in climate and ocean conditions, predictable sequelae of the sun's poleward progression. In late spring, air and sea surface temperatures begin a warming trend that continues through mid- to late August. A pycnocline develops and strengthens with increasing surface temperatures and winter-spring discharges of fresh water from rivers and estuaries. By early summer, water below the pycnocline is isolated from the mixed layer, and oxygen replenishment occurs largely by diffusion as turbulent mixing decreases with the late spring-summer reduction of frontal passages and strong winds. Prevailing spring and summer winds in coastal regions of the NEGOM are northerly, easterly, southerly or nearly calm (Blaha and Sturges 1981; SAIC 1997), depending on the period of record and distribution of stations selected for analysis. Prevailing westerly winds (i.e., to the east), as observed through most of the period from January through late July 1998, are uncommon in the NEGOM.

In addition to unusual winds, precipitation patterns during the first seven months of 1998 were atypical with respect to the 104 year period of record. Above average volumes of fresh water entered east-central portions of the NEGOM throughout winter, and a large, days-long "pulse" of fresh water from heavy rains in coastal watersheds reached this region of the Gulf in mid-March. It is likely that nutrient loading in shelf waters increased during the period of high river runoff and estuarine flushing. Rainfall ended after mid-March, and unusually warm, dry weather dominated eastern portions of the NEGOM until late July. With increasing temperatures, the cessation of storms and greatly diminished discharges of fresh water, a strong pycnocline may have developed in NEGOM shelf waters in late March or April, a month or more earlier than the seasonal norm.

Unusual climatic conditions were temporally correlated with, but probably causally unrelated to anticyclonic ocean features in the NEGOM described by Nowlin *et al.* (1998). As described by these authors, clockwise circulation and cool water upwelling were forced by an anticyclone located over DeSoto Canyon during the period of interest from April through July 1998. Nowlin *et al.* demonstrated that widespread upwelling occurred prior to their 5-16 May cruise, with the penetration of cool, near-bottom water to, or possibly inshore of the 10 m isobath on much of the shelf between Mississippi Sound and Cape San Blas. The maximum penetration of cool bottom water during the first half of May and in mid-July occurred near the head of the DeSoto Canyon. Reports of unusually cool water nearshore and observations of distressed or dead marine organisms suggest that pulses of cool water also penetrated to innershelf depths after mid-May, in June and in early July.

Nowlin *et al.* (1998) presented clear evidence of upwelling prior to early May; however, AVHRR satellite images of sea surface temperatures indicate that upwelled water did not reach the surface in nearshore shelf waters until about 11-12 May, after which it was detected (with considerable temporal and areal variation), between Mississippi Sound and the southern Big Bend region through 18-20 July. Remote sensing supported by observations of commercial divers suggests that upwelling was strong and persistent west of Cape San Blas and east of Pensacola Bay, generally corresponding to the region where mass mortalities occurred and ecological impacts were most pronounced. Ecological conditions were less affected east and west of what appears to have been the central, or core upwelling area.

Strong innershelf upwelling occurred prior to cruise N2 in May, several weeks before mass mortalities were first reported. Because cause and effect relationships between upwelling and mass mortalities are uncertain and of great interest, speculative, non-mutually exclusive explanations for the weeks-long lag between upwelling and mass mortalities are offered. Caveats are assumed to be givens. First, it is possible that dissolved oxygen concentrations in upwelled DeSoto Canyon water were higher in April and mid-May than during the last two weeks of May. Dense concentrations of the tropical, cool water-tolerant alga, *Heterosiphonia* cf. *gibbesii* (see Pakker *et al.* 1995) were not observed until late May-early June, within the time frame of mass mortality events on reefs off Panama City. The source of *Heterosiphonia* is not known, but a propagule of some size may have been transported onto the shelf by anticylonic currents described earlier. According to Nowlin *et al.* (in press), chlorophyll concentrations beneath the pycnocline were low (80 to >90% transmission at 660 nm) suggesting that the algal population occupied and increased in the mixed layer, and that its physiological tolerance to cool water was greater than that of the normal "June grass" bloom of *Cladophora*, a warm water alga. As nutrients in the mixed layer were depleted by growth of the algal bloom which co-occurred with blooms of non-toxic dinoflagellates and other phytoplankters, the *Heterosiphonia* population began to die, sank beneath the pycnocline, and contributed to a positive feedback loop of increasing BOD and decreasing dissolved oxygen concentrations. Evidence supporting very low dissolved oxygen concentrations is weak, and based on one credible measurement. On 1 July, National Marine Fisheries Service divers reported a strong thermocline at

4.5-7.5 m, in water 14 m deep in St. Andrew Pass. Visibility at the bottom was reduced to a few meters by floc and rafts of what appeared to be green algae. At the surface and at 7.5 m depth, respectively (the length of the Hydrolab cable), temperatures were 29.0 and 21.4° C; salinities were 32.8 and 35.3 psu; and dissolved oxygen concentrations were 5.91 and 0.37 mg $\cdot l^{-1}$. Water temperature at the bottom was 19°C. Hypoxic oxygen concentrations ($\leq$2.0 mg$\cdot l^{-1}$) were not encountered by Nowlin *et al.*, although concentrations near 3 mg$\cdot l^{-1}$ were measured during cruise N2 in early May. Mass mortalities attributed to low dissolved oxygen concentrations also occurred after cruise N2, suggesting that hypoxic or anoxic conditions also occurred after mid May. For this view to have merit, it must be assumed that hypoxia or anoxia developed rapidly — not only in the benthic boundary layer, but a sufficient distance above the bottom to account for the vertical reach of wrecks and reefs. Under a strong pycnocline it may be possible that respiration in resident benthic communities, coupled with the consumption of oxygen by microbial decomposers, could have been great enough rapidly to have lowered dissolved oxygen concentrations to levels stressful or fatal to marine organisms.

A second speculation is coupled with the first. Elevated nutrient concentrations in upwelled water were observed at inner and midshelf depths offshore St. Andrew Bay, Choctawhatchee Bay and Santa Rosa Sound, where organically rich sediments and high nutrient levels have been well documented (SAIC 1997). It is possible that Hurricanes Allison, Erin and Opal, which passed over these estuaries in 1995, translocated large amounts of their sediments to the shelf (see Isphording *et al.* 1987). With the additional flushing of nutrients and organically-rich sediments during flood conditions in mid-March 1998, chemical oxygen demand, in addition to an increased biological oxygen demand associated with algal decomposition, may have consumed much of the oxygen from upwelling water as it moved shoreward.

Other, somewhat less convoluted explanations are proposed. These suggest that: (1) Mass mortalities may have occurred in April but at depths greater than those usually explored by divers. If so, the question of what caused mass mortalities remains wanting. (2) Hypoxic ($<$ 2 mg$\cdot l^{-1}$) or anoxic water believed to be responsible for mass mortalities from mid-May through early July may not have originated in DeSoto Canyon, but advected into the region from the west; or (3) Water from DeSoto Canyon upwelled onto the shelf (but not to the surface) in April, where it remained as a relatively cool bottom layer beneath a strong pycnocline. During succeeding weeks (until about mid-May) dissolved oxygen in the relic watermass was gradually depleted as a result of high BOD/COD. It is difficult to attribute mass mortalities to causes other than oxygen stress. Toxic dinoflagellates were not present in abundance, and results of toxic screening by the Florida Marine Research Institute were negative (FMRI pers. comm.).

Although many marine organisms died during the upwelling event, systematic sampling was not possible, and neither the numbers of organisms nor the species involved can be known or approximated with confidence. Divers tend to avoid reefs known to have suffered extensive mortalities, and follow-on observations of benthic, reef-associated organisms, if made, are unknown to the author. In late July, however, pelagic fishes in the vicinity of reefs were reported to appear normal in abundance and diversity.

SUMMARY AND CONCLUSIONS

Atypical climatic conditions in portions of the NEGOM, including eastward winds and early formation of a pycnocline were related to the 1997-1998 ENSO and atmospheric dynamic conditions (ENSO-NP). Eastward and shoreward shelf currents and the upwelling of deep water from DeSoto Canyon were attributable to a persistent anticyclone located over the canyon. Correlations but not causation between climate and ocean conditions were found. Mass mortalities of pelagic and benthic organisms in the Panama City-Destin region are attributed to putative hypoxic, or perhaps anoxic conditions caused by a large biological oxygen demand. BOD was clearly exacerbated by a dense algal population of a tropical, but cool water-tolerant species of red alga, *Heterosiphonia* cf. *gibbesii*. Nutrient-rich sediments deposited on the shelf by floods in 1998 and by hurricanes in 1995 may also have increased total oxygen demand. Correlations but not causation between cool water upwelling, hypoxia, anoxia, and mass mortalities were found. The ecological consequences of dramatic, but relatively short-term mass mortalities in populations of adult benthic and pelagic animals, and of meroplankters recruiting to shelf habitats could not be adduced from the information available. Major long-term consequences of the upwelling event are expected to be relatively minor.

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SESSION 1J

ISSUES FOR THE MILLENNIUM: DEFINING SOCIAL AND ECONOMIC ISSUES FOR THE YEAR 2000 AND BEYOND

Co-Chairs: Dr. Claudia Rogers and Dr. Harry Luton

Date: December 10, 1998

Presentation	Author/Affiliation
Introduction	Dr. Claudia Rogers Minerals Management Service Gulf of Mexico OCS Region
Findings of the Gulf of Mexico Baseline and Community Study	Ms. Barbara Wallace TechLaw, Inc., Bethesda, MD
Helicopter Transportation in the Gulf of Mexico	Mr. Neill Osborne Air Logistics
Downsizing the Operation Instead of the Company	Mr. J.L. Rike Rike Service, Inc.
Coping with Uncertainty and Minimizing Regret: Shifting the Emphasis in Environmental Assessment	Dr. Keith Storey Mr. Mark Shrimpton Community Resource Services Ltd.
Panel Discussion	Dr. Claudia Rogers Minerals Management Service Gulf of Mexico OCS Region
Conclusion: The Issues Identified	Dr. Claudia Rogers Dr. Harry Luton Minerals Management Service Gulf of Mexico OCS Region

INTRODUCTION

Dr. Claudia Rogers
Minerals Management Service
Gulf of Mexico OCS Region

This session addressed social and economic issues for the year 2000 and beyond. It was divided into two segments: the first featured panel members and their individual expertise, and the second consisted of an open discussion among the experts. The presented a cogent and well-founded identification of some of the factors facing residents, political leaders and policy-makers as they attempt to deal effectively with oil and gas extraction activities.

Barbara Wallace, the first panel member, summarized the preliminary results of the MMS study she is managing on oil/gas-related activities and their effects on coastal communities along the Gulf of Mexico. She set the stage for the morning by examining trends and focusing on a few key issues that she and her research team identified. Ms. Wallace told of such factors as the following: (1) changes in how individuals learn a profession (from a relative and on-the-job training to more formal, highly technical skill certification) and changes that better their worth on the market; (2) the importance of world oil trends varies by geography and economies (the importance is high in Louisiana and Texas, low in Mississippi and Alabama and lowest in Florida); (3) fluctuations in oil and gas prices and employment levels discourage workers enough to warrant relocating their families and income searches and excluding the future possibility of returning to "the oil patch" when jobs are plentiful; and (4) future MMS studies should combine both county-level evaluations with community-level ethnography to overcome the barrier of aggregated numbers.

Neill Osborne traced the history of air transport and the changes it has undergone in response to oil and gas extraction in the Gulf. He also discussed future trends he sees as affecting us in this part of the country. He spoke of the sheer numbers of aircraft, from 130 in the early 1970s to 600+ in 1983, scattered over 20 onshore service bases along the Gulf of Mexico. From 1983 to 1990, the numbers changed from 33 operators to 3 and from 600+ aircraft to about 350. As of 1997, there were 636 helicopters operating, indicating a re-strengthening of oil and gas extraction. And during that same year, 1997, there were only 1.27 accidents per 100,000 hours in flight. Mr. Osborne had us consider the future in terms of increasingly sophisticated GPS (global positioning system) tracking and communication, aircraft which would be larger, faster, more costly and more safe, and aircraft manufacturing following the oil industry example of globalized contracts.

J. L. Rike addressed the need to look for more reservoirs of oil and gas with smaller rigs, platforms and/or ships as opposed to downsizing the companies. He also evaluated the future of oil and gas activities in light of new technologies, price structures and regulations. Mr. Rike outlined his strategic approach of making the oil or gas operation smaller, more responsive and more efficient and cost effective. This would avoid the need to fire employees, only to try to re-hire them once favorable conditions returned. He specified a number of technological developments which made smaller operations more attractive and feasible – 3-D seismic, slim-hole drillings, hydraulic rigs, progressive cavity pumps. He warned, too, that governmental regulations also must change to reflect the new downsizing trend in operations.

Mark Shrimpton and Keith Storey completed this first potion of the session by looking at the onshore implications of offshore development, from construction to operation, and how to recognize the uncertainties involved and their effects at the community level. Dr. Storey directed our attention away from the traditional emphasis of social impact assessment to the potentially affected communities. He would have us look first to the goals or objectives of those communities and their respective capacities to deal well with external changes. He also urged that the environmental impact assessment process include different viewpoints of what should be evaluated, from the proponent's perspective as well as the perspectives of the government and local residents. Mr. Shrimpton reserved his remarks for the second segment of the session.

Dr. Claudia Rogers is an anthropologist with Minerals Management Service in the Gulf of Mexico office charged with social and economic impact assessments. She and her colleague, Dr. Harry Luton, also an anthropologist, develop and monitor social science research.

FINDINGS OF THE GULF OF MEXICO BASELINE AND COMMUNITY STUDY

Ms. Barbara Wallace
TechLaw, Inc., Bethesda, MD

In 1996, a team of economists, anthropologists, and a social historian embarked on a three-year study to increase the understanding of Outer Continental Shelf (OCS) development impacts on Gulf of Mexico (GOM) communities through the use of a regional trends analysis using secondary data sources and examination of specific issues using field work in selected communities. The context of the impacts in terms of the social history of the region was also to be explored. The study also set out to use different methodological approaches to examine the economic and social impacts to identify strengths and weaknesses of the approaches in answering some of the study questions.

The first year of the study was spent selecting the geographic units of study, including the field work communities, identifying and selecting issues on which to focus the field work, and selecting the variables for the regional trends analysis. The second year was spent actually undertaking the research. Now that the research has been completed, we are in the process of completing the analytical work for the study's report and the synthesis of the project pieces.

OVERVIEW OF THE APPROACH

Issue Selection

The issues on which the study focused were selected in a three-step process in which key issues were identified in a literature review, and screened or filtered through pre-established issue selection criteria, and then confirmed at a team meeting with MMS and the study's Scientific Review Board (SRB). Four issues emerged from the issue selection process as areas for further research:

- Demographic and economic change along the coast
- Community histories
- Labor processes
- Education

Community Selection

The study areas were selected in a three-step process. First, a cluster analysis was used to identify groups of similar counties/parishes based on variables from the *Socioeconomic Baseline Study of the Gulf of Mexico* prepared for MMS by Louisiana State University. Eventually, the cluster analysis identified eight groupings of counties/parishes from Florida to Texas. Then, expert opinion from MMS, the research team, and the SRB was used to select five study counties/parishes from four of the clusters. The five counties/parishes became the focus of the regional trends analysis. The field work was conducted in six communities within these counties/parishes. The communities were selected following scoping trips and using expert opinion from MMS, the research team, and the SRB. The study areas and related counties/parishes and communities are shown in Table 1J.1

Table 1J.1. Study areas and related counties/parishes and communities.

Mobile Bay Study Area	**South Louisiana Study Area**	**Coastal Bend Texas Study Area**
• Baldwin County, AL Gulf Shores • Mobile County, AL Theodore	• Lafourche Parish, LA Schriever • Terrebonne Parish, LA Galliano	• San Patricio County, TX Ingleside Mathis

Regional trends variables. The regional trends analysis focused on 55 variables selected after a review of socioeconomic impact studies, consideration of data accessibility and project resources, and consultation with MMS and the SRB. The variables are grouped as population, economic, public finance, and social.

EMERGING FINDINGS

Two recurring themes from the regional trends analysis and the field work are highlighted below as examples of high-level emerging findings.

Impacts from offshore oil and gas vary widely among the study area states, counties, and communities. In terms of production, Louisiana and Texas exhibit substantial levels of OCS-based extraction activities; the other study area states (Florida, Alabama, and Mississippi) do not. Louisiana is the largest OCS oil and gas producer in the Gulf, but Texas is a bigger overall oil and gas producer. Examination of the selected economic, population, and social variables show a similar pattern— the variables track somewhat with offshore oil and gas activities particularly in Louisiana and Texas, but not in Florida, Alabama, and Mississippi. Of the study area states, counties, and communities, offshore oil and gas is only important to the economies of Louisiana and Lafourche and Terrebonne Parishes, and to a lesser degree for Texas and San Patricio County.

In terms of histories of the communities, there is variation in the factors that shaped them. While oil and gas has been a part of the communities, it has not always been highly visible. One study community where oil has had an important role is south Lafourche Parish where the story is one of oil and fish. Throughout the historical progression of oil development from land to marsh to bay to the outer continental shelf, local Cajuns have sought ways to articulate with and buffer against, the industry. When the industry was booming, they put their generations-long knowledge of boats, bayous, and open water into service for the oil industry. During the downturns, they could resume traditional pursuits in the fisheries. In contrast, the other study communities were shaped largely by non oil-related factors — for example, the location of a munitions dump in south Mobile, Alabama; changes in agriculture in Mathis, Texas; the demise of sugar plantations in Schriever, Louisiana; and leisure and servicing the leisure class in Gulf Shore, Alabama. There is actually an absence of substantial historical, social, and economic impacts from OCS development in many of the areas we examined, which reenforces findings of earlier studies that the oil and gas impacts vary among areas.

The effects of national policies and international geopolitics can be seen at the local level. GOM oil and gas activities operate within the world context of energy production (the big picture) and within the regional context (the little picture). The big picture often drives the little picture. For example, GOM OCS crude and condensate prices track world oil prices and events affecting supplies and prices. During the industry's early good times, outsiders came to fill available jobs. When oil prices fell in the mid 1980s and there was a downturn in the industry in the Gulf, some GOM workers left the south Louisiana area to follow oil jobs in Mexico, the North Sea, and Nigeria, some who had migrated to the area because of available jobs left, and others returned to traditional pursuits in fisheries or patched together whatever jobs they could. In the recovery period in the mid-1990s, there was some resistance to returning to the oil industry by those who had lived through the good times and the downturn.

Local effects of national policies and international geopolitics can be seen in non-oil and gas activities as well. World War II brought huge sums of federal dollars and many military bases to the Gulf Coast states. The effects of these policies can be seen in a number of ways in this study: the fluctuating military population, particularly in San Patricio County; the use of tax-free industrial bonds to attract industry to a closed military base in Mobile, Alabama; use of German prisoners of war as field hands in the sugar fields to overcome war-induced labor shortages; the building of homeports and the designation of the Naval Station-Ingleside as the Mine Warfare Capitol of the World; and the impacts of the Servicemen's Readjustment Act (i.e., the G.I. Bill) on education and work.

IMPLICATIONS OF EMERGING FINDINGS FOR MMS

The initial findings may have implications for MMS in terms of

- Resource allocation for further study of OCS social and economic impacts
- Focusing future work on the most promising variables
- Using insights gathered from field work to interpret some of the county-level economic and social impacts
- Understanding the contexts in which the oil and gas industry operate and the types and interrelationships of impacts experienced
- Recognizing that there is more to the GOM than the offshore oil industry

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Barbara Wallace is a Project Director at TechLaw, Inc. (Bethesda, MD) and head of TechLaw's marine economics practice. She has undertaken studies of OCS-related social and economic impacts since 1984 and has completed studies for MMS in all of the OCS planning areas. Ms. Wallace holds graduate degrees in urban planning and international development and an undergraduate degree in sociology.

HELICOPTER TRANSPORTATION IN THE GULF OF MEXICO

Mr. Neill Osborne
Air Logistics

This paper describes the nature of helicopter transportation in the Gulf of Mexico as it relates to the changing service industry. To effectively discuss the helicopter service business in support of offshore oil and gas exploration and production it is important to provide a brief history of our industry.

In 1946, a young man named Peter Wright departed the New Jersey offices of Helicopter Air Transport to sell helicopter service to Oil Companies. Helicopter Air Transport was the first commercial helicopter operator in the United States. Mr. Wright was able to convince Standard Oil of California to try the helicopter. Through a geophysical contractor, the Robert H. Ray company of Houston, Helicopter Air Transport was able to demonstrate to many in the seismic survey business the capabilities of this aircraft. Mr. Wright and crew loaded a new Bell Helicopter 47B into a moving van and drove it to Houma, Louisiana. Houma must have seemed to be the end of the earth to the crew from New Jersey. The inhospitable marshes of South Louisiana proved to be indicative of the demanding physical locations that would justify the cost of using a helicopter.

Because of its unique capabilities, the helicopter piqued the interest of seismic surveyors. Seismic survey and oil company personnel from around the world traveled to south Louisiana to look at this new machine. This first mission trial in the marshes south of Houma was plagued with breakdowns but when the aircraft was operational, it did much more work than the marsh buggy could do. In those days the marsh buggies had big wheels that played havoc with the active fur trapping business. The helicopter was much more acceptable to the trappers than ground vehicles that demolished the marsh that provided their livelihood.

Although the helicopter demonstration in 1946 was a technical success, it was a professional failure because Helicopter Air Transport soon went bankrupt. But the concept of using a helicopter to support oil exploration had been originated and would be reintroduced when Bell Helicopter set up its own business to provide helicopter service for the seismic efforts of South Louisiana.

The early days of helicopter support was a difficult learning period for our industry's entrepreneurs but also a very exciting time. The Bell 47 continued to be the aircraft of choice for seismic work as it had the right combination of payload and cost.

When asked to make the short flight from the marshland to offshore, the helicopter was up to the task. The aircraft special equipment consisted only of a "wet compass" for navigation and rubber float pontoon landing gear for occasional water landings—either planned or unplanned. Frequently during periods of reduced visibility and low clouds the pilot would head for the drilling rig using the pilotage technique of time, distance and heading to find nothing but gulf water where there should have been a rig tender vessel or drilling structure. Even though there were many challenges, the reciprocating engine powered helicopter, traveling at 60-70 mph provided good service for those early offshore drillers and producers. The Bell 47 continued to be the helicopter of choice until light turbine engines were developed and became available to aircraft manufacturers. The total helicopter fleet supporting the Gulf of Mexico offshore drilling and production operations grew to almost 100 of these sturdy, small Bell aircraft by the early to mid 1960s. The French company, Aerospatiale, introduced one of the first turbine powered helicopters used in the gulf—the Alloette. This aircraft, with its new generation engine was noisy but had the advantage of flying at 90 mph—a major improvement in speed. It also offered a significant increase in payload, providing four passenger seats instead of the two and three passengers the 47 could transport. It was, however, expensive to maintain and operators found support for the aircraft less than acceptable as response time for replacement parts and technical support from Europe was excessive. Because of its expense and these support problems, the aircraft never became popular with Gulf users.

The helicopter industry as a whole was the benefactor of technology improvements developed for our military in support of the Vietnam war. The Bell Huey became a mainstay for troop transport and close-in helicopter gunship support in Vietnam. Very soon after the aircraft was developed for the military it was offered to commercial users where it found wide acceptance in the Gulf of Mexico.

The civilian Bell 204, as it was named, would carry seven passengers and was ideally suited to provide the transport type service which was required to support drilling rigs and production field personnel crew change activity as offshore exploration and production continued to increase and gradually move farther offshore. Only a few short years after the development of the 204, Bell upgraded this aircraft to the Bell 205 with much better payload and passenger seating—up to 13 seats and, depending on the distance of the flight, up to 2700 pounds of payload. This product improvement was again primarily developed for the U.S. Military with the civilian market being only an afterthought. But the Bell 205 was introduced to the Gulf Coast market in the mid-1960s. This was excellent timing for Bell as offshore crews were increasing in size and the need for the additional payload and speed was paramount to offshore users.

Another major military requirement developed for our country's Vietnam efforts played a significant part in improving helicopter transportation not only for Gulf Coast users, but also for all helicopter users throughout the world. The Army needed to improve the capabilities of the aircraft flying observation missions. Bids were solicited from several helicopter companies. Each new design in the competition would be powered by the recently developed small, yet powerful gas turbine engine capable of over 300 horsepower while weighing only 150 pounds—a truly remarkable improvement of the power vs. weight ratio, which is crucial to helicopter manufacturers and users. Hughes Helicopters won the initial military contract and built thousands of the OH-6, Cayuse helicopters for the Army and thousands more of the civilian variant Hughes 500 line for commercial and private use. Although Bell and Hiller lost the military bid, both companies elected to produce a civilian version of its product. Hiller's 1200 Series helicopter achieved limited success. However, the Bell 206 series of helicopters have become the most popular light helicopters ever produced.

By the early 1970s the Gulf Coast helicopter fleet totaled almost 130 aircraft and consisted of Bell 47's, 204's, 205's, 206's, Hughes 500's, Aerospatiale's Allouettes and the Sikorsky S-55 which was powered by a radial designed, reciprocating engine. The 55 was a sturdy aircraft which carried six to seven personnel at approximately 100 mph. The 55 provided many years of service to Gulf Coast users beginning in the 50s, but never experienced wide acceptance as a transport aircraft due to its speed and lower payload.

The early 1970s continued to see rapid growth in offshore exploration and production with corresponding growth in helicopter demand. The German aircraft manufacturing company, MBB, developed a 5-place twin engine helicopter using two lightweight Allison gas turbine engines. Several oil companies accepted the additional operating costs of the aircraft for their offshore flights because of the second engine and the BO-105 is still in service today. Bell Helicopters also developed a twin engine variant of the 205 naming it the Bell 212.

Another significant development of the mid-1970s was the introduction of IFR or instrument flight rule flying to the Gulf of Mexico. With the advent of IFR capable aircraft such as the Bell 212 and the infrastructure and procedures in place to allow IFR flight, helicopter operators could offer to the oil companies near all weather flight capability. With the frequent low ceilings and reduced visibility conditions of the Gulf Coast the ability to fly IFR greatly increased the utilization of transport sized aircraft.

Growth in offshore activity continued during the 1970s and the Gulf Coast helicopter fleet reached 500 aircraft by late 1979. This growth continued into the 1980s until by 1983 over 600 helicopters were engaged in offshore Gulf of Mexico flight activity. Thirty-three helicopter operators conducted business from approximately 20 offshore support hubs from Corpus Christi, Texas to Mobile, Alabama. But then, as now, the most productive finds and the bulk of offshore development and helicopter requirement remain in the central gulf areas.

Several new helicopter types were introduced during this growth period including the Aerospatiale AS-350 Astar, a six-place single engine machine and the AS-355 Twinstar a twin engine variant of the same design. Additionally, the Aerospatiale 330J Puma found a niche in the Gulf market. This machine was capable of carrying 18 passengers at 120 kts airspeed but, of course, the cost for these capabilities was considerable. Bell Helicopters introduced the 214SuperTransport to compete with the Puma and other large helicopters. The 214ST also carried 18 passengers at 125 kts and boasted a range of over 400 miles allowing it to frequently make flights to distant offshore locations without the need to refuel. Bell also introduced a medium-size twin, the 222 which found limited acceptance due to its mid sized design. Bell also re-engineered its successful twin engine 212 with a new rotor system and increased its available horsepower, naming the new machine the 412—it could fly faster and carry more payload than the 212. Sikorsky introduced a sleek new aircraft, the S-76A, which could carry 12 passengers at 150 mph. The S-76A was well received by the Gulf market and also the corporate and air-medical markets.

It seemed to all in the offshore helicopter support business that paradise had been found. There was plenty of work for helicopter operators and new, better, bigger and faster designs were on the horizon for our use. But then, the bottom fell out.

During the bust years starting in the mid-1980s the competition for a shrinking market forced many of the 33-helicopter service companies to sell out to their competition or to close their doors. By 1990 only a hand full of operators remained. The big three helicopter operators in the Gulf that did survive were PHI, ERA and Air Logistics. Oil companies that operated their own fleet of offshore helicopters were also affected by the slowdown and were forced to compete with operators for helicopter service work to offset the expense of their helicopter flight departments. Pricing was predatory and frequently below cost in the mistaken belief that if the customer could be retained, even at a loss, future pricing could offset these loses. These pricing schemes led only to disaster.

The fleet of helicopters utilized by the Gulf of Mexico Oil and Gas Exploration and Production Companies dropped drastically during this time period from 600 machines to less that 350. By the time of Desert Storm in 1991, the helicopter service business had neared completion of the purge caused by the severe downturn in the GOM market. In 1992 and 1993 business remained relatively flat but then the combination of improvements in seismic technology, tax relief, improving oil prices and increasing demand for oil and gas created new interest and activity offshore. By the mid-90s, to support this surge in our market, new and used helicopters were once again acquired by the larger operators to support the renewed demand plus new operators also entered the once prohibitive offshore market. Today, over 25 companies operate helicopters in the Gulf of Mexico.

Aircraft upgrades have continued over the past several years. Sikorsky has improved the S-76 by offering more powerful engines and improving other features of that aircraft. The S-76C model offers better payload, range and single engine performance than the original S-76A. Eurocopter has continually upgraded the Puma series of aircraft so that the recently introduced Super Puma Mark II can carry 20 passengers with a range of 460 NM. This aircraft could see service in the Gulf in support of deep-water activity.

Helicopter manufacturers were encouraged by the upturn in our market as well as demand for helicopters in other markets such as military, logging, air-medical, corporate support and search and rescue. Manufacturers initiated the design process for some new helicopters and accelerated those already on the drawing boards.

In 1997, offshore helicopter activity rivaled that of the early 80s. Gulf of Mexico activity supported utilization of 380 single engine helicopters, 114 light twin engine aircraft, 131 medium twin and 11 heavy twin engine helicopters for a total of 636 helicopters in service on the Gulf Coast. A remarkable 3,759,642 passengers were transported during 471,513 flight hours and 1,705,629 flights.

To support this level of flight activity, each operator must have heliport bases near the oil company's shore base facility. Aircraft receive nightly, routine maintenance at these bases. The base frequently serves as the departure and arrival heliport for the crews working offshore as well as the operational base with quarters for the pilots & maintenance technicians during their time at work. Each of the large three operators have heliports similar to this Patterson facility near the shore base locations utilized by Gulf Coast oil companies. Over sixty-heliport support bases are currently in operation on the Gulf of Mexico Coastline.

Additionally, each operator must be able to provide fuel to their helicopters offshore with strategically located refueling stations, typically, a two-thousand gallon fuel tank plus all required filtration and pumping equipment. There are currently over 250 refueling points in service in the Gulf of Mexico.

To provide maximum aircraft availability to production efforts, many Gulf Coast users require helicopters to remain offshore each night. These aircraft must have nightly maintenance inspections and frequently be rotated back to the helicopter operators support base for more extensive maintenance or component replacement. Over 60 aircraft remain offshore each night in support of production efforts.

Flight following is a responsibility that the operator must address. Each aircraft must be in contact with company flight following facility at all times. Frequent updates of the aircraft's location, destination and other pertinent information is a must to ensure rapid response in the event of an emergency. Currently, the most accepted method of maintaining this contact with each aircraft is for the operator to locate offshore radio sites on platforms or drill rigs which are then remoted back to the shore by microwave phone lines. To provide seamless radio coverage, the offshore radio sites must be within 75 miles of other company radio sites enabling the pilot to constantly be in communications with his flight following base. At the present time, over 100 remote radios keep the 600 Gulf Coast helicopters in contact with their flight followers.

Accident data for 1997 reveals a total of six aircraft accidents for the year. An accident is defined by the National Transportation Board as any event that occurs while the aircraft is in operation that causes substantial damage to the aircraft or serious injury or death to an occupant. Of the six accidents, there was one crew member fatality resulting from a mid-air collision and there was one engine-related accident. A normal industry measurement for comparison of accidents is to develop a rate per 100,000 flight hours. The 1997 Gulf of Mexico helicopter accident rate per 100,000 hours was 1.27. This rate compares favorably to those rates experienced by other air transportation businesses. For example, the accident rate per 100,000 hours for all commercial helicopter operations in the US was 3.33 per 100,000 flight hours.

Most airlines utilize accidents per 100,000 departures as a comparative measure. The U.S. scheduled airline accident rate for 100,000 departures was 0.44 while the GOM helicopter rate per 100,000 departures was 0.35. Clearly, Gulf of Mexico helicopter operators provided a commendable level of safety for their passengers in 1997.

To forecast what the future of helicopter utilization and service may look like for the Gulf of Mexico I must preface my predictions with a qualifier. Assuming favorable conditions, which include an economic structure that allows helicopter operators the income to modernize their helicopter fleet and services, the following possible changes may become reality.

Today's flight following system may be replaced with a GPS based, satellite transmitted two way tracking and communication system. Studies are already underway that may pave the way for this system. Numerous aircraft are currently being tracked through use of satellite communication of data from the aircraft to a base station. Exact GPS position reports are transmitted each 30 seconds allowing the operator and the oil company to know at any given time the location and status of the aircraft. Each aircraft will most probably be equipped with a TCAS or Traffic Collision Avoidance System. This onboard warning system will detect other aircraft that could be close enough to cause a mid-air collision and alert the pilot to the hazard.

As deep-water exploration increases in the more distant portions of the Gulf, larger aircraft capable of higher speeds will be required to support oil and gas efforts. Flight activity will more closely resemble helicopter activity in the North Sea where long distance flights have been the norm for many years. Larger platforms with accompanying increased personnel on these platforms will also drive the need for larger aircraft.

Completely new designs which are planned for completion and introduction between the present and the year 2000 that may be found in service to Gulf users include Sikorsky's S-92, Eurocopter's EC-155 and Bell Helicopter's 609 Tilt-Rotor. Both of these designs represent state of the art manufacturing techniques and business partnering.

The S-92 will carry the Sikorsky nameplate, but in actuality, this aircraft manufacturing process is a collaborative team effort. The aircraft is to be constructed in modules by aircraft manufacturing companies throughout the world. Companies in Taiwan, Brazil, Spain, China and Japan as well as Sikorsky in the U.S. will build various major components of the S-92 which will then be completed by Sikorsky for the customer's specific mission. This aircraft will seat 19 offshore workers with a range of 410 N.M. With auxiliary fuel tanks the aircraft will have a 700-mile range with a reduction of payload. Like the Super Puma Mark II, this aircraft could see service in support of deep- water activity.

Under new aircraft certification rules, all aircraft must meet even more stringent design safety requirements than in the past. Major dynamic components such as the main rotor hub and yoke must be designed with redundant load paths. Aircraft performance for transport aircraft such as the S-92 must assure single engine flight capability in all phases of flight to include the power intensive take-off and landing segments.

Recently designed and now in production is the Europcopter, EC-135. This aircraft features the newer fenestron for directional control which enhances safety by replacing the conventional tailrotor. Eurocopter is also finalizing plans for a new medium, transport sized aircraft which should be in production by the year 2000. This aircraft will cruise at close to 170 mph while transporting 12 passengers up to 250 miles offshore without the need for refueling stops. The aircraft will be equipped with state of the art avionics and navigation systems as well as an onboard Health and Usage Monitoring System which continuously reports on the status of critical aircraft dynamic systems and support systems. The 155 will also meet the new demanding performance standard that will allow continued flight in any phase of flight with one engine inoperative. Redundant main gearbox lubrication systems and a fail safe main rotor hub will also enhance the safety of this new helicopter.

Another totally new design for vertical flight is the Bell Helicopter Tiltrotor aircraft. The concept for this aircraft has existed for many years but development efforts stalled due to the cost to prove the concept. Once again, our industry benefited from the design of an aircraft for the U.S. military. Through efforts of the US Armed Forces Commanders, funds were allocated several years ago for the development of an aircraft that could carry 20 or more combat troops into confined landing zones but cruise to the LZ at much greater than traditional helicopter airspeeds. Bell Helicopter and the Boeing Aircraft Company created a joint venture to develop such an aircraft. The Bell Boeing V-22 Osprey is now being produced for the US Military. This twin engine tiltrotor aircraft will take off vertically, transition the rotors from vertical flight positioning to forward flight which will enable the aircraft to fly at speeds approaching 300 kts and then reconfigure to the vertical landing or helicopter mode of flight for arrival. With the production of the Osprey well under way, Bell announced two years ago the plan to build a smaller version of the aircraft for civilian use. The Bell 609 Tiltrotor is designed to carry nine passengers and will transport offshore workers from Gulf Coast heliports to locations some 200 N.M. offshore in less than an hour while achieving speeds exceeding 270 kts.

All of these new designs will come with much higher price tags than the existing Gulf of Mexico fleet of aircraft. This increased cost may well motivate oil companies to partner with other oil companies and even helicopter operators to minimize their expense. Although some sharing of helicopter assets has occurred over the last few years, it will be even more financially attractive to Gulf Coast users in the future to develop cost sharing partners.

It can also be expected that alternative schedules for offshore personnel will be utilized to help offset the increased cost of transportation for these workers to and from their offshore work site. By transitioning from the more traditional seven-days-on and seven-days-off work schedule to a fourteen-on and fourteen-off or a similar longer stay schedule, gulf users may significantly curb the added expense of helicopter transportation.

As in life, the one constant in our industry is change. By the year 2000 we will have witnessed helicopters and its uses mature along with the offshore, Gulf of Mexico exploration and production efforts, from the pioneers like Igor Sikorsky and his first operational vertical flight aircraft to technology that will produce a 300 mile per hour, all weather capable, satellite linked, state of the art flying conference room.

Today, business for helicopter operators in the Gulf is good. The safety record of the companies who operate helicopters in the Gulf of Mexico continues to be outstanding. New technologies that support our business and new innovations in design will enable us to carry more passengers, fly farther and fly faster. As long as the demand remains as it is today and as long as those who fly helicopters in the Gulf and the companies who support those efforts continue as they do today—the future of helicopter transportation in the Gulf will be stable, dependable, safe and "Flying to a high standard."

Mr. Osborne holds an Airline Transport Pilot license and has flown and managed helicopter operations in support of Gulf of Mexico exploration, production and product transmission for twenty-seven years. He currently serves as Vice President of Aviation for Air Logistics. He is immediate past Chairman of the Helicopter Association International, which he still serves as Director. Mr. Osborne also is Vice Chairman of the International Federation of Helicopter Associations. Mr. Osborne attended The University of Texas at El Paso and has studied business management at Penn State University.

DOWNSIZING THE OPERATION INSTEAD OF THE COMPANY

Mr. J.L. Rike,
Rike Service, Inc.

Regulators work under competing and often mutually contradictory constraints. Their political basis prescribes a win-win: to increase domestic production, government revenues, company profit sheets, local participation, and safety; and to decrease foreign imports, cheating, monopoly power, pollution, and impairment to ancillary uses of the same environment. Given these constraints, it is a miracle that the regulators manage at all, and even more so if they can minimize their intrusiveness and maximize their fairness. Although no regulated industry is enraptured with its regulators, everyone in the oil industry who has worked internationally knows horror stories of how bad it can be, and generally gives high marks to MMS.

The most unfortunate aspect of regulations is their tendency to become a self-fulfilling prophecy. They start from a given historical situation and tweak it and channel it to meet the political objectives. In the process, the previously accepted norm, with the required alternatives, becomes set in concrete—the regulations make it difficult to radically change the way we operate.

Accepted practices taken from history are no longer adequate to meet current and expected conditions, and future optimal practices must differ considerably from the past. Achieving those optimal practices, however, will require cooperation from the regulatory community.

PRESENT PRACTICE

Offshore, drilling is dominated by big rigs, whether on platforms, drill ships, or semi-submersibles. The platforms are big as well, to accommodate the big drilling rigs. Constraints of the past have forced this trend: a high risk of failure to find reserves forced attention on large reservoirs, which require large platforms, which require large up-front investments, which also require large reservoirs. We are trapped in a vicious circle. There is nothing wrong with large reservoirs; they are quite profitable. The problem with the vicious circle is that it usually excludes consideration of small-to-medium reservoirs.

Within this scenario, only large derrick-type rigs could do the job. Using trebles instead of singles cuts tripping time in half, and trip time dominates the time-to-TD equation for deeper wells. Large reservoirs require large tubulars, which means large hook loads, and only derrick-type rigs can handle them. And a large rig requires a large platform.

Subsea drilling is one part of the solution because it gets rid of some of the structures. Submerged production systems alleviate that when they are truly well-to-pipeline systems, but these are extremely expensive. The risk of capsizing on the drill-ship means using singles instead of trebles, and slowing down drilling, which raises the expense. The semi-submersible solves that problem, but it has higher cost still. And the recent developments in the deepwater environment have run up the per-diem prices even higher than they were in the 80s. So, at least as currently practiced, only the largest reservoirs can justify subsea operations.

Branching into new horizons, such as deepwater or Arctic environments, helps boost domestic production, but they require very costly new technologies and a long time to learn to make them affordable, so only large reservoirs can justify these new areas.

Realistically, we need to ask, how many "North Slopes" are left out there? The U.S. consumes about a North Slope every year. How much oil is readily available in smaller reservoirs left untouched by strategies that can focus on large reservoirs alone? How many cuttings on the ocean floor are justified to reduce long payout, since big rig-and-platform systems require tremendous up-front investments? And how much longer can we expect a population that is getting "greener" in outlook by the day to leave those exemptions in place?

A CHANGED PICTURE

Technology advanced, industry evolved, and public opinion changed markedly since the current strategy became the norm.

First and foremost, 3D seismic has had tremendous impact on drilling risk: the risk that you've missed the high point on the structure, the risk that there is no true "trap" at all, and the risk that you will meet big, nasty surprises. The surprises are still there, and always will be, but they have to be much smaller now to escape detection.

EPA regulations have changed the way drilling cuttings are handled on land. With the reclassification of these wastes as hazardous, the cost of disposal increased vastly—we can no longer just fill a pit and cover it over at the end of the job. Two strategies have evolved to help face this challenge.

Slim hole drilling is one response. Volume is proportional to diameter squared, so drilling smaller holes greatly reduces the volume of cuttings. At the same time, it reduces mud inventory and its disposal cost, and the smaller tubulars reduce hook loads. It was the first solution attempted precisely because it is old wine in a new bottle: almost all the ancillary technology needed for completion and production had already been developed thirty years ago.

The other response is to view cuttings as temporary residents at the surface. The cuttings are ground up, made into a slurry, and injected just below the previous casing seat. Discarded mud is handled as part of that slurry, doubling the value of the idea. At present, this can only be done on land because of regulations on cement jobs offshore. There are always some cuttings left uninjected at the end, so some cuttings still require disposal, but the total has been reduced by a factor of three to five.

Workover costs offshore spurred the development of non-derrick rigs. The hydraulic rig, or snubbing unit, was originally a piece of fallback safety equipment when a drilling rig took a big kick with limited casing in the hole, but then it became associated with concentric workovers. Its ability to work under pressure made it much easier and safer to use clean workover fluids, which in turn led to higher productivity. Currently, hydraulic rigs can handle 9 5/8" pipe and hook loads up to ¾ million lbs., and these numbers increase yearly. Boat, barge, and jack-up mounted units are also readily available. Some operators have used them for deepening work for years, despite the fact that they employ singles rather than trebles.

A related development is the coiled tubing unit, originally envisioned as a "hollow wireline." Economic constraints on the North Slope created an economic incentive to use large OD coils. The conversion of the progressive cavity pump into a hydraulic motor coupled with the easier bending of thin-walled pipe was the foundation for short-radius horizontal drilling—no other technology could turn a corner that sharply. One rig has been constructed with the coil immediately above the injector, so that the entire coil can be rotated slowly, thereby maintaining dynamic friction between coiled tubing and the hole, rather than static friction. The objective is to be able to drill longer horizontal sections before lock-up. Cost per-foot for drilling with coiled tubing has dropped sharply as the industry has accumulated experience.

There is no reason why the hole drilled with coiled tubing has to be horizontal. Since the pipe is continuous, there are no connections to slow trips, so its slower drilling rate is partially compensated by its faster trip time on deeper holes. Currently, coiled tubing is available up to 6 5/8"OD. There are boat and barge mounted units, but that's presently the support equipment for the reel, not the injector assembly; with no ability to create a riser, it is not used as a subsea rig. However, smaller diameter pipe will bend readily enough to run over a subsea flowline loop, so it can be used from the central production platform in subsea wells equipped for TFL intervention.

On the North Slope, BP already uses these two rig types together to reuse exhausted boreholes: a modified snubbing unit runs all casing strings and a coiled-tubing unit drills short-radius horizontal drain holes.

Other properties of these rigs, or of industry itself, work to their advantage. Regulation, lawsuits, and insurance all push for lowering risk, and the snubbing unit is inherently safer technology than the conventional rig—it was originally devised to get the conventional rig out of trouble. Coiled tubing and snubbing rigs use much smaller crews, so manpower and support costs are much lower. And both rigs are designed to work under pressure, so drilling can proceed while underbalanced, whether that is planned or unplanned, leading to faster drilling rates. Here again, the regulations as presently formulated do not allow us to capture this advantage at present offshore, but it is becoming common in land drilling (e.g., air drilling) and on offshore workover operations where MMS has given permission.

The soft price of oil, cheaper in constant dollars than before the first OPEC price shock, means that cheaper development methods are necessary for sheer survival, not just profit maintenance. These small rigs have low mobilization costs, so there is little need to hold them when they are not in use. We pay for them only when we use them, and scheduling is very flexible. Two and sometimes three can be in operation at one time on the same platform, and these can share their auxiliary equipment, further reducing costs. If used routinely for drilling, the order of slot usage can be optimized to exploit this, getting the platform to full production much sooner than a conventional rig could. Since the per-diem costs are much lower, total drilling costs are lower in spite of the extra time to TD on each well.

Finally, the structure of the industry has changed. Partnerships and alliances have converted many companies, at the far upstream end, into project-packaging outfits and financial conduits, so those companies are mostly property portfolio-oriented. Their technological domination of the industry is now mostly concentrated at the downstream end, on production, refining, and marketing, and on mega-projects such as the recent deepwater development. This pushes the upstream risks onto contractors, but provides for higher profits. Hence, research is more and more dominated by the service companies and contractors, so new technological developments are rapidly shared.

PRESENT OFFSHORE STRATEGY

Part of these developments have been incorporated into our offshore routine. New areas and many old ones are explored using 3D seismic methods. Some prospects get discarded, but exploratory wells are drilled on the medium to mega-prospects to prove fluid content and feet of pay. Since these are throwaway wells, they are already slim-hole, because it is cheaper and faster. They are made with derrick type rigs because coring has not yet been adapted to the other rig types, and because the wells require larger safety factors than needed for development wells.

These new proven reservoirs come in many sizes. The large and mega-reservoirs are consistent with present methods that produced the vicious circle, and we are at home with it. The medium-sized reservoirs are put off until oil prices go up. The small reservoirs are dismissed as uneconomic.

Why do we still stay in the vicious circle, with its big rigs and big structures? Part of the reason is "that's the way we've always done it." Part of the reason is that regulations favor it at present.

THE DOWNSIZING VISION

For small-to-medium development drilling anywhere, consider the following vision. The basic equipment includes a pile driver (sometimes), a large snubbing unit, a large coiled tubing unit, slurrification and injection equipment, small tankage and inventory, a small crew, and commensurate crew support facilities. All drilling is done slim-hole with cuttings reinjection.

First, where soil conditions permit, a pile driver sets drive casing. Otherwise, a large snubbing unit spuds the hole and sets the conductor. The rig then drills and sets surface casing, and possibly the first intermediate casing. Then the coiled tubing unit drills the lower part of the hole, where trip time becomes a bigger part of the time-to-depth equation. The snubbing unit sets all casing strings. Indeed, with a snubbing unit already over the hole, drill collars can be added for vertical drilling, solving certain present coiled-tubing drilling problems. The final part of the hole is drilled vertically or horizontally, as desired. The final completion can be done by either unit as desired, since some operators will use coiled tubing as the production tubing.

Nothing in this scenario is incompatible with the offshore environment. Smaller platforms become possible, since the rig system is small. Multiple wells can be drilled simultaneously, reducing even more the payout time needed for the smaller platform. The cuttings storage systems for slurrification will likely be on a barge or boat, so the excess not normally injected can be moved to another well in progress; and with multiple wells being drilled simultaneously, even this is not a strict necessity. So there are no hazardous wastes at the end of the job requiring disposal on land or at sea, and no special purpose disposal wells need be provided.

Nothing in this vision is incompatible with a drillship, albeit one on a much smaller scale than any seen to date. Without a derrick, the camber (maximum survivable roll of the ship) problem disappears, so operations can continue in a wider range of sea states, and the per-diem cost will surely be much lower. An additional bit of technology might be required if the hydraulic rig cannot handle the riser diameter, but a mast could be raised for this operation. Risers are already handled in singles, not trebles, so a fifty-foot mast-type derrick (as used on truck-mounted drilling rigs) would be sufficient, and sea state limitations would only occur during riser assembly or disassembly.

PROBABLE EVOLUTION

Land drilling in the U.S. is dominated by many small and a few medium-sized reservoirs, because 139 years of exploration have reduced the stock of mega and large reservoirs (except in Arctic environments) and seriously depleted the stock of medium-sized reservoirs. They also face more stringent EPA regulations with respect to cuttings disposal. Land operators had to find cheaper ways to exploit new fields, or fold. So all the technologies mentioned above are already in use, to one extent or another, and cost per-foot has been dropping as each has become more common. All that is missing is to put it all together as a coherent strategy.

It has been slow in coming because the per-diem cost of conventional land rigs is not so very different from the smaller rigs, so the savings envisioned are far smaller than what can be achieved in water locations. Water locations also provide mobility so that the low volumes of cuttings remaining at the end can be transformed into zero volumes, by barging the leftovers to an active reinjection site. As water locations begin to use these methods, the lower cost of becoming a player will change the mix of operators there, shifting the balance toward more small-scale, local participation.

Inland water locations will be first, partly because the roster of land and inland water operators are very similar—they will be less afraid of the new paradigm—and partly because EPA regulations are the same, so operators feel the same regulatory pressures. As development drilling shifts to smaller rig types, fewer inland waterways will need to be straightened or widened, and the ease of directional drilling with steerable downhole motors on coiled tubing means fewer will need to be cut in the first place. The benefit to Louisiana, besides revenue, will be less saltwater intrusion from the Gulf, less coastal erosion, and more economic productivity from other sectors, such as fishing and tourism.

The state waters in the continental shelf have the same regulators as the nearby land, so this technology will transfer there rapidly once established in inland waters. The savings will be greater, however, because new structures can be downsized as well. The lower up-front investment will translate into a wider range of reservoir sizes exploited.

Assume for a moment that OCS regulations evolved to be consistent with this technology. The first OCS-area operations of this type will surely be in heavily played or exhausted areas, because OCS areas face an additional financial hurdle, pipeline cost, which tends to force the step-out areas to stay in the "vicious circle." But otherwise it will follow the state waters pattern. As water depth increases, the reduction in platform cost becomes more and more dramatic, however, and the widening of reservoir sizes exploited will be even more dramatic.

Areas of the OCS more suited to subsea production face an additional delay, the development of the mini-drillship discussed earlier. So the methods will have to become quite common in the platform areas before the drilling companies will be willing to take the risk involved in new ship designs, particularly if the price of oil stays soft. But the only technological hurdle is the riser-handling system, either a "large-jaws" hydraulic rig or a small mast-type derrick. So the major risk is that the first mini-drillships will be underutilized, which will result in a delay, and not a barrier to entry. The mini-drillship will likely be three to seven times cheaper to construct than a conventional drill ship, so the delay should not be all that long.

So the technology will move from land to inland waters to near-coastal areas to OCS platform areas to subsea areas, the way oil technology has always moved. But only if we grant the assumption that the regulation from MMS and other agencies evolves to embrace, perhaps even foster these methods. As regulators, you can say, "No," and we pursue other visions. Possibly you feel safety and stability is enhanced when only the largest players can enter the game. Possibly you feel that a few large structures are easier to regulate than many smaller structures. Possibly you feel that enhanced domestic production, by exploiting the small-to-medium reservoirs presently ignored, is not a significant part of your charge. Or maybe you feel that cuttings discharge to the ocean floor is a minor consideration, perhaps because you feel the green tide in public opinion is ebbing rather than growing.

Or you can become excited about the dream, change the regulations overnight (hoping thereby to push us quickly into the vision), and perhaps create as many future problems as you solve.

Or you can study it carefully, identify your concerns—for safety, environment, government revenues, etc.—and tell the industry exactly what we need to show, and exactly what standards of proof you will demand, before the regulations can be changed to embrace this vision. You can become part of the dynamic process that ensures that the strategies and equipment employed provide broad benefits to our nation, and not simply serve the god of cost control.

This vision will make it to the state waters—the industry has been groping toward it for many years. Whether it strays one inch past the three-mile limit depends a great deal on whether MMS is proactive or reactive.

Movement in this direction from a regulatory standpoint is currently visible. New thinking about well control training to focus on objectives rather than specific items to be taught is in the right direction. Other moves by MMS to regulate by performance rather than specification will allow the needed changes to occur faster.

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J.L. Rike is chairman and CEO of Rike Service, Inc, and has spent 49 years in the petroleum industry, including 22 years with Exxon (Humble) followed by 27 years as a worldwide consultant and trainer. He has worked in drilling, production, unitization, reservoir analysis, completion and workover design, development engineering, and training in locations all over the United States, onshore and offshore, Canada, Central and South America, Africa, Middle East, North Sea, Far East, Russia and Eastern Europe. J. L. Rike has played key roles in the development of new completion concepts, directional perforators, sand control, coiled tubing rigs, well control in drilling and workover, concentric tubing workover and completion operations, and advanced offshore completion practices. He also has authored patents and papers on these new developments, as well as cementing, perforating, wireline operations, workover economics, and worldwide industry practices.

COPING WITH UNCERTAINTY AND MINIMIZING REGRET: SHIFTING THE EMPHASIS IN ENVIRONMENTAL ASSESSMENT

Dr. Keith Storey
Mr. Mark Shrimpton
Community Resource Services Ltd.

INTRODUCTION

Change, complexity, uncertainty and conflict play fundamental roles in resource and environmental management. These elements create opportunities as well as problems for analysts, managers and others, but a key challenge is to recognize their importance and determine how to function in their presence. The focus of this paper is that of uncertainty and how it might best be addressed in the context of planning for the social and economic consequences of offshore petroleum activity.

Our understanding of biophysical systems, of human societies, or of the interactions between natural and social systems is at best incomplete and often imperfect. We are aware that conditions and circumstances in the future could well change, yet decisions have to be made because it is not realistic to wait until we develop the level of understanding we would like to have before committing to a given path of action. Given the realities of change, complexity and uncertainty, environmental and resource managers are increasingly looking at approaches which allow for adaptation which accept that we should learn from experiences, both good and bad (Mitchell, 17).

In this regard the thesis of this paper is that the utility of socio-economic impact assessment (SEIA) can be improved by shifting the current emphasis on prediction to focus on (i) minimizing regret by acknowledging the potential for inaccuracy of such predictions; (ii) maximizing flexibility by designing and using appropriate impact management approaches; and (iii) maximizing learning through appropriate monitoring and auditing procedures. This is seen as being particularly important and valuable in respect of the offshore petroleum industry given the high levels of uncertainty that typically characterize its activities.

THE ROLE AND IMPORTANCE OF PREDICTION

In many respects we understand very little about the ways in which social and economic systems work. As a consequence we are generally poor at predicting, with any degree of accuracy, the impacts of major resource development activities on those systems. For this reason the current approach to environmental assessment which emphasizes impact prediction, rather than impact management, may not be in the best interests of those whom the assessment exercise is designed to serve.

The design of mechanisms to manage the social and economic outcomes of projects, programs or policies are as, if not more, important than the predictions themselves. If assessment predictions are erroneous, then actions based upon them are likely to be inappropriate or inadequate. Where outcomes are uncertain, the alternative is to put in place mechanisms that encourage review and revision of predictions and assessment conclusions, and which permit flexibility in the ability to respond to changing conditions. A pragmatic, management-oriented approach towards socio-economic assessment is likely to have greater utility than one which seeks to refine and improve predictive capabilities.

If the primary role of SEIAs is to facilitate decision-making, then impact prediction is a necessary stage in that process, but it should not be considered an end in itself. The traditional focus of assessments on project approval and predictive technique often seems to forget that the essential purpose of impact assessment is to help those likely to be affected to "be prepared," to minimize the possibility of the unexpected occurring and to address the potential consequences of the expected outcomes. Impact prediction may, in fact, play only a minor role in being prepared.

PREDICTION DIFFICULTIES AND MANAGEMENT APPROACHES: HIBERNIA CASE STUDY

The construction of the production platform for the Hibernia offshore oil project on the Grand Banks east of Newfoundland illustrates the difficulties of accurately predicting activity levels and well-designed management approaches can overcome this.

Hibernia, Newfoundland's first commercial offshore oil field, was discovered in 1979. Current estimates put recoverable reserves at 666 million barrels with a planned peak production of 150,000 barrels per day. The field is 315 km east-south-east of St. John's, the provincial capital, in the relatively shallow (80 m) but seasonally ice-infested waters of the Grand Banks. The production platform is a fixed, concrete, gravity-base system (GBS) design, adopted, in part, as the result of pressure from the provincial government which wanted a project that would generate large amounts of work in a province with very high unemployment levels. The GBS and one of the five main topsides modules, plus a number of smaller components, were constructed at a greenfield site at Bull Arm, Newfoundland. Other modules were built in South Korea and Italy and shipped to Bull Arm for assembly and eventual mating of the topsides with the base. The completed platform was towed to the field in May 1997 and first oil was produced in November 1997.

Table 1J.2 illustrates expected and actual labor demand from project initiation to peak activity in 1995. As is often typical of such projects, actual labor requirements proved far different than expected. The "errors" in part resulted from a project delay resulting from the 1992 pull-out of Gulf Canada and from design problems and revisions. The significance of these predictive "errors" was not so much in the potential implications for labor supply but rather the implications of accommodating that labor in a rural area where there was little rental accommodation.

To avoid "swamping" local communities with a major influx of labor a work camp was established for workers commuting beyond a 50-mile radius. This approach effectively "insulated" local communities from excessive demands on services and infrastructure. In fact, by 1994 only 77 workers, or 2.5% of the workforce, together with 46 spouses and 56 children, had moved into the area as a result of the project (Newfoundland 1994).

The use of the camp also allowed a rapid response when labor demands increased. Table 1J.3 illustrates the differences between predicted and actual numbers housed on site over the 1990-1995 period. The camp was originally designed to accommodate 1,500 workers, but this was initially increased to 3,000 and subsequently a further 480 rooms were added. In 1995, demand for accommodation onsite did exceed supply, causing some local rent inflation. However, this proved to be a relatively short-term problem.

Table 1J.2. Predicted and Actual Employment Levels, Bull Arm Construction Site, 1990-1995.

Year	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**
Predicted	250	850	1155	1465	2265	3600
Actual	116	972	898	3060	4019	5779

Sources: Mobil Oil Canada, Ltd. 1985; HCSEMC 1990-1995.

This case study indicates that predictive accuracy of project outcomes is more likely to result from luck than inspired modelling techniques. However, it also suggests this may not be of primary importance. What is important is not whether the impact predictions *per se* prove to be correct, but whether what was wanted from the project was actually achieved. In the Hibernia case, a primary impact management objective—minimizing community disruption—was achieved thanks to the implementation of an appropriate management strategy.

REQUIREMENTS FOR A MANAGEMENT-ORIENTED APPROACH TO SEIA

The Hibernia case study also serves to illustrate a number of aspects of, and trends in, SEIA in Canada. First, the assessment was project-based (rather than being concerned with a program or policy) and had a strong focus on community effects with, not least, a concentration of effort on trying to predict the consequences the project would have for a small number of geographic "impact areas." Second, over the extended course of the assessment (while work on it started in 1981, the SEIA was not submitted for review until 1985 and approved in 1986) there was a slow shift way from the formal goal of project approval towards an assessment exercise that could contribute to the management of project effects. This was driven by an expectation, fully-realized, that the uncertainty that is characteristic of the offshore petroleum industry in general, and large construction projects in particular, would rapidly make impact predictions redundant.

We believe that the experience with Hibernia and other such assessments points towards a need for more management-oriented approaches to SEIA. In particular, we think it shows a need to use: (i) a scoping of potential impacts which focuses on those which can usefully contribute to management; (ii) assessment approaches which eschew prediction of the unknown (and in many cases unknowable) in favor of capacity-based evaluations of the known; and (iii) a monitoring of socioeconomic measures that contributes to the management effort. The rest of this section discusses further each of these requirements.

THE SCOPING OF COMMUNITY EFFECTS

Progress has been made from early compendious assessments which sought to predict the effects of projects on virtually all significant social or economic phenomena. It has been recognized that this approach results in there being very limited and ineffective analysis of the effects on a very large number of things. There has, in response to this, been a growth in the use of scoping exercises which seek to focus the assessment effort on a subset of topics that past research, key informants and professional knowledge indicate may be subject to "significant" effects. However, the scoping effort usually fails to move beyond this identification of topics of concern to asking the question: "so what?" and, in particular, an identification of the goals and objectives that the host communities want to achieve.

CAPACITY-BASED ASSESSMENTS

Most assessments are "source-demand" driven; that is, a certain level of activity associated with a project or "source" will generate a particular level of "demand" on local infrastructure, services, etc. However, as discussed above, predictions of activity levels are often incorrect with obvious implications for any projected consequences and responses. Where impacts are spatially concentrated and the types of impacts known, an alternative approach is to focus on the "capacities" of those components of the socio-economic system which are on the receiving end of the project outcomes.

An example illustrates this approach. A company proposes to build a refinery in a Newfoundland community which has a current population of 7,000. It is expected that direct refinery employment will be in the order of 900 workers. Skill levels required and local labor market characteristics suggest that only some of the required workers can be provided from the local area. Non-local hires have the option of moving to the community where the plant is located or commuting there on a daily basis. The community is anxious to know how to respond and, in particular, whether or not there is likely to be a significant demand for local housing.

The predictive model suggests that the population change through in-migration would likely be in the range of 900 to 1,650, leading to a requirement for 374-593 housing units. Only low confidence levels could be attached to these projections. However, study of the local housing market showed that 50-60 dwellings were already available, while vacant serviced land would permit the construction of another 300 units. While there was no guarantee that the market would respond quickly to demands, it was concluded that there was sufficient capacity in the system to adequately respond to the range of potential demands suggested by the predictive "source-demand" model. But, in a contrasting example, analysis of the local water supply system indicated that it was already being utilized beyond its design capacity, and that *any* new demand would exacerbate this problem. Such analyses allow the planner or decision-maker to determine where capacity thresholds are exceeded and system bottlenecks may arise, while reducing the dependence on "spuriously accurate" predictions in which there is little confidence.

MONITORING AND AUDITING

If effective management is to be realised, then monitoring and auditing of outcomes provides an essential feedback function. However, if this is to be useful, monitoring and auditing must focus on the "achievement of desired objectives" rather than on "prediction verification," as is too often the case. The limitations of the latter approach are illustrated by an example.

Examination of 143 socio-economic predictions in the Hibernia assessment (Mobil 1985) found that only 86 were "suitable" for audit.[1] However, of these 67 could not be verified as there were no monitoring data, and for a further 11 the data were inadequate. Of the remaining 8 "auditable" predictions, 6 proved to be significantly wrong (Locke and Storey 1997). This type of audit fails both to adequately demonstrate the accuracy of the assessment and to reflect the reality of the situation. In fact, expenditure and employment levels exceeded the proponent's commitments and the anticipated negative outcomes either did not occur or were significantly less than many intervenors had feared when the assessment was reviewed.

Monitoring and auditing is often rarely done and when it is, it is rarely done well. This results in what Sadler (129) describes as the "paradox of EIA"— where the absence of follow-up precludes any opportunity to learn from project experience, inhibiting both project management and the advancement of impact assessment. By focusing monitoring and auditing on desired objectives rather than prediction verification the utility of the EIA process could be significantly increased.

CONCLUSIONS

Since the formal adoption of EIA in the 1970s the process has evolved significantly, albeit in a piecemeal fashion. From an early concern with assessment methods, attention first shifted to screening and scoping, the "front end" of the process, to help focus assessments. More recently increasing emphasis has been given to the "back end" of EIA - impact management and follow-up through monitoring and auditing. This reflects the greater role of EIA as a management rather than simply a decision-making tool. However, if it is to be successful in this role then the design of assessment procedures needs to be rethought. Monitoring and auditing should not be independent of and subsequent to the assessment phase. Rather the desired objectives of the project, program or policy in question should provide the basis for the follow-up program design which in turn should influence what is assessed and how. By focusing on *desired* outcomes we may perhaps shift the emphasis of assessment away from prediction and more towards management.

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[1] Includes predictions that were sufficiently detailed and precise, still relevant and had occurred.

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PANEL DISCUSSION

Dr. Claudia Rogers
Minerals Management Service
Gulf of Mexico OCS Region

Mr. Shrimpton began this segment of the session with an overview of social trends in the oil and gas industry, from technology to economics to business practices, and how they can be understood in the framework of impact assessment. He called our attention to the massive projects currently operating or under construction, projects such as Hibernia in hazardous waters off Newfoundland and Mars in deep water in the Gulf of Mexico. These are indicative of the trend toward retrenchment of larger companies, the pooling of capital resources, and the increased globalization of manufacturing, administration and finance of such large projects.

On the labor side of that same equation, there are only a small number of skilled, technically-trained workers. These significant labor shortages have resulted in an international labor force comprised of individuals from many countries brought together to work on one project or platform. The implications of these trends for valid social impact assessments is to "de-problematize" the oil industry, analyzing it in terms of its component parts rather than its complex, international whole. De-problematizing also means properly addressing oil companies' increased attention to and investment in their workers and beneficial effects on local communities.

Other panel members expanded the discussion to consider additional factors of the implications of large-scale mergers such as Exxon and Mobil at the local level.

- How are business decisions made regarding, say, the selection of support bases?
- How do local business owners plan for or respond to decisions beyond their influence or control?
- What community characteristics are more or less sensitive to external forces?
- What part does the state political structure play on how a local area is affected by oil and gas activities?
- Given the future need for a highly skilled, university-trained workforce, where can companies recruit such people?

This need for highly skilled workers is particularly true in the aviation field. When the U.S. military was extensive and active throughout the world, companies had a ready supply of technicians and pilots who were experienced, licensed and well-trained. That is no longer the case.

If merging companies continue to look principally to profits as motive for action, then research will suffer and be focused on profit or market-based utility and questions of "what else is there" rather than "what else is possible." Current extraction projects also leave companies vulnerable to terrorism and massive projects even more so. Witness the offshore security precautions in the North Sea and the fact that resource management now includes conflict management as well. Conflict must be addressed at different levels, from local residents to environmental purists.

Dr. Claudia Rogers is an anthropologist with Minerals Management Service in the Gulf of Mexico office charged with social and economic impact assessments. She and her colleague, Dr. Harry Luton, also an anthropologist, develop and monitor social science research.

CONCLUSION: THE ISSUES IDENTIFIED

Dr. Claudia Rogers
Dr. Harry Luton
Minerals Management Service
Gulf of Mexico OCS Region

Those present readily agreed on a few key, overarching themes:

1. Oil and gas extraction is so complex that issues will change in number, scope and intensity.

2. The industry is not monolithic; it is global with a multiplicity of cross-cutting ties which can also be competitive.

3. Given the complexity of oil and gas activities, construction, transportation and operations become even more significant.

4. Technological changes in every phase of the oil and gas-related activity, such as air, sea and land transportation, directly effect costs of extraction.

5. Increased costs change the use of capital, leading to more partnerships, from helicopter companies and other supporting services, e.g., the Edison-Chouest "one-stop shopping" center at Port Fourchon, Louisiana, to the partnerships formed when mergers occur.

6. Uncertainty is also a given, due to the volatility of oil and gas, a volatility which local communities cannot control.

7. The success of the oil and gas industry is due and will continue to be due in major part to its adaptability to changing physical environments, labor forces, community demands and economics.

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SESSION 2G

ACOUSTIC/PRESSURE WAVE EFFECTS ON MARINE MAMMALS AND SEA TURTLES, PART II

Co-Chairs: Dr. William Lang and Ms. Colleen Benner

Date: December 10, 1998

Presentation	Author/Affiliation
Behavioral Responses of Marine Mammals to Acoustic Disturbance Document Not Submitted	Dr. W. John Richardson LGL Ltd., Environmental Research Associates
Acoustic- Pressure Wave Effects on Sea Turtles	Dr. Molly Lutcavage New England Aquarium
Acoustic/Explosive Effects on Marine Mammals Document Not Submitted	Dr. Darlene Ketten Woods Hole Oceanographic Institution

ACOUSTIC- PRESSURE WAVE EFFECTS ON SEA TURTLES

Dr. Molly Lutcavage
New England Aquarium

INTRODUCTION

In July 1998, a juvenile loggerhead sea turtle was killed during explosive platform removal of a caisson in the Matagorda Island area. The turtle surfaced a few yards from the caisson four minutes after denotation of two 50-lb Comp B charges and died during airlift to veterinary facilities. The loggerhead's carapace was cracked along its entire dorsal margin, and its lungs contained pooled blood and foam in the airways. Death was attributed to liver hemorrhage. In over 11 years of monitoring surveys conducted by the NMFS-offshore industry sea turtle and porpoise observer program (Gitschlag *et al.* 1997) this was the most recent of documented impacts, which included three mortalities and two nonlethal injuries (G. Gitschlag pers. comm.). But since detonation was officially cleared following the required pre-denotation surveys (John J. Kenny pers. comm.) it also emphasizes the fact that the observer system may occasionally fail to detect submerged turtles. This unsatisfactory outcome does not necessarily reflect upon the failure of monitoring efforts but highlights the fact that sea turtle breath hold diving capabilities and behavior are wide ranging and not easily predicted (Lutcavage and Lutz 1997).

Except for the very small number of direct observations on dead or injured animals, there is very little known about the harmful effects of underwater explosions on sea turtles. Likewise, we have virtually no information on the impacts of seismic operations on sea turtle physiology or behavior. Extensive data on these subjects simply do not exist because laboratory and field studies are lacking. In spite of this data gap, we can nonetheless review aspects of the sea turtle's functional anatomy, physiology, and life style that may be impacted by offshore oil and gas exploration activities. With this information and documented case studies in mind, informed decision making and planning may proceed with some confidence that harm to sea turtles can be minimized.

POSSIBLE IMPACTS OF EXPLOSIVE PLATFORM REMOVALS AND SEISMIC ACTIVITY ON SEA TURTLES

In the publication "Guide to the Effects of Underwater Shock Waves on Arctic Marine Mammals and Fish," S.H. Hill (1978) interpreted the effects of underwater shock waves on vertebrate animals documented in experimental studies undertaken by the Lovelace Foundation and Dept. of Defense (e.g. Yelverton 1973). These studies used terrestrial animals and fish as subjects. Hill's review, and others examining the same data sets (e.g. Goertner 1982) provide a point of reference for considering the possible physiological damage to sea turtles and other aquatic animals from underwater pressure waves. Damage predictions from the Lovelace Foundation studies were based on actual trials and modeling of physical parameters of explosions and how they would impact highly simplified and idealized animal body compartments. Conclusions were that the primary sites of damage are the lungs and hollow organs, which comprise the major tissue-gas phase interfaces in the vertebrate body. In general, immediate damage occurs from concussive effects of the pressure impulse, and major insults may include hemorrhage and gas emboli caused by air and gas in capillary beds which can then lodge in the lungs, heart, and brain. These physiological trauma could then lead to fatal cardiac arrest and stroke. Hill (1978) also reported that sensory organs, especially the eyes and ears, were damaged by pressure impulses. Trauma included hemorrhage of capillaries in the eye and severing of the optic nerve. In general, the most severe damage occurred in the smallest animals, suggesting that size afforded some protection against harmful consequences (Hill 1978).

The impacts of offshore oil and gas platform removals and seismic operations on sea turtles are a necessary concern because of their overlap in time and space. There are five sea turtle species occurring in the Gulf of Mexico: the Kemp's ridley (*Lepidochelys kempi*), the loggerhead (*Caretta caretta*), the hawksbill (*Eretmochelys imbricata*), the green turtle (*Chelonia mydas*), and the leatherback turtle, (*Dermochelys coriacea*). Under the Endangered Species Act of 1973, all are designated as endangered or threatened species because their populations have been greatly depleted worldwide as a result of human activities (Lutcavage *et al.* 1997). In the Gulf of Mexico, sea turtles are seasonably abundant inshore, but their ranges may extend offshore and several species are highly migratory. Some sea turtles, particularly loggerhead and green turtles, use oil and gas structures as foraging and resting habitats (Klima *et al.* 1988; Gitschlag *et al.* 1997), and even the highly pelagic leatherback has been sighted under platform pilings. Offshore platforms function as artificial reefs, and like other structures such as fishing piers, may be attractive to sea turtles because they offer food resources and shelter.

Sea turtles are uniquely adapted for a life at sea, and primarily one of submergence. Their body plan is streamlined, and their limbs and shell are shaped for efficient hydrodynamics and underwater propulsion. They have orbital salt glands to eliminate excess salts and maintain fluid balance, a reduction in bony shell material, and very compliant chest walls to cope with pressure changes associated with diving. On average, sea turtles spend 95% of their time submerged, engaged in feeding, swimming, and resting, and are capable of some of the longest and deepest dives known among breath hold divers (Lutcavage and Lutz 1997).

Based on biotelemetry studies of freely diving sea turtles, the range of dive patterns is quite broad, and varies in relation to species, sex, size, activity, and water temperature. Even within a species such as the Kemp's ridley, routine voluntary dives may last only 12-18 minutes, while occasionally they may range upwards of several hours (Byles 1989). In coastal regions juvenile loggerhead sea turtles routinely make short, shallow dives, but offshore they may dive to over 200 m and submerge for 40 minutes or more (Lutcavage and Lutz 1997). The common theme linking all sea turtle dive patterns is repetitive diving: i.e. sea turtles spend only a few minutes per hour at the surface where we can see and detect them. This remains a challenge of all monitoring programs.

Sea turtles initiate a dive by holding their breath after inspiration. The lung is the primary oxygen store (with the exception of a deep diving leatherback turtle), but also serves as the major buoyancy organ (Lutcavage and Lutz 1997). Regulation of buoyancy is critical for a marine air-breather that feeds, travels, avoids predators, and rests while submerged. The lung is a paired, wedged shaped organ attached by a thin membrane to the carapace and fused to the dorsal ribs. Turtles lack a diaphragm, and ventilate their lung at the surface through movements of their pectoral and pelvic girdle muscles. Their chest wall is very compliant, which is important for these divers since they regularly face large pressure changes related to diving. The sea turtle lung bears a superficial resemblance to mammalian lungs, being finely divided, and has a large respiratory gas surface area and a delicate gas-tissue barrier only a few cell layers thick. Like the lungs of some marine mammal divers, the sea turtle lung also has unique structural adaptations related to diving. Airways are reinforced with myoelastic tissue that affords some protection against irreversible collapse at depth, and also supports high ventilatory flow rates. Although these adaptations apparently protect the lung against routine pressure-volume changes, compensation is limited, and underwater blast impacts produce time-pressure impulses of a vastly different scale. Based on published impacts on other vertebrate lungs (Hill 1978), the sea turtle lung would be vulnerable to gas emboli and disruption of respiratory function. In experimental studies, green sea turtles undergoing rapid decompression in hyperbaric studies died from pulmonary gas emboli (Berkson 1967).

Sea turtles routinely hold their breath only as long as their lung oxygen supply is accessible. If they are to remain active and capable of repetitive diving, they have to surface and replenish oxygen stores to remain within aerobic limits (Lutcavage and Lutz 1991). The fact that their breath hold capacities are limited is reflected in enforced tow time studies conducted by the NMFS (Henwood and Stuntz 1987). After 60 minutes of enforced tows, the rate of comatose and dead turtles rose exponentially; sea turtles were submerged past their normal tolerance and became asphyxiated and drowned. When sea turtles and other vertebrate divers submerge, they undergo physiological changes, known collectively as the diving response, to conserve energy stores. This response results from a suite of integrated events in the central and peripheral nervous system that modulate heart rate and circulation, and meters oxygen delivery to critical organs—brain, heart, and working muscles. For example, diving heart rates range from a few beats per minute during rest periods to high rates associated with swimming exercise. Heart rate is also subject to conscious control, because sea turtles often increase their heart rate and cardiac output in anticipation of surfacing. Damage resulting from concussion, gas emboli, shock, or lung collapse could interfere not only with oxygen delivery to vital organs, but could also insult the central nervous system controlling the protective dive response, and which might prove fatal.

Unlike marine mammals, sea turtles are primarily heterotherms that regulate their body temperatures through shifts in behavior (Spotila *et al.* 1997). But vasomotor responses allow them to cool and warm by varying blood flow to the skin and periphery. For example, in the tropics, nesting leatherbacks sometimes are noticeably pink from vasodilation to the skin, which may lower body temperatures after strenuous nesting activity. Some sea turtles bask on beaches (Pacific green turtles) or at the sea's surface (leatherbacks) to warm themselves. It is therefore conceivable that disruption of the vasomotor response could compromise thermoregulatory functions and undermine fitness.

Beyond the cardiorespiratory and circulatory system, there is little information on the impacts of underwater explosions on other organs, particularly the sensory systems. Unfortunately, information on basic structure and function of sea turtle vision is limited, but for a visual predator like the sea turtle, it is conceivable that damage to the eyes and optic nerve would have detrimental impacts on behavior. Slightly more information is available from studies on the structure of sea turtle ears and hearing (e.g. Ridgeway 1969; Lenhardt *et al.* 1983; Moein *et al.* 1994; Moein Bartol *et al. in press*). These studies found that the sea turtle ear has unique components and responses not present in other turtles. Like the marine mammals, the sea turtles lack an external ear, and instead have a layer of thick subtympanal fat composed of facial tissue. Their ears are structured for sound conduction through bone and water, and the bones of the skull, carapace and columellar are sound transducers, but subtympanal fat may serve a yet undefined role in underwater hearing (Dr. D. Ketten, pers. comm.). Sea turtle ears respond primarily to low frequency sound, in the 200-700 hz range (Ridgeway 1969; Moein Bartol *et al. in press*).

Beyond basic studies on hearing, there have been only a few attempts to identify how sea turtles respond to seismic activity and air guns, considered as a possible deterrent for dredging activities (Moein Bartol *et al.* 1994). In experimental field trials, behavioral responses to air guns varied among trials, suggesting that individuals habituated to discharges. However, following exposure to air gun trials, loggerhead sea turtles exhibited short-term physiological stress, including increased plasma cortisol, glucose, and white blood cell counts, although handling may have also contributed to these changes. Loggerheads also suffered a temporary phase shift in auditory evoked response, but this resolved within two weeks, suggesting that disruption of hearing physiology was of short duration. In general, we have very little information that would allow us to evaluate the potential impacts of underwater explosions and seismic activities on sea turtle vision and hearing. Nonetheless, in the underwater world, these senses are certainly critical to survival.

DOCUMENTED IMPACTS ON SEA TURTLES

If we are to fully evaluate the scope of impacts of explosive platform removals and seismic activities on the sea turtles, it is helpful to review documented case histories. Concern was first raised in 1986, when 51 sea turtle carcasses, primarily juvenile Kemp's ridleys, stranded within a 30-day period on Texas beaches, in proximity to 10 platform removal operations (Klima *et al.* 1988). That summer, the NMFS conducted a field trial holding four juvenile loggerheads and four Kemp's ridleys in cages distributed 260-915 m away from an explosive removal (using four 23 kg charges of nitromethane placed in pilings). Although none died, five out eight sea turtles were rendered unconscious, and damages included fractured scutes, immobility, cloacal prolapse, capillary damage in the eyes, and persistent abnormal vasodilation (in the loggerheads). Although all of the physiological insults resolved within two weeks, these animals were given full supportive veterinary care, and it is possible that in the wild they may not have fared so well. In the very few cases where sea turtles have been harmed by monitored explosive platform removal operations, conclusive links were established by prompt retrieval and expert examination of the carcass. Because of rapid post mortem decomposition, by the time sea turtles strand on Gulf of Mexico beaches, it is virtually impossible to establish cause of death, which may have resulted from any number of causes such as drowning in fishing gear, ship strikes, underwater explosions, intentional killing, and ingestion of toxic marine organisms.

The lessons learned from the long-term NMFS and offshore industry sea turtle and porpoise observer program is that monitoring can reduce mortalities but is not 100% effective (G. Gitschlag, pers. comm.). Lacking definitive studies, at this point we can only make reasonable assumptions that oil and gas exploration activities may impact sea turtles Table 2G.1) based on what we know about their functional anatomy, physiology, and behavior Our ability to protect sea turtles from harm would also be advanced by having a better understanding of basic functions of their sensory systems. If we are to protect endangered sea turtles in their Gulf of Mexico habitats, common sense, caution, and an understanding of their unique life styles should help us significantly reduce harmful interactions.

Table 2G.1. How oil and gas exploration activities may impact sea turtles.

Vulnerable to damage
• Sea turtle respiratory system
• Buoyancy control and diving
• Central nervous system
• Heart
• Vasomotor control
• Sensory systems: ears and eyes
• Visceral organs
• Behavior: feeding, energetics

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SESSION 2H

GIS ACTIVITIES

Co-Chairs: Dr. Norman Froomer and Ms. Michelle Morin

Date: December 10, 1998

Presentation	Author/Affiliation
GIS Activities: Introduction	Dr. Norman Froomer Ms. Michelle Morin Minerals Management Service Gulf of Mexico OCS Region
The MMS Coastal and Ocean Resource Information System (CORIS) Document Not Submitted	Dr. Norman Froomer Ms. Michelle Morin Minerals Management Service Gulf of Mexico OCS Region
Integrating Environmental Studies Data into CORIS: The Deepwater Data Model Document Not Submitted	Mr. Peter Bottengerg Environmental Systems Research Institute
The Gulf-Wide Information System Database: What's Completed; What's To Be Done Document Not Submitted	Dr. Norman Froomer Minerals Management Service Gulf of Mexico OCS Region Ms. Lynda Wayne Louisiana State University
Facilitating Integrated Regional Ocean Management Using a Web-Based Geographic Information System	Mr. Nicholas Schmidt, Program Manager Ms. Cindy Fowler, Senior Spatial Data Analyst National Oceanic and Atmospheric Administration Coastal Services Center Mr. Robert M. Neely, Programmer Analyst Mr. Eric Treml, Programmer Analyst Technology Planning and Management Corporation
GIS and Oil Spill Contingency Planning in Louisiana Document Not Submitted	Mr. David Gisclair Louisiana Oil Spill Coordinator's Office

GIS ACTIVITIES: INTRODUCTION

Dr. Norman Froomer
Ms. Michelle Morin
Minerals Management Service
Gulf of Mexico OCS Region

The GIS Activities Session focused on activities underway at MMS to develop Geographic Information System databases and applications for use in offshore natural resource management. The first presentation by Norman Froomer and Michelle Morin described the MMS Coastal and Offshore Resource Information System (CORIS). CORIS is a relational database that holds the environmental data that MMS will use for regulatory and planning analyses. CORIS stores tabular data in an ORACLE database and use s the Spatial Database Engine for storing spatial data.

MMS intends to incorporate data deliverables from MMS Environmental Study Program data deliverables when appropriate. The next presentation by Mr. Peter Bottenberg described the work that Environmental Systems Research Institute (ESRI) is doing for MMS to assist in this objective. ESRI is developing data formats for data deliverables from deepwater environmental studies and GIS applications that will use these data for regulatory and planning analyses.

Much of the data currently contained in CORIS was developed through the Gulf-Wide Information System (GWIS) project. GWIS developed a consistent and complete environmental database extending from Corpus Christi, Texas to Tampa, Florida. These data were developed by each of the Gulf states and several federal agencies according to database specifications that allow the diverse data sets to be used together for regional analyses. The next presentation by Dr. Norman Froomer and Ms. Michelle Morin described the status of the GWIS data, which is currently in the Quality Assurance/Quality Control phase of completion.

Mr. Nicholas Schmidt of the National Oceanic and Atmospheric Administration (NOAA) described a project that the NOAA Coastal Services Center has developed to support ocean management through a web-based GIS. The NOAA project depicts geographically laws and regulatory statutes with implied geographic boundaries that were not explicitly specified in original documents.

Finally, Mr. David Gisclair of the Louisiana Oil Spill Coordinator's Office described a project to develop a GIS oil spill and emergency planning database for the state of Louisiana. MMS has worked cooperatively with LOSCO on this project in that the data that this project develops will be incorporated into the MMS CORIS database, and the GWIS biological data for Louisiana will be incorporated into the LOSCO database. The GIS Activities Session focused on activities underway at MMS to develop Geographic Information System databases and applications for use in offshore natural resource management.

FACILITATING INTEGRATED REGIONAL OCEAN MANAGEMENT USING A WEB-BASED GEOGRAPHIC INFORMATION SYSTEM

Mr. Nicholas Schmidt, Program Manager
Ms. Cindy Fowler, Senior Spatial Data Analyst
National Oceanic and Atmospheric Administration
Coastal Services Center

Mr. Robert M. Neely, Programmer Analyst
Mr. Eric Treml, Programmer Analyst
Technology Planning and Management Corporation

ABSTRACT

Because existing governance and management regimes for ocean resources in the U.S. are fragmented, complex, and thus poorly understood, the nation is ill-equipped to address the inevitable conflicts and problems arising offshore. A wide variety of laws, regulations, programs, and special jurisdictions have evolved over time to protect, develop, and manage ocean resources. Ocean policies and programs, however, have historically been developed and implemented as single-purpose regimes, with little thought to how they would interact with other resource management considerations (National Research Council 1997). At both the national and international levels, 1998 has been declared "Year of the Ocean," and consensus among ocean and coastal managers is building in favor of more integrated, comprehensive ocean management supported by the best available science and spatial information. Hence, there is a great need for the development of ocean management information systems that integrate environmental data with spatially referenced legal, political, and jurisdictional frameworks to help resource managers and policy makers make sense of offshore jurisdictional complexities. With the National Oceanic and Atmospheric Administration providing leadership for the U.S., staff at its Coastal Services Center (CSC) are building upon ongoing state-level efforts to develop a regional model for a Web-based ocean governance and management geographic information system (GIS). This prototype – the Southeast Ocean Planning GIS (Ocean GIS) – will help facilitate the shift from fragmented management of individual ocean resources to integrated management of ocean ecosystems. It will do so by providing resource managers in the Carolinas, Georgia, and Florida access to regional geo-referenced regulatory and environmental spatial data critical to timely, integrated decision making and analysis of complex and often conflicting jurisdictional issues. In addition, the Ocean GIS will serve as a model for regional ocean management information systems. To assess its effectiveness and potential usefulness in obtaining these objectives, CSC staff will solicit feedback from states with a stake in ocean management issues to evaluate the utility of the Ocean GIS and to identify deficiencies common to this and other similar GIS-based ocean and coastal planning tools. The results of this evaluation will serve as guide posts for the ongoing development of the Ocean GIS and similar tools designed to facilitate comprehensive, integrated approaches to ocean management.

INTRODUCTION

The ocean waters of the southeastern U.S. comprise one of the richest and most productive of our nation's vast marine resource regions. The inhabitants of the coastal states of this region, whether directly or indirectly, benefit in many ways from the bounty of the Atlantic Ocean and Gulf of Mexico. The ocean and coastal areas of the Southeast support multiple activities, including commercial and recreational fisheries, oil and gas production, coastal recreation, commercial trade, and essential ecosystem functions. Though the warm waters, low-lying sandy beaches, and expansive tidal marshes distinguish this region from others in our nation's immense marine territory, it, too, is increasingly affected by humankind's changing relationship with the seas. In the Southeast, as elsewhere in the U.S., the environmental quality of marine areas and resources, and the economic value of ocean and coastal industries, such as trade, tourism, fishing, and energy extraction, could be jeopardized unless decisive steps are taken to protect and effectively manage these sensitive ocean and coastal environments (Heinz Center 1998).

A wide variety of laws, regulations, programs, and special jurisdictions - collectively constituting the region's ocean governance and management framework - have been developed over time to protect, develop, and manage ocean resources. Ocean policies and programs typically were developed and implemented as single-purpose regimes, with little thought to how they interacted with other resource management considerations. From the shoreline seaward to the 200-nautical mile boundary of the U.S. Exclusive Economic Zone (EEZ), the federal government, coastal states, and local jurisdictions have many overlapping interests and authorities. Balancing the need for renewable ocean resource use and enjoyment with extraction of nonrenewable resources, navigation, recreation, and protection of the ocean ecosystem presents one of our nation's greatest challenges and responsibilities for the 21st century (National Research Council 1997).

Fortunately, numerous efforts are currently underway to address the need for more comprehensive, integrated approaches to regional ocean and coastal management. At the international level, 1998 has been declared "Year of the Ocean" by the United Nations in an effort to focus attention on ocean issues. To complement this international effort, the U.S. has also declared 1998 "Year of the Ocean," with the National Oceanic and Atmospheric Administration (NOAA) assuming a prominent leadership role. Other key components of the U.S. effort to address ocean management concerns include possible Congressional ratification of the United Nations Convention on the Law of the Sea, and political efforts to establish a high-level, Stratton-type committee to evaluate and make recommendations for improving the U.S. ocean governance and management framework. As these initiatives continue to focus attention on important ocean issues, they also underscore the need for easily accessible geographic information that enables resource managers to conduct critical spatial analyses. To meet these needs, the NOAA Coastal Services Center (CSC) and its partners have developed a prototype Web-based regional Ocean GIS that will help resource managers make sense of the complex jurisdictional, political, and legal frameworks that constitute our national ocean governance and management framework.

THE NEED FOR REGIONAL SPATIAL ANALYSIS CAPABILITIES

The existing governance and management regimes for ocean resources in the southeastern U.S., as elsewhere, are fragmented, complex, and thus poorly understood. Generally, the states have control of the sea bottom and marine resources out to the three-mile federal-state boundary (43 U.S.C. §§ 1301 *et seq.*). Within this area, states have the authority to manage, administer, lease, develop, and use the natural resources of the ocean; the federal government retains considerable control over commerce, navigation, defense, fisheries, and international matters. Under section 8(g) of the Outer Continental Shelf Lands Act, states share nearshore revenues from production within three nautical miles seaward of the federal-state boundary. States may also exert influence over federal activities within the U.S. Territorial Sea, which extends 12 nautical miles seaward from the shoreline (or 9 nautical miles beyond most federal-state boundaries), as well as within the EEZ, which may extend 200 nautical miles or more seaward from the shoreline.

Federal agencies have a variety of overlapping authorities and jurisdictions. Some of the most important players include the U.S. Coast Guard, U.S. Environmental Protection Agency, U.S. Minerals Management Service (MMS), U.S. Army Corps of Engineers, and NOAA. This fragmented approach to management of ocean resources at the national level often results in redundant efforts, inefficiency, ineffectiveness, and lack of coordination among agencies with tangled, overlapping jurisdictions. Perhaps more problematic are the unidentified jurisdictional gaps in the existing governance framework that potentially can hinder effective ocean management and the appropriate use, conservation and protection of important ocean resources. These factors emphasize the need for the development of regional spatial frameworks such as the Ocean GIS which will help make sense of offshore jurisdictional complexities.

Because natural resources typically transcend political boundaries, and because many ocean issues span multiple state and federal agency jurisdictions, regional cooperation is an essential component of efforts to integrate approaches to ocean management. Furthermore, comprehensive ocean management is dependent in large part upon the contributions and efforts of the individual coastal states. Unfortunately, only a few coastal states – including California, Oregon, and Florida – have attempted to compile the data necessary for integrated, coordinated approaches to ocean planning, governance, and management. Each has met with some success, but also with problems, such as lack of essential data. Such data is typically dispersed among many federal and state agencies, which clearly suggests the need for development of a consistent, management-oriented data framework. To be effective, the content and structure of a digital spatial database must address the important issues of ocean planning and governance and provide resource managers with a basis for assessing alternative management strategies and tactics.

BUILDING A PROTOTYPE INTERNET-BASED REGIONAL OCEAN GEOGRAPHIC INFORMATION SYSTEM

Within the past decade, the development and increased availability of geographic information system (GIS) technologies have provided natural resource managers with powerful decision making tools. Capable of storing, processing, analyzing, and displaying multiple overlapping spatial data sets, GIS has typically been applied to terrestrial systems or relatively small-scale marine environments. However, the applicability of GIS to large-scale marine regions is particularly appealing given the apparent need for improved regional approaches to ocean management.

The idea for a regional ocean GIS for the Southeast was originally conceived by NOAA's Office of Ocean and Coastal Resource Management (OCRM) and the State of North Carolina. Following this genesis, a partnership was forged between OCRM and NOAA CSC, which was tasked with providing technical leadership for the development of a regional Ocean GIS. During 1996 and 1997, OCRM and CSC held a series of scoping meetings with partners from the States of North Carolina, South Carolina, Georgia, and Florida, as well as other relevant federal and regional agencies, to identify priority issues within the region. Concurrently, the Florida Marine Research Institute (FMRI) developed a prototype ocean GIS for Florida's extensive marine areas. The product of this effort – the Florida Statewide Ocean Resource Inventory (SORI) – yielded an Internet mapping and data retrieval application for 150 geo-referenced marine and coastal data sets (Florida Department of Environmental Protection 1998). In early 1998, CSC and FMRI began an ongoing effort to expand upon SORI by building a prototype Ocean GIS to include the marine region bounded by the Carolinas, Georgia, Florida, the U.S. EEZ, and maritime boundaries.

The Ocean GIS project built an integrated issue-driven Internet interface with an interactive Web-based GIS tool using the Environmental Systems Research Institute's (ESRI) MapObjects™ Internet Map Server and Visual Basic®. MapObjects is a collection of mapping and GIS components, including an ActiveX control (OCX) and ActiveX automation objects. For this project, MapObjects was used within the Visual Basic development environment.

As with SORI, a key objective of this project was to develop an inventory of fully attributed data sets documenting the spatial extent of the southeastern regional ocean governance and management framework. In this the initial phase of regional prototype development, CSC project staff focused on federal-level framework components. In addition, effort was also applied to locating and incorporating many of the issue-related environmental data sets identified as important by project partners.

The U.S. federal management framework is comprised of several important sub-components: the legislative framework, which establishes the legal mandate for regulation and management of ocean resources; the institutional framework responsible for implementing those mandates; and political boundaries that determine, in large part, the geographic scope of management jurisdictions. A functional regional Ocean GIS must include geographically and legally accurate depictions of these components to facilitate meaningful and substantive analyses on the part of resource managers. However, because legal and geographic definitions are sometimes inconsistent or uncertain, and because the fundamental purpose of statutory components vary depending on legal intent, these prerequisites present some interesting challenges to those charged with assimilating, interpreting, and developing geo-referenced legal information. Because it sometimes highlights deficiencies, the process of geo-referencing the management and governance framework is, in itself, an exercise in facilitating the shift to comprehensive, integrated ocean governance and management.

Geo-referencing the U.S. Federal Legal Framework

Numerous federal laws are relevant to the governance of ocean and coastal resources. Because the authority and influence of many laws with respect to ocean management issues are often obscure or uncertain, CSC had first to identify those laws that constitute the cornerstones of ocean governance in the southeastern U.S. These laws can be characterized broadly as those that:

- Designate or authorize marine protected areas (e.g., National Marine Sanctuaries, National Estuarine Research Reserves, National Parks and Seashores, National Estuary Programs).
- Designate or authorize site-specific uses (e.g., dredged material disposal sites, fishery enhancement areas, military training areas, National Priority List sites).
- Establish broad, geographically comprehensive regulatory authority (e.g., Endangered Species Act, Marine Mammal Protection Act, Coastal Zone Management Act).
- Establish geographically indiscrete or undefined regulatory authority.

To define the geographic extent of pertinent laws, CSC compiled an inventory of key federal statutes with direct relevance to ocean and coastal resource management. To accomplish this task, CSC project staff relied upon the expertise of numerous federal and state agency workers, the developers of SORI, the U.S. Code, the Code of Federal Regulations, and numerous other legal sources. After compilation, the spatial extent of each law, if relevant, was determined either through reliance upon the sources listed above, or through data developed by CSC, other agencies, and/or Ocean GIS partners.

Geo-referencing the U.S. Federal Institutional Framework

A process parallel to that utilized to inventory and determine legislatively-determined spatial extents was employed to identify key components of the U.S. federal institutional framework for ocean management. Numerous federal agencies share responsibility for implementing and enforcing federal laws drafted to manage and promote the stewardship and appropriate use of marine resources. In fact, any one agency is typically responsible for ensuring compliance with a number of federal laws, and the institutional structures of these agencies are often as complex as the laws they are mandated to enforce. For example, the top-down institutional hierarchy of the U.S. Army Corps of Engineers includes divisions that are organized within unique regions into regulatory districts (typically defined by state boundaries), civil works districts (typically defined by watersheds), and military works districts (typically defined by combinations of state boundaries). Other federal organizations involved in the management of ocean resources include the U.S. Department of Commerce (NOAA National Marine Fisheries Service, NOAA National Ocean Service [NOS]), the U.S. Department of the Interior (National Park Service, Department of Fish and Wildlife, MMS), the U.S. Department of Transportation (Coast Guard, Maritime

Administration), the U.S. Department of Agriculture (Forest Service, Bureau of Land Management), the U.S. Environmental Protection Agency, and the Federal Emergency Management Agency. Each of these agencies is generally divided into geographically and programmatically distinct jurisdictional units responsible for regional implementation and enforcement of federal programs. Hence, as with the legal framework, the federal institutional framework is a complex regime of geographically overlapping jurisdictions, the mapping of which is essential to enhanced regional ocean management.

To spatially define these multiple jurisdictions within the Ocean GIS prototype, CSC relied extensively upon many of the same sources mentioned with respect to the development of geo-referenced legislative data layers. (At the time of this writing, spatial data for some of these components had yet to be developed.)

Geo-referencing Political Boundaries

The final spatial policy component of the ocean governance and management framework is composed of numerous political boundaries that define the extent of state and national sovereignty over ocean territories and the resources therein. These boundaries include the state/federal boundary, the U.S. Territorial Sea boundary, the U.S EEZ boundary, and international maritime boundaries. To acquire spatial data for these boundaries, CSC relied primarily upon MMS and NOAA NOS.

Integration with Other Data Layers

The initial Web-based prototype of the Ocean GIS also makes available a number of environmental data layers, such as those delineating the spatial extent of physical resources (e.g., bathymetry, bottom type, shoreline) and living resources (e.g., coral communities). Important economic layers include active offshore oil and gas lease blocks and commercial ports.

Using ESRI's MapObjects Internet Map Server, these disparate spatially referenced data layers were integrated into the prototype Web-based regional Ocean GIS.

Synthesis and Presentation of Information Via the Internet

Internet users who visit the Ocean GIS website have unrestricted access to the data, which can be downloaded in ESRI coverage and shapefile formats for use in ArcView® and ARC/INFO® GIS applications. In addition, users are able to view these data spatially, examine their associated attributes, navigate to relevant on-line resources through hyperlinks embedded in the tabular data, perform basic analyses, identify relevant legislation and agency jurisdictions at any geographic location, and print reports and maps via the Internet. All of these functions are available to users without the purchase of any software except a basic Web browser.

Other key features of the Ocean GIS site include links to the following:

- Summary and Federal Geographic Data Committee-compliant metadata records for all data layers
- "Scenarios" that utilize available data layers to demonstrate the applicability of a regional Ocean GIS to various management issues, or highlight deficiencies in digital geographic data and data sources
- Statutory summaries, U.S. Code, and relevant on-line programmatic and managing agency resources

CONCLUSION

Though much has been accomplished to date, the need for continued development of the Ocean GIS is great. (In fact, development of the Ocean GIS is an ongoing project at CSC.) The present data inventory included in the prototype is substantial but insufficient in some cases to provide for truly meaningful analyses and suitable resolution of ocean issues. This deficiency is the result of numerous factors that may be overcome in the future, including the limited time and resources committed to this project to date, inadequacies in available data, lack of important data, and concern over the legal and geographic accuracy of certain "official" data sources.

In addition to data concerns, much has yet to be learned about how to develop and maintain a fully functional regional Ocean GIS. As it has from the outset, CSC remains sensitive to the needs of its partners and committed to the development of a useful regional management tool. To ensure that these objectives are met, CSC has established a partnership with Oregon State University's (OSU) Marine Resource Management program to conduct an assessment of states' needs and perceptions with respect to the utility of a regional Ocean GIS. Funded by CSC and the National Spatial Data Infrastructure (NSDI) Benefits Program, this effort will team CSC staff with marine policy and management experts at OSU to determine how best to ensure that the Ocean GIS achieves the NSDI-mandated objectives of efficiency, effectiveness, and equity.

The target population for the benefits analysis will consist of the state coastal and ocean resource management community. Working closely with CSC and utilizing a jointly-developed assessment framework, researchers at OSU will compare and contrast three approaches to ocean management – (1) regional (e.g., the Southeast), (2) single-state (e.g., Oregon, California) and (3) no ocean management policy (e.g., Louisiana).

To measure the benefits associated with these three approaches, OSU will utilize the assessment framework to conduct an inventory of existing state ocean management programs and the degree to which GIS is currently being used to implement intrastate and/or regional program objectives. Case studies will subsequently be developed that highlight states' needs with respect to the application of GIS technologies, digital spatial data, and the Internet, to achievement of ocean management objectives. By identifying and highlighting the needs of state ocean management programs through case studies, this assessment will provide valuable feedback and guidance for ongoing development and application of a regional Ocean GIS. In addition, it will capitalize on the existing momentum and agreement among many managers that a GIS can serve as a rallying point for regional integrated ocean management.

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SESSION 2J

PROPOSED REVISIONS TO THE MMS OIL AND GAS LEASE FORM: A WORKSHOP FOR INDUSTRY COMMENTS

Co-Chairs: Mr. Chuck Hopson and Mr. Steve Waddell

Date: December 10, 1998

Presentation	Author/Affiliation
Session Overview	Mr. Steve Waddell Minerals Management Service Gulf of Mexico OCS Region

SESSION OVERVIEW

Mr. Steve Waddell
Minerals Management Service
Gulf of Mexico OCS Region

This session consisted of a four-part workshop to elicit comments from the industry regarding the proposed revisions to the MMS oil and gas lease form:

1. Introduction and Team Charter – the introduction to the workshop was to discuss the recent changes made to the lease form document by the lease document team. Our charter was to review the lease form for present-day application to comply with recent directives on plain English writing. In the process, we were to take out any provisions that were redundant with existing regulations.

2. Comparison of Proposed Revision to Current Lease Form – we discussed with industry the changes made to the existing form and our reasoning for the changes.

3. Industry Comment and Open Discussion – basically, industry was not happy with our revisions. However, a subsequent public workshop was help at the GOMR office and we had a warm reception. Industry maintains that there is nothing wrong with the existing form and "if it ain't broke, don't fix it."

4. Summary and Where Do We Go from Here? – The lease team has reviewed all comments by industry and has made recommendations to the quality council at headquarters. At the present time, the lease form has been put on hold indefinitely.

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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 **Royalty Management Program** 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.