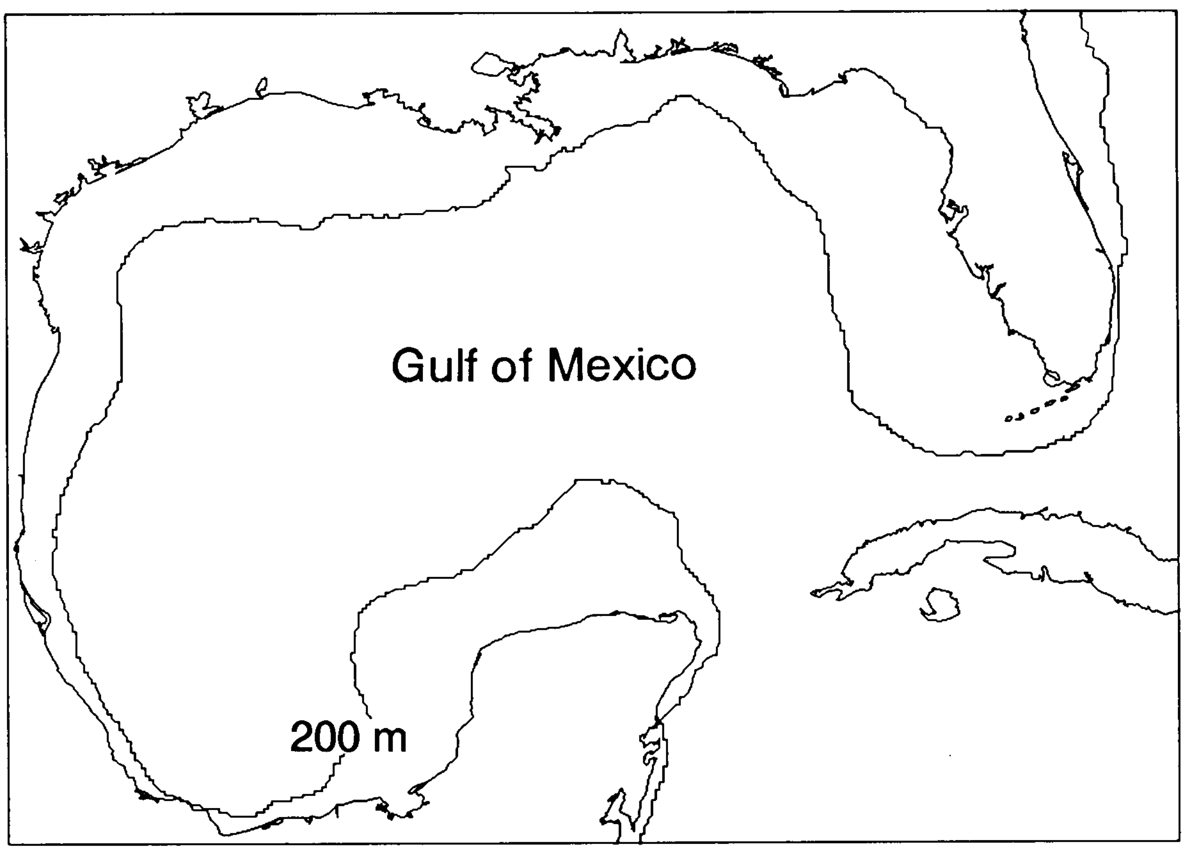
OCS Study
MMS 92-0027

Proceedings: Twelfth Annual Gulf of Mexico Information Transfer Meeting

November 1991



MMS
U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

OCS Study
MMS 92-0027

Proceedings: Twelfth Annual Gulf of Mexico Information Transfer Meeting

November 1991

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SUMMARY

This Proceedings volume presents summaries of the presentations and discussions of the Twelfth Annual Information Transfer Meeting (ITM) held on November 5-7, 1991, in New Orleans, Louisiana. These annual ITM's have been sponsored by the Minerals Management Service (MMS), Gulf of Mexico OCS Regional Office, since 1980 in support of the OCS oil and gas program to foster exchange of information among participants, including MMS staff; invited speakers from academic institutions, Federal and State agencies, industry, conservation groups, and knowledgeable individuals; contractors for MMS-funded environmental and socioeconomic studies; and the audience of general invitees. This volume includes session introductions by the respective session chairpersons, followed by short accounts of presentations by the authors.

The Minerals Management Service invites comment and constructive criticism on the annual Information Transfer Meetings and the resulting Proceedings document.

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ABBREVIATIONS AND SYMBOLS

ADCP	-	Acoustic Doppler Current Profiler
ANGTS	-	Alaska Natural Gas Transportation System
ANPR	-	Advance Notice of Proposed Rulemaking
ANWR	-	Arctic National Wildlife Refuge
APA	-	Administrative Procedure Act
APHIS	-	Animal and Plant Health Inspection Service, USDA
API	-	American Petroleum Institute
ARCO	-	Atlantic Richfield Company
AVHRR	-	Advanced Very High Resolution Radiometer
AXBTs	-	aerial expendable bathythermographs
Ba	-	Barium
BAT	-	best available technology
BBL	-	bottom boundary layer
$bbl \bullet d^{-1}$	-	barrels per day
BCT	-	best conventional pollutant control technology
BLM	-	Bureau of Land Management
BPT	-	best practicable control technology
BWPD	-	barrels water produced per day
Ca	-	Calcium
CAMP	-	California Monitoring Program
CBL	-	Coastal Boundary Layer
CEIP	-	Coastal Energy Impact Program
CEQ	-	Council on Environmental Quality
CFR	-	Code of Federal Regulations
CGA	-	Clean Gulf Associates
cm	-	centimeter
CMC	-	Center for Marine Conservation
CMD	-	Coastal Management Division
COTR	-	Contracting Officer's Technical Representative
CSA	-	Continental Shelf Associates, Inc.
CTD	-	conductivity, temperature, depth
DFI	-	Decision Focus Incorporated
DHH	-	Department of Health and Hospital
DMO	-	Data Management Office
DO	-	dissolved oxygen
DOE	-	Department of Energy
DOI	-	Department of the Interior
DOR	-	dispersed oil removal
DOT	-	Department of Transportation
EBB	-	electronic bulletin board
EEZ	-	exclusive economic zone
EFG	-	East Flower Garden Bank
EHI	-	Evans-Hamilton, Inc.
EIA	-	environmental impact assessment
EIS	-	environmental impact statement
EOR	-	enhanced oil recovery
EPA	-	Environmental Protection Agency
ESP	-	Environmental Studies Program
FID	-	flame-ionization detection

ABBREVIATIONS AND SYMBOLS
(cont'd)

FOSC	-	Federal On-Scene Coordinator
FPSO	-	floating production, storage and offloading units
FR	-	Federal Register
FRU	-	fast response unit
ft	-	feet
FWPCA	-	Federal Water Pollution Control Act
FWS	-	Fish and Wildlife Service
FY	-	Fiscal Year
g	-	grams
GC	-	gas chromatography
GC/MS	-	gas chromatography/mass spectrometry
GEOSAT	-	Geodetic Satellite
GERG	-	Geochemical and Environmental Research Group of Texas A&M University
GIS	-	Geographical Information System
GOES	-	Geostationary Operational Environmental Satellites
GOM	-	Gulf of Mexico
GPECM	-	General Purpose Environmental Cost Model
gpm	-	gallons per minute
GUIS	-	Gulf Islands National Seashore
ha	-	hectare
HMB	-	hexamethylbenzene
HMSC	-	Hatfield Marine Science Center
HOSS	-	High-Volume Open Sea Skimmer System
ICP/MS	-	inductively coupled argon plasma/mass spectrometer
IES	-	Inverted Echo Sounders
IMO	-	International Maritime Organization
INAA	-	Instrumental Neutron Activation Analysis
INTERMAR	-	Office of International Activities and Marine Minerals
IOGCC	-	Interstate Oil and Gas Compact Commission
IR	-	infrared spectroscopy
ITM	-	Information Transfer Meeting
JIP	-	Joint Industry Projects
JSL	-	*Johnson Sealink* (name of a submarine)
kg	-	kilogram
km	-	kilometer
LaSER	-	Louisiana Stimulus for Excellence in Research
LATEX	-	Texas-Louisiana Physical Oceanography Program
LC	-	Langmuir circulations or Loop Current
LGS	-	Louisiana Geological Survey
LOOP	-	Louisiana Offshore Oil Port
LSU	-	Louisiana State University
LUMCON	-	Louisiana Universities Marine Consortium
LWDPS	-	Louisiana Water Discharge Pollution System
m	-	meter
MAS	-	Marine Advisory Service
MASGC	-	Mississippi-Alabama Sea Grant Consortium
mi	-	miles
MIDAS	-	Multiple Interface Data Acquisition System

ABBREVIATIONS AND SYMBOLS
(cont'd)

MIRG	-	Marine Industry Group
mm	-	millimeter
MMS	-	Minerals Management Service
MOMS	-	Meteorological and Oceanographic Measurement System
MPPRCA	-	Marine Plastics Pollution Research and Control Act
MS	-	mass spectrometry
NDBC	-	National Data Buoy Center
NECOP	-	Nutrient Enhancement Coastal Ocean Productivity
NEPA	-	National Environmental Policy Act
nm	-	nautical miles
NMFS	-	National Marine Fisheries Service
NOAA	-	National Oceanic and Atmospheric Administration
NODC	-	National Oceanographic Data Center
NORM	-	naturally occurring radioactive materials
NPDES	-	National Pollutant Discharge Elimination System
NPS	-	National Park Service
NSF	-	National Science Foundation
NSGCPO	-	National Sea Grant College Program Office
NSPS	-	new source performance standards
NWS	-	National Weather Service
OCS	-	Outer Continental Shelf
OCSLAA	-	Outer Continental Shelf Lands Act Amendments
OHMSETT	-	Oil and Hazardous Materials Simulated Test Tank
OOC	-	Offshore Operators Committee
OPA 90	-	Oil Pollution Act 1990
OPEC	-	Organization of Petroleum Exporting Countries
OSC	-	On-Scene Coordinator
OSCP	-	Oil Spill Contingency Plan
OSIM	-	Office of Strategic and International Minerals
OSRV	-	oil spill response vessel
OSU	-	Oregon State University
PAH	-	polynuclear aromatic compounds
PAIS	-	Padre Island National Seashore
PCA	-	Principal Component Analysis
PCB	-	polychlorinated biphenyls
pCi/l	-	picoCuries per liter
PI	-	photosynthesis-irradiance or Principal Investigators
ppb	-	parts per billion
ppm	-	parts per million
PRDA	-	Program Research and Development Announcement
PV-WAVE	-	Precision Visuals Workstation Analysis and Visualization Environment
QA/QC	-	quality assurance/quality control
QCG	-	Quality Control Group
R&D	-	Research and Development
RCPWAVE	-	Regional Coastal Processes Wave Model
RO	-	reverse osmosis
ROV	-	remotely operated vehicle
RRT	-	Regional Response Team
RTL	-	Retransmitted Loran-C System

ABBREVIATIONS AND SYMBOLS
(cont'd)

SAIC	-	Science Applications International Corp.
SAR	-	Synthetic Aperture Radar
SCAT	-	Shoreline Cleanup Assessment Teams
SFSC	-	Southeast Fisheries Service Center
SOOP	-	ships of opportunity
SRB	-	Scientific Review Board
STD	-	salinity, temperature, density
STRI	-	Smithsonian Tropical Research Institute
TA&R	-	Technology Assessment and Research
TAMU	-	Texas A&M University
TIO	-	Texas Institute of Oceanography
TOC	-	total organic carbon
TQCR	-	Transmittal Quality Control Record
TRW	-	topographic Rossby wave
UIC	-	underground injection control
USACE	-	U.S. Army Corps of Engineers
U.S.C.	-	United States Code
USCG	-	U.S. Coast Guard
USGS	-	U.S. Geological Survey
UVF	-	Ultraviolet fluorescence
VMIC	-	Venezuelan Mexican Isthmus Crude
VOA	-	volatile organic analytes
VOSS	-	vessel of opportunity skimming systems
WFG	-	West Flower Garden Bank
WPCD	-	Water Pollution Control Division
XBTs	-	expendable bathythermographs
yd^3	-	cubic yard

ACKNOWLEDGEMENTS

The Minerals Management Service wishes to thank all ITM participants. Special recognition goes to the speakers whose timely individual and panel presentations stimulated discussions and exchange of technical information. Authors are listed by name in the agenda, and again in an index beginning on page 521.

We are grateful to the Chairs and Co-Chairs for the many hours each spent in organizing and chairing the sessions, as well as for their time spent editing the presentation summaries. They are listed by name in the table of contents as well as the beginning of each session.

Appreciation is extended to the staff of Geo-Marine, Inc., the Contractor who handles the logistics for these meetings, and the Doubletree Hotel who always go beyond expectations to meet the needs of all.

Special recognition is given to Dr. Sneed Collard, University of West Florida, and his graduate students for their assistance with projectors and lights, and their general helpfulness.

OPENING PLENARY: DECISIONMAKING

Session: OPENING PLENARY: DECISIONMAKING

Co-Chairs: Dr. Richard Defenbaugh
Mr. Ruben Garza

Date: November 5, 1991

Presentation	Author/Affiliation
Opening Plenary: Decisionmaking: Session Introduction	Dr. Richard Defenbaugh Minerals Management Service Gulf of Mexico OCS Region
Information for Outer Continental Shelf Decisionmaking – A New Protocol	Mr. J. Kenneth Adams Regional Supervisor Leasing and Environment Minerals Management Service Gulf of Mexico OCS Region
Adequacy of Information for Decisionmaking	Ms. Dinah Bear General Counsel Council on Environmental Quality Executive Office of the President
Risk Analysis as a Tool to Focus Decisionmaking Issues: Some Do's and Don'ts of Risk Analysis	Dr. Dale Nesbitt Senior Vice President Decision Focus Incorporated

OPENING PLENARY: SESSION INTRODUCTION

Dr. Richard Defenbaugh
Minerals Management Service
Gulf of Mexico OCS Region

The primary purposes of the Opening Plenary Session are to welcome attendees to the Information Transfer Meeting (ITM) and to initiate the meeting with one or two major presentations that are of interest to a broad cross-section of meeting attendees, and are pertinent to the interests of the Minerals Management Service's (MMS) Gulf of Mexico Outer Continental Shelf (OCS) Regional Office.

ITM INTRODUCTION

The primary purposes of the ITM are: (1) to provide a forum for "scoping" topics of current interest or concern relative to environmental assessments or studies 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 MMS research programs or study projects; and (3) to foster an exchange of information of regional interest among scientists, staff members, and decisionmakers from MMS, other Federal or State governmental agencies, regionally important industries, and academia and to encourage opportunities for these attendees to meet and develop or nurture professional acquaintances and peer contacts.

The ITM agenda is planned and coordinated each year by the MMS Gulf of Mexico OCS Regional Office staff around the three themes mentioned above -- issues of current interest to the Region or the MMS oil and gas program; accomplishments of the agency; and regional information exchange. Presentations are "invited" through personal contacts between session chairpersons and speakers who have demonstrated knowledge or expertise on the subject of interest. A few presentations are accepted in response to our call for "contributed papers."

Meeting support funding is provided through the MMS Environmental Studies Program. All meeting logistical support is provided by a contractor (Geo-Marine, Inc.) and subcontractors selected through the usual Federal procurement process. A proceedings volume is prepared for each ITM, based on presentation summaries submitted by each speaker and on session introductions prepared by session chairpersons.

OPENING PLENARY SESSION INTRODUCTION

The Opening Plenary Session is planned each year to address changing themes, which have included environmental topics, industry technology, offshore resources, marine research, and OCS program issues. This year's Opening Plenary Session was planned to consider and encourage discussion on the issue of "adequacy of information for decisionmaking."

In late 1989, the National Academy of Sciences released a report commissioned by the President which concluded that the information base in three OCS planning areas was generally inadequate for making lease sale decisions. Given the information base that was then available for those areas, this report touched off a heated debate on "how much information is enough?" This controversy has been resolved in the political arena for most OCS planning areas, which are now deferred from leasing for the remainder of this decade. However, this issue is still meaningful within the Gulf of Mexico, which has historically produced more than 95 percent of all the oil and 99 percent of all the gas from the Federal OCS, and which remains the mainstay of the Federal OCS natural gas and oil program.

For management of the OCS natural gas and oil program in the Gulf of Mexico, how much information is enough? What sorts of information are more important than other sorts of information? How can critical information needs be recognized to support study planning? These are some of the issues our invited speakers were asked to consider in their remarks to the ITM Opening Plenary Session audience.

Dr. Richard Defenbaugh is Deputy Regional Supervisor for Leasing and Environment within the Gulf of Mexico OCS Regional Office. His graduate work at Texas A&M University on the natural history and ecology of Gulf of Mexico estuarine and continental shelf invertebrates led to an M.S. in 1970 and a Ph.D. in 1976. He began his career in the Federal service in the Bureau of Land Management's (BLM) New Orleans OCS Office in 1975 and has been involved with BLM/MMS environmental studies and assessment programs since then. He served as Chief, Environmental Studies Section from October 1981 to September 1991, when he moved into his current position.

INFORMATION FOR OUTER CONTINENTAL SHELF DECISIONMAKING – A NEW PROTOCOL

Mr. J. Kenneth Adams
Regional Supervisor
Leasing and Environment
Minerals Management Service
Gulf of Mexico OCS Region

I would like to discuss with you today the need for a review of the information available to support Outer Continental Shelf (OCS) decisionmaking - our plans for conducting such a review - and the integral role that this and future Information Transfer Meetings (ITMs), most importantly the interaction with knowledgeable and concerned individuals that is established here, can play in this process.

We now have a formal requirement for review of available information as a step in our planning process. This step is to ascertain whether such information is sufficient to proceed with environmental and other analyses.

Specifically, a review of the information available to support the planning process for lease sales to be held in 1994 and subsequent years is being initiated with this meeting.

My remarks this morning and of the speakers to follow should provide some basis for a continuing dialogue concerning environmental, social, and economic information needs in the light of a risk assessment protocol.

Actually, the current environmental information base available for the Gulf of Mexico is extensive. The Minerals Management Service (MMS) has conducted an Environmental Studies Program since 1973 to provide support for decisions about leasing and development of oil and gas resources in the Gulf of Mexico. Approximately $103 million have been spent in this Region since the program's inception. In addition to the studies and research sponsored by the MMS, other entities regularly engage in research which provides a significant amount of relevant data to support OCS leasing decisions.

However, we surely realize that no information base will ever be complete in an absolute sense; and this is especially true of the environmental data available to support OCS decisionmaking. All decisions on OCS activities are made with some degree of uncertainty about the extent and severity of potential impacts and require some degree of judgement. The various statutory requirements which address information used in OCS decisions certainly recognize this limitation.

As indicated in Table 1.1, the National Environmental Policy Act (NEPA) and its implementing regulations prescribe a method for the evaluation of potential adverse environmental effects in a manner that will allow decisionmaking to go forward in the face of uncertainty.

I am sure Ms. Bear will have more to say about this later. The NEPA, as it pertains to activities of the Minerals Management Service, requires the use of a systematic, interdisciplinary approach to protect the human, marine, and coastal environments from potentially adverse effects resulting from oil and gas leasing on the OCS. The Act emphasizes the integrated use of the natural and social sciences in planning and decisionmaking to ensure that the environmental effects of an action are fully understood and evaluated. The Council on Environmental Quality was established by NEPA to oversee the actions of Federal agencies in complying with the Act. One principal goal of their regulations

Table 1.1. Statutory Concerns Regarding Information for Decisionmaking.

National Environmental Policy Act	
	- decisionmaking in the face of uncertainty
	- information gaps and uncertainty made clear
OCS Lands Act	
	- relevant environmental and predictive information
Coastal Zone Management Act	
	- sufficient information must be provided
Endangered Species Act	
	- best data available

is to improve the decisionmaking process. They require - in the face of scientific uncertainty - that agencies clearly state this uncertainty. Essential information which can be obtained for non-exorbitant cost must be included. If the costs are exorbitant or if the means to obtain the information are not known, there is a positive requirement to weigh the need for the action against the risk of the environmental effects.

The OCS Lands Act, in discussing information needs, states that the "timing and location of exploration, development, and production of oil and gas .... shall be based upon a consideration of existing information concerning the geographical, geological, and ecological characteristics of such regions; and relevant environmental and predictive information for different areas of the Outer Continental Shelf.

The Coastal Zone Act Reauthorization Amendments of 1990 specify that OCS oil and gas lease sales are subject to the requirements of the Coastal Zone Management Act. States with approved coastal management programs can disagree with a consistency determination if they find that sufficient information has not been provided in the determination.

Under the Endangered Species Act, the U.S. Fish and Wildlife Service and the National Marine Fisheries Service can determine whether "additional data would provide a better information base from which to formulate a biological opinion." The Federal agency involved can agree to extend the formal consultation process and obtain the requested data or the managing agencies can issue a biological opinion using the best data available.

It is in this environment - where the need to make decisions based on imperfect information is recognized - that we will be conducting annual reviews of the information available to support OCS decisions.

For each lease sale we will determine the issues of concern to be addressed in the environmental impact statement (EIS) and conduct a review of the information available for the analysis of these questions. Because our EIS is an assessment of the risk to the environment from various OCS activities, it is appropriate to consider our evaluation of information in light of such an environmental risk assessment protocol and discuss how to best integrate such a review into our analytical process.

Environmental risk assessment is really nothing totally new to our environmental analyses. It is, however, a somewhat more structured and concrete framework within which to discuss environmental impact assessment. Before we deal with the information aspects of this approach, it is worthwhile to review some of the lexicon of this evolving field and point out synonyms we currently use to describe the concepts. Dr. Nesbitt will likely address these concepts from a much more expert vantage point in his presentation.

I have used the word "aspects" in the caption for Table 1.2 instead of steps because these processes are not necessarily linear - in fact, with annual analyses they become somewhat circular.

The first identifiable process is called risk identification; also known as issue identification or scoping in EIS jargon. In this process we must identify the attributes of the environment (called resources in our EIS) which are placed at risk by the risk factors (also known as impact producing factors or OCS activities).

Table 1.2. Aspects of Environmental Risk Assessment.

Risk Identification (issue identification; scoping)
- environmental attributes at risk (resources)
- risk factors (impact producing factors; activities)

Risk Components
- expected frequency of occurrence
- severity of the consequences

Information Base Review
- evaluation of knowledge for each:
  activity
  resource
  risk component

Risk Analysis
- the description of uncertain consequences
- characterizes the knowledge available for decision

Risk Management of OCS Activities
- decision affecting the consequences of an activity
- process of evaluation and selecting alternative actions
- identification of risk reduction measures
- deciding among alternative means of reducing risk
- monitoring the effectiveness of risk reduction measures
- no amount of data is a substitute for judgement

We conduct a preliminary risk assessment to distinguish between significant issues and issues not analyzed in the EIS. For example, a significant interaction is the risk to coastal birds of an oil spill emanating from OCS operations.

Every risk analysis has at least two basic components: the expected frequency of occurrence (or probability) of some event and the severity of the consequences were the event to occur.

We have begun to use a risk matrix as a graphic depiction and reminder of these relationships as shown in Figure 1.1.

Understanding the information content of this approach is crucial to successful analyses. Using the example of the risk to coastal birds of an OCS oil spill, we must know the likelihood of a spill occurring and contacting the bird's habitat and the severity or magnitude of the environmental harm caused thereby.

In our review of the information base available to analyze decision options, we must consider the state of knowledge for each activity, each resource, and each risk component. Only if we understand the weak links in this information web will we be able to provide decisionmakers with some measure of the uncertainty associated with our predictions.

Risk analysis is in fact sometimes defined as the description of uncertain consequences which characterizes the knowledge available for decision. Whether we verbalize this process as predicting the risks to the environment, or estimating the environmental effects, or forecasting the reaction of the ecosystem to perturbations, objective parties recognize that there are varying degrees of certainty with which these things can be known. Some risks, based on experience and years of study, can be known with fair certainty. For example, the more common effects of oil spills in the marine environment or the effects of drilling fluid disposal can be predicted with some degree of certainty. Other environmental risks, for example the risk to the red snapper population of large scale removal of oil platform artificial habitat, can be predicted with less certainty.

Risk management of OCS Activities will thus involve some degree of uncertainty because of information deficiencies. Our goal is to reduce the uncertainty associated with this process so as to provide the decisionmakers with a reliable basis for evaluating and selecting alternative actions. Then management decisions affecting the consequences of an activity can be rationally made. Identification of risk reduction measures can be accomplished and decisions among alternative means of reducing risks can also be made.

EXPECTED FREQUENCY OF ENVIRONMENTAL EFFECT	EXPECTED SEVERITY OF ENVIRONMENTAL EFFECT			
	1	2	3	4
A	1A	2A	3A	4A
B	1B	2B	3B	4B
C	1C	2C	3C	4C
D	1D	2D	3D	4D
E	1E	2E	3E	4E

Environmental Risk Index	Recommended Degrees of Concern
HIGH (1A, 1B, 1C, 2A, 2B, 3A)	Management Action and Corrective Action Recommended
MEDIUM (1D, 2C, 3B, 3C)	Management Attention Needed, Corrective Action Probable
MODERATE (1E, 2E, 3D, 3E, 4A, 4B)	Management Informed, Possible Corrective Action
LOW (4C, 4D, 4E)	Management Informed Only

Figure 1.1. Risk analysis matrix.

An integral component of risk management is of course monitoring the effectiveness of risk reduction measures selected. And, in all of this we must recognize that no amount of data is a substitute for judgement.

Our plan is to use our ITMs as the mainstay of our information base review on an annual basis. This new requirement for reviewing the information base provides an opportunity to better integrate many of the programs we already have ongoing and should be used to define issues to be addressed at subsequent ITMs and in subsequent studies.

If done in the context of a risk assessment protocol, we can better devise an information strategy. For instance, if we cannot estimate the frequency of an effect or the severity of an effect then information needs to be gained before we can even make a crude analysis of risk. If an activity falls within a high risk zone on the matrix, yet there is substantial uncertainty associated with the risk estimate, then additional information is warranted. Alternatively, if the risk is estimated to be low but we cannot make a very precise estimate of exactly how low, we may choose not to pursue additional information useful in analyzing this particular risk. Or, we may decide that it is most important to invest our information acquisition resources in devising or improving risk reduction measures for high risk interactions or in determining the effectiveness of risk reduction measures already in place. Of great use to decisionmakers would also be improvements in defining the degree of uncertainty associated with any particular analysis.

With an environmental risk assessment protocol as our focal point, we look forward to working with you through these meetings and other avenues as our consideration of information to support OCS decisions evolves into a strategy for our environmental studies program to become more fully integrated with and supportive of our environmental risk analyses.

Mr. J. Kenneth Adams is currently the Regional Supervisor for Leasing and Environment in the Gulf of Mexico OCS Region of the Minerals Management Service. Since 1984, he has been responsible for managing all OCS leasing and environmental activities in the Gulf of Mexico. He has served on Presidential and Secretarial assignments concerning OCS controversies and natural resource damage assessment. Throughout his government career since 1974, he has been associated with oil and gas issues including stints as a regulatory specialist with the Environmental Protection Agency and as a research scientist with the Fish and Wildlife Service.

Mr. Adams is a member of the American Bar Association, Section of Natural Resources, Energy, and Environmental Law, and the Louisiana State Bar Association. He is also a member of the Society for Risk Analysis. Mr. Adams received his J.D. from Loyola Law School in 1987 where he attained Moot Court and Law Review honors. He received his M.S. degree in marine science from the University of West Florida in 1972. He has published both law review and scientific articles on a variety of topics including wetlands regulation, oil spill contingency planning, and environmental risk assessment.

ADEQUACY OF INFORMATION FOR DECISIONMAKING

Ms. Dinah Bear
General Counsel
Council on Environmental Quality
Executive Office of the President

The Council on Environmental Quality (CEQ) was established by the National Environmental Policy Act (NEPA) of 1970, and was placed in the Executive Office of the President. The CEQ is a small agency whose role fluctuates from administration to administration, reflecting the priorities of the President.

The CEQ's activities include preparation of the annual Environmental Quality Report for the President's transmission to Congress. Also, the CEQ provides policy advice to the President on activities or issues of current interest. For example, the CEQ is currently involved in preparation of a national report and outreach efforts regarding the United Nations Development and the Environment Conference, to be held in Brazil in 1992. The CEQ is involved in formulating U.S. policy for that meeting, which promises to be important for possible conclusion of the climate change convention, possible development of a biological diversity convention, and a tropical forest agreement. Other areas of current policy advice include the wetlands controversy, biodiversity, and Coastal America. Also, the Chairman of the CEQ chairs the President's Commission on Environmental Quality, an advisory committee composed of private sector leaders, which focuses on ways the private sector can undertake new environmental initiatives which go beyond compliance with regulations to further progress in the environmental arena. And a new activity for CEQ is the President's Environmental and Conservation Challenge Awards to recognize environmental accomplishments.

A major role of the CEQ, and the main subject of this presentation, is oversight of the NEPA process. The CEQ acts as the administrative interpreter of the Act. The CEQ publishes NEPA regulations, which are binding on all Federal agencies, to implement the procedural divisions of NEPA. The CEQ reviews and ultimately must approve all Agency procedures which are formulated to implement the NEPA process in the various agencies. The CEQ works to resolve, through an informal process or a formal non-binding referral process, interagency disputes or issues raised by the private sector or representatives of State or local governments. The CEQ works with the Justice Department on litigation questions and provides advice to the Executive Branch on impacts of proposed legislation on NEPA. And CEQ provides educational presentations and training programs regarding NEPA.

The Minerals Management Service (MMS) invited me to speak about the adequacy of information, a very important issue. The letter of invitation suggested that the audience would be "particularly interested in information you can share on the distinction between 'critical' and 'desirable' information for informed decisionmaking in the context of CEQ determinations of acceptability of environmental impact statements (EIS)."

However, there has never been a court case, CEQ NEPA interpretation, or legal distinction between "critical" and "important." The closest distinction of this type in the NEPA regulations is "incomplete" and "unavailable" information, where if incomplete information relative to a reasonable foreseeable significant adverse impact is essential to a reasoned choice among alternatives, and the overall cost of obtaining the information is not exorbitant, then the agency has a duty to acquire that information.

"Essential" sounds a lot like "critical," so the question seems to be, what is "essential," what is "critical,", what is "important." Neither the CEQ, the courts, other Federal agencies, or the States can answer that question; only the MMS (for MMS actions) can answer that question.

Because of the controversies which surround Outer Continental Shelf (OCS) oil and gas program, other players have suggested answers to this question, or have suggested that MMS' answer is not adequate, but under NEPA there is no "holy grail" of adequacy. There is no objective checklist of criteria or standards by which an EIS may be judged adequate except by the agency's own decisionmaking needs.

The reason for this is very simple; neither NEPA nor the CEQ regulations mandate a process which results in a particular outcome; rather they demand a process. The heart of the NEPA process is thinking, especially of what information is needed to make a decision. The decisionmaker must articulate those factors which are important in making the decision.

The CEQ has received very few complaints about the MMS for compliance with the NEPA process. Even critics of the OCS program have agreed that MMS' compliance with the NEPA process is good, that MMS' work is in many respects professional and credible; that it is done by good people. However, they have questioned the linkage between the information that is gathered and the actual decisionmaking process.

The decisionmaking process is unique and generic to each Federal agency. This is one reason for courts' deference to agencies in NEPA litigation. The CEQ regulations are full of flexibility, particularly in terms of content, and also in the linkage between the information and decisionmaking, because of the broad range of activities covered.

The courts are typically deferential to the agencies in NEPA litigation, and litigation is decreasing. During the mid 1970's, we had about 180 NEPA lawsuits per year. In recent years, the annual caseload has been about a quarter of that, with the government winning about 95-97 percent of those cases. The court repeatedly, in NEPA litigation, has deferred to the agency's discretion regarding the adequacy of information needed for decisionmaking.

But the linkage between substance and procedures and management of the process sometimes leaves much to be desired. It is important to remember that the value of the NEPA process lies in its integration with the planning process, not production of good documents which can withstand litigation challenges. The NEPA's purpose is to infuse environmental values into decisionmaking and to conduct the process of analysis in a participatory manner.

Many of the problems and frustrations of NEPA that CEQ or others see are not the kinds of issues which are dealt with through litigation. Most agencies now, certainly MMS, have become skilled at the process in terms of public participation, information gathering, and other basic "how do you do it" aspects.

Currently, CEQ is trying to focus on two rather broad categories of concerns. The first is "managing the process." This includes focusing on sections of the CEQ regulations designed to reduce delay, duplication, and paperwork. Examples of problems within the context of these regulations include an agency not integrating an EIS into a management plan, but having separate documents running on separate tracks, with separate public hearing processes; not setting time limits; not coordinating adequately with State governments; not complying with page limitations; and producing an EIS which cannot be read and understood by the average person.

The second broad category of focus is integration of the NEPA process into the decisionmaking process. This recognizes that each agency is unique, with politics, policies, personnel, and personalities which give the agency its own culture. The challenge to agency staff is to figure out how best to integrate the NEPA process into the agency's culture.

This gets back to the issue of what kind of information is needed and valued by the decisionmaker. The information in an EIS should not be influenced only by the public, by other Federal agencies such as the Fish and Wildlife Service, by coastal States, but also by the actual needs of the decisionmakers, such as those within the MMS and the Department of the Interior. For instance, what kind of information would lead the MMS to believe that oil and gas production can be appropriately undertaken in a particular area? And conversely, what kind of information would cause MMS to decide that initiating a lease sale in a particular area would not be appropriate? Neither NEPA, CEQ regulations, the courts, the States, nor other interested parties can decide; the particular answers to these questions must be decided by the MMS.

Ken Adams said earlier that "no amount of data can substitute for judgement." This is an important statement. The MMS spends more money and time focusing on information gathering than many other agencies and has developed an incredible base of knowledge about the marine environment in response to NEPA controversies. But all the information in the world will not lead to good decisions unless it is the kind of information the decisionmaker needs to make a good decision. And, of course, producing the "perfect EIS" will not change the attitudes of OCS critics or reduce the controversies associated with the program.

Incomplete and unavailable information has been mentioned previously. Originally, NEPA and the CEQ regulations required a "worst case analysis" if an agency proceeded in the face of uncertainty. The issue of "worst case analyses" became extremely controversial in the early 1980's, and the CEQ regulations were amended in 1986 following ANPR and APA rulemaking (40 CFR 1502.22). These amendments include two substantive changes; deletion of the "worst case analysis" and elimination of the requirement for agencies to "weigh the need for the action against the risk and severity of possible adverse impacts were the action to proceed in the face of uncertainty" while in the process of preparing an EIS.

The CEQ believed that the weighing of risks and benefits for the particular proposal at hand is properly done after completion of the entire NEPA process and must be reflected in the Record of Decision. Nothing, however, prohibits a decisionmaker from withdrawing a proposal during the course of the EIS preparation.

The final amendment requires all Federal agencies to disclose the fact of incomplete or unavailable information when evaluating reasonably foreseeable adverse significant impacts on the human environment in an EIS and to obtain that information if the overall costs of doing so are not exorbitant.

"Incomplete information" is information which the agency cannot obtain because the overall costs of doing so are exorbitant in the context of resources available to the agency. "Unavailable information" is information which cannot be obtained because the means to obtain it are not known.

If the agency is unable to obtain the information because overall costs are exorbitant or because the means to obtain it are not known, the agency must (1) affirmatively disclose the fact that such information is unavailable; (2) explain the relevance of the unavailable information; (3) summarize the existing credible scientific evidence which is relevant to the agency's evaluation of significant adverse impacts on the human environment; and (4) evaluate the impacts based on theoretical approaches or research methods generally accepted in the scientific community.

Impacts which have a low probability of occurrence but catastrophic consequences should be evaluated if the analysis is supported by credible scientific evidence and is not based on pure conjecture, and is consistent with the "rule of reason," or common sense. Evaluations of these sorts, and analyses where the means to obtain information are not known, include presentation and consideration of responsible opposing views which are supported by theoretical approaches or research methods generally accepted in the scientific community.

A less well known requirement of CEQ regulations (40 CFR 1502.2) requires that the EIS state how alternatives considered in it and in the Record of Decision will or will not achieve the environmental policies set forth in Title 1 of NEPA and other environmental laws and policies. These policies and goals are seldom read, often reinvented, but are well worth remembering. Title 1 sets forth that the environmental policy of the Federal government, "in cooperation with State and local governments and other concerned public and private organizations, is to use all practicable means and measures, including financial and technical assistance in a manner calculated to foster and promote the general welfare, to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans" (42 U.S.C. 4331).

The CEQ recently conducted a random survey of sample EIS to see how this requirement was being fulfilled. The results were mixed, but two themes ran throughout the responses of those agencies which seemed to be having difficulties fulfilling this mandate. First, the agency did not have substantive environmental objectives which guided their decisionmaking, and thus no criteria by which to judge the adequacy of alternatives for purpose of decisionmaking; and second, the decisionmakers were not personally involved in the NEPA process.

Current initiatives for CEQ in the NEPA area include an initiative to identify and publicize examples of successful models of the NEPA implementation not only for compliance with the law and regulations, but also for incorporation in the decisionmaking process. Also, CEQ is holding a series of regional 3-day conferences on NEPA implementation, with a special focus on ecological issues. We are exploring an expansion of education and training opportunities for NEPA practitioners, and will continue to strive for more effective, efficient NEPA compliance throughout the Executive Branch.

Ms. Dinah Bear has served as General Counsel for the CEQ since January 1983, and served as Deputy General Counsel for CEQ from 1981 to 1983. Ms. Bear has lead responsibility for oversight of implementation by Federal agencies of the NEPA. She received her Bachelor of Journalism from the University of Missouri at Columbia, and her Juris Doctorate from McGeorge School of Law in Sacramento, California. She currently chairs the American Bar Association Standing Committee on Environmental Law.

RISK ANALYSIS AS A TOOL TO FOCUS DECISIONMAKING: SOME DO'S AND DON'TS OF RISK ANALYSIS

Dr. Dale M. Nesbitt
Senior Vice President
Decision Focus Incorporated

I have been invited here this morning to talk about how to use risk analysis to focus one's thinking, which I have interpreted to mean how to make better decisions. I have interpreted my charge quite broadly. In particular, I plan to address some of the most important "Do's" and "Don'ts" of risk analysis, illustrating in particular how the seductive allure of risk analysis can easily lead us astray. I have chosen to make my remarks largely outside the emotionally charged realm of environmental or economic risk analysis, using simple illustrative examples from other fields liberally. I find it enlightening to present the critical "Do's" and "Don'ts" using simple, highly personalized examples. I find that highly personalized examples are must easier to understand and accept at the visceral level.

I sometimes compare risk analysis to chemotherapy. The poisons used in chemotherapy are powerful toxins. They are designed to kill every cell in the body. One hopes that the treatment kills the bad cells faster than it kills the good cells and that the patient lives. Risk analysis is similar in that the concepts are seductively appealing, so much so that they are more easily abused than other techniques. With risk analysis, one must be vigilant to ensure that the good outshines the bad; otherwise, unaided judgment may actually be better than formal risk analysis.

Risk analysis, also known as decision analysis or statistical decision theory, combines alternatives (what can we do), information (what do we know), and preferences (what do we want) in a logical package that has a significant implication for the "right decision." Figure 1.2 illustrates how the three rudimentary puzzle pieces are integrated by risk analysis logic into good decision with maximal probabilities of good outcomes. I will focus primarily on the question of uncertainty or probabilities in this talk. This is not to devalue or deemphasize the other areas. It is to say, however, the probabilities are invariably the most important and most abused part.

The advantages of formal risk analysis are several, as indicated in Figure 1.3. Perhaps the primary advantage is that it "shines sunshine" on the process and each of its disparate individual elements. It serves the same role that "freedom of the press" serves in our political system. It ensures that assumptions and conclusions are not surreptitiously or unscrupulously "snuck by" the public. The formal risk analysis method brings probabilities to the table so that they can be examined and debated. It allows combination of subjective and objective inputs and allows ex ante identification of each. Happily, software and methodologies have been developed and are now available to help perform risk analysis. They help people get the probabilities right, which is not an easy task. Most of us remember how counterintuitive and difficult our probability and statistics courses in high school and college were. It always seemed rather easy to make the wrong assumptions, get the wrong answer, or make the wrong calculations. Automation has assuredly helped us in this score, but probabilities are still very, very hard.

The disadvantages of formal risk analysis illustrated in Figure 1.4 are outweighed by the advantages, but they do exist. Risk analysis is disarmingly appealing since the process seems so simple. Disarming is the operative word. It looks so darn good in form and format that the true content can sometimes be overlooked. It can be used to "pull a fast one" on people who are allured by its guile. Formal risk analysis can provide a fancy, high technology framework for making egregious mistakes. Just as one can record garbage on a compact disk and render it more listenable, one can embed garbage in risk analysis and render it more palatable and salable. Risk analysis can be an effective a vehicle for advocacy rather than truth or objectivity. It can be used to advocate a point of view rather than to analyze a course of action. Vigilance as to the worst misuses, which I will try to illustrate in this talk, is the best defense.

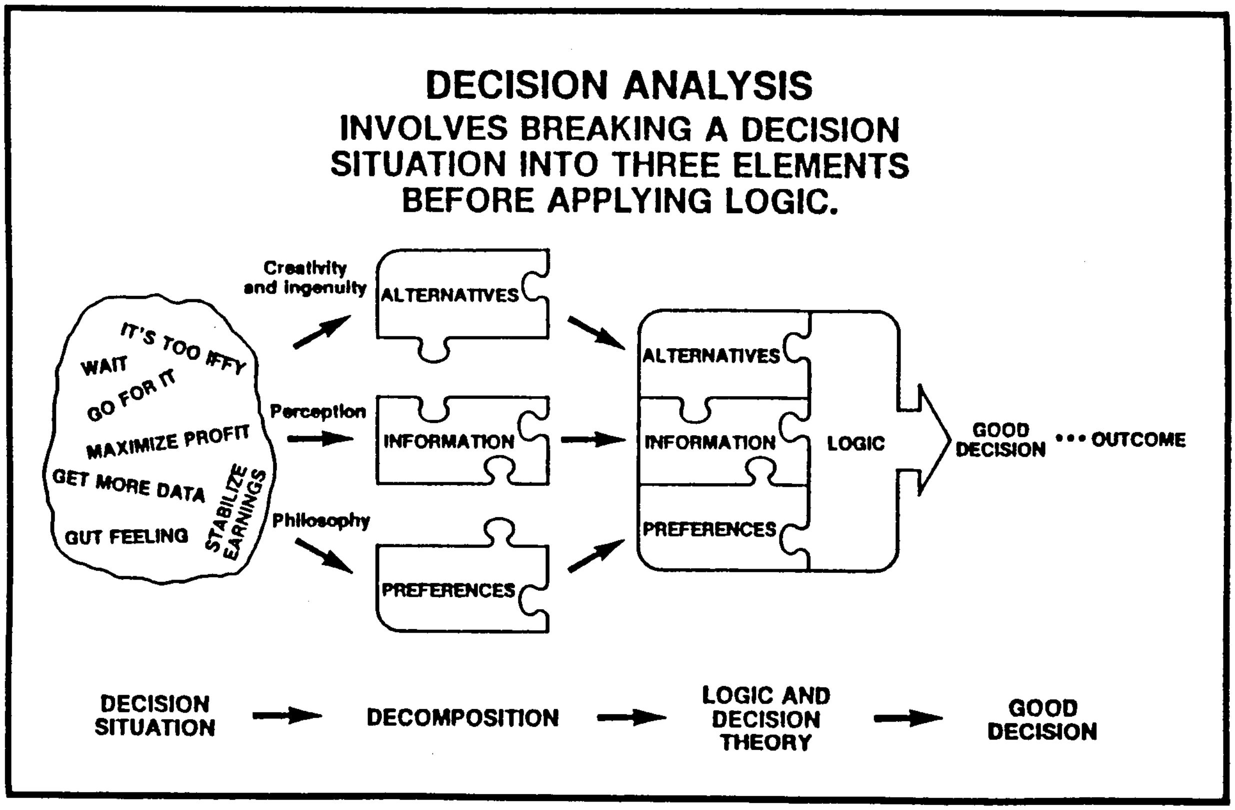

Figure 1.2. Decision analysis involves breaking a decision situation into three elements before applying logic.

ADVANTAGES OF RISK ANALYSIS

- Shines sunshine on the process and each of its disparate individual elements
- Brings probabilities to the table
- Combines subjective and objective inputs
- Software and methodology now exist to help you
- You can get the probabilities right

Figure 1.3. Advantages of formal risk analysis.

DISADVANTAGES OF RISK ANALYSIS

- It is disarmingly appealing
- It provides new ways to make egregious mistakes
- It can be a vehicle for advocacy rather than objectivity

Figure 1.4. Disadvantages of formal risk analysis.

NOTABLE PAST EXAMPLES, GOOD AND BAD

At the risk of starting out in the negative, I will offer several historical examples of the egregious misuse of risk analysis. I will follow with a few equally compelling success stories.

- The 1975 Interagency Task Force on Synthetic Fuels Commercialization was given the task of justifying President Ford's multibillion dollar synthetic fuels incentives program. The President had announced and advocated a multibillion dollar federal subsidy program to commercialize synthetic fuels from coal and oil shale. An extensive and elaborate risk analysis showed that the proposed program would be a monumental waste of money, as OPEC could not possibly maintain the high oil price. Unfortunately, for political reasons, the conclusion was largely ignored. With benefit of almost 20 years hindsight, the cost of the synthetic fuels technologies that were and would have been subsidized under the plan is more than twice the present cost of crude oil, a colossal waste. The one facility that was built as a result of the program, the Great Plains Coal Gasification Plant, sits idle on the South Dakota plains. It is a $2 billion discotheque, a $2 billion blunder and testament to politics gone awry. Its market value is zero. The variable operating cost of the plant far exceeds the local price of natural gas!

- The proposal to build the Alaska Natural Gas Transportation System (ANGTS) was promoted by Northwest Pipeline and various members of Congress in 1981. Promoters sought and received Congressional approval for a $50 billion pipeline from Prudhoe Bay to the lower 48 states across Canada. The project would deliver Prudhoe Bay gas to markets on the West Coast and in Midwestern states. The risk analysis conducted was based on highly suspect, biased, incorrectly gathered judgment regarding future oil and gas prices (Figure 1.5). In particular, the project was justified on the tenuous assumption that gas price would be just like oil price and that oil price would continue at exorbitant levels.[1] The consensus line in the diagram, upon which the project was justified, is a blatant caricature of analytical dishonesty and lack of integrity. As a result of this biased, politically-motivated risk analysis, Northwest Pipeline has testified that it has invested about $1.5 billion in unrecoverable funds to date. The Canadian partner, Foothills Pipeline, has testified that it has invested an additional $0.5 billion in unrecoverable (wasted) funds.

[1]We told the study participants that both assumptions were dead wrong. Against our advice, they went ahead with a completely arbitrary and subjective estimate of oil and gas prices.

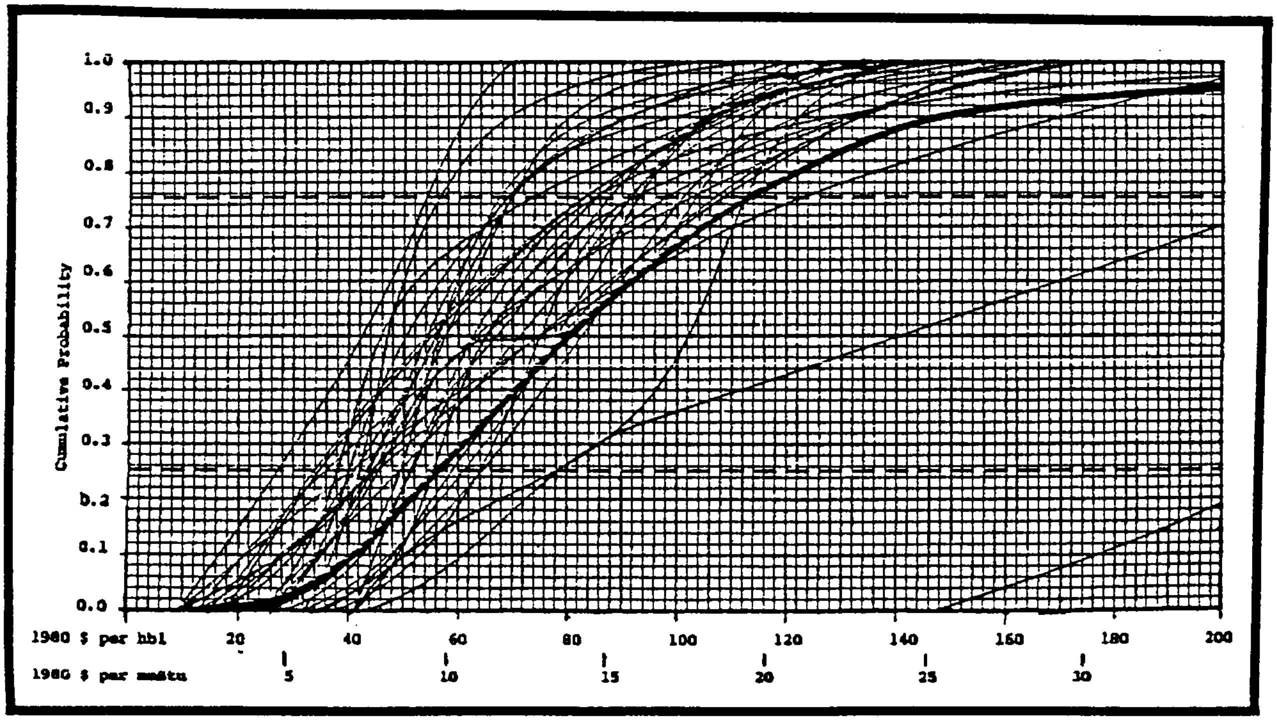

Figure 1.5. Individual experts' and composite distributions of the price of world oil in the year 2000.

It is humorous to further examine the expert judgments made in 1980 regarding the price of world oil in the year 2000. The heavy black line in Figure 1.5 is the consensus judgment. It indicates a median value at about $80/barrel. That is, real oil price in 2000 should be $80/barrel expressed in 1980 dollars. For reference, the price of oil today in 1992 is approximately $10/barrel expressed in the same 1980 dollars. We are low by a mere 800 percent!

What should have been done in 1981 is to rely on a structural model of oil and gas prices. Many were available, and most were characterizing ANGTS as uneconomic and wasteful.

- The Rasmussen Study on Commercial Nuclear Power Plant Safety in the early 1970s conducted a risk analysis showing that the risk of spontaneous nuclear plant failure was infinitesimal but that the risk of human-induced failure (human error and/or deliberate sabotage) was significant. Not only were the probabilities of damage from human events higher but also the consequences were worse. This finding that human rather than physical problems were the leading term in nuclear plant risk quickly became such a hot issue that the human risk portion of the study was "killed." The results of the risk analysis of human error was suppressed. Three Mile Island and Chernobyl both brought home the importance of human error. This was foreseen 15 years earlier in the Rasmussen study.

The problems with these studies generally emanate from the five problems I will discuss shortly, what I term the five fallacies of risk analysis. Before going to the fallacies, however, let me contrast the foregoing bad examples with a few of the good examples of formal risk analysis.

- The Department of Energy (DOE), Fossil Energy Office's analysis of technical risks of tertiary (enhanced) oil recovery (EOR) in 1981 was a unique and fascinating risk analysis. The EOR research and development (R&D) involves significant out-front costs and faces highly uncertain technological and geological barriers. DOE's view was that the technical risks were daunting, so daunting that nobody would undertake technology development without significant government participation. Quite surprisingly, however, risk analysis demonstrated that the technological risk was minuscule relative to oil price market risk. The conclusion was that in spite of the technological uncertainties, EOR R&D was and is an effective hedge against the much larger uncertainties of oil price and market availability. A further conclusion was that any government involvement should be "at the margin" of the R&D that industry itself would otherwise undertake. The appropriate government role was to accelerate R&D that would otherwise be inappropriable to private entities.

- Atlantic Richfield Company (ARCO) in 1985 (before oil prices had dropped below $27/barrels) conducted a study of future oil prices. They needed answers to a number of questions: What is a legitimate upper bound on future oil price (i.e., how high is high)? What are the precursors for high future oil price (what would it take for high price)? What is a legitimate lower bound on future oil price (how low is low)? What are the precursors for low future oil price (what would it take for low price)? What is a legitimate probability distribution between the two bounds? ARCO released a paper publicly at the end of 1985 containing a probability distribution over oil price developed from risk analysis in tandem with two structural models of oil price. ARCO was successful in "calling the turn" on oil prices at the time, and their rating on Wall Street continues to reflect their perspicacity. In particular, they were able to presage the significant drop in oil prices before it occurred and we believe before their competitors.

- An example of a risk analysis in the petroleum industry is shown in Figure 1.6, the "wildcatter's problem," where the uncertain variables are shown as circles, the decision variables are shown as boxes, and the models are shown as double circles. The arrows between the various variables represent the probabilistic relationships between them. Much of the seminal literature regarding use of decision analysis in the petroleum industry has the basic form in Figure 1.6. Producers have built and executed risk analysis of various properties quickly and efficiently because commercial software systems are now available to incorporate all the necessary alternatives, probabilities, and values and calculate the final bottom line. My company, Decision Focus Incorporated (DFI), offers one such program at a price comparable to Lotus 123 that allows the solution of influence diagrams of the form in Figure 1.6 or larger on a personal computer. It is called InDia (shorthand for Influence Diagram).

The seminal textbook on risk analysis in the petroleum industry[2] makes the following point about the success of property evaluation using risk analysis:

> *"...we may have the need to quantify or assess many types of risks:*
>
> - *Risk of an exploratory or development dry hole*
> - *Political risk*
> - *Economic risk*
> - *Risk relating to future oil and gas prices*
> - *Risk of storm damage to offshore installations*
> - *Risk that a discovery will not be large enough to recover initial exploration costs*
> - *Risk of at least a given number of discoveries in a multi-well drilling program*
> - *Environmental risk*
> - *Risk of gambler's ruin*
> - *etc."*

[2]Newendorp, P.D., *Decision Analysis for Petroleum Exploration*, Petroleum Publishing Company, Tulsa, Oklahoma, 1975, p. 299.

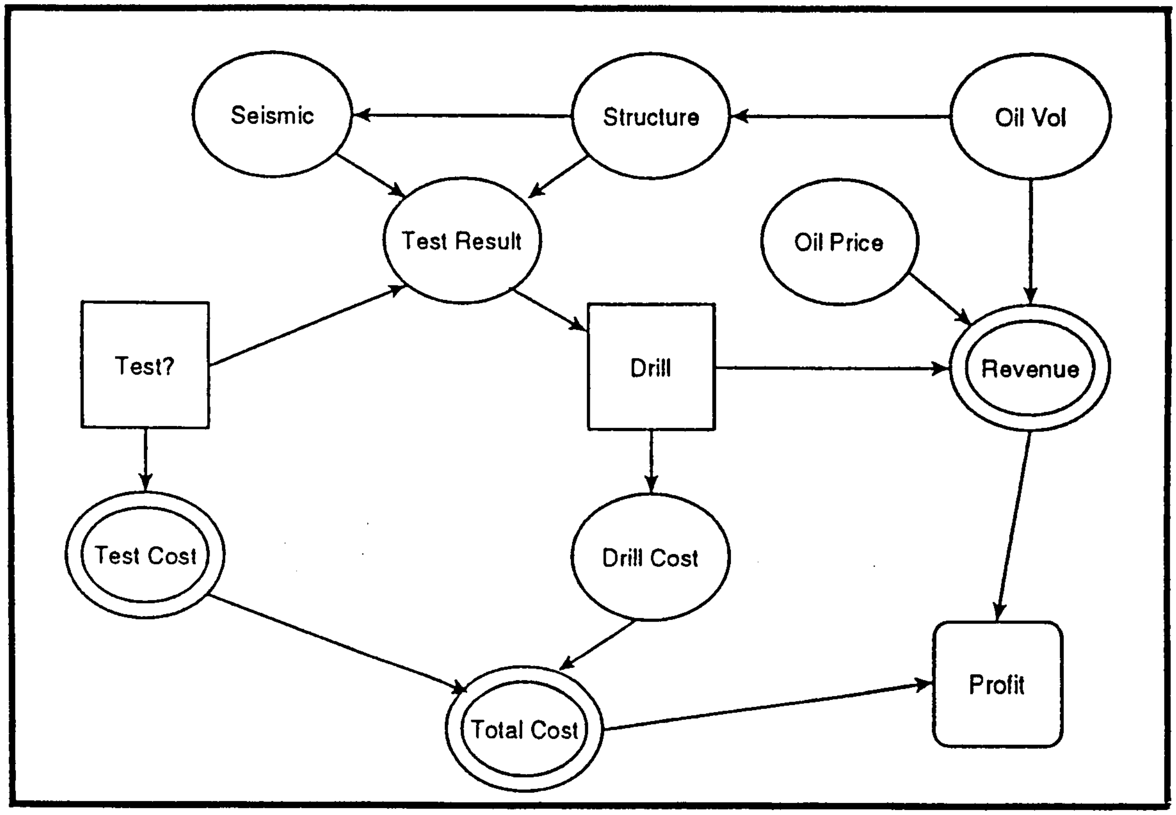

Figure 1.6. Basic form for decision analysis in the petroleum industry.

FALLACIES OF RISK ANALYSIS

This section begins with several fallacies of risk analysis that can turn an otherwise competent and professional job into a dishonest or incorrect sham. I have attempted here to include what I consider to be the most important and most frequently encountered fallacies.

Fallacy No. 1 – Probabilities Can Be Whatever I Want Them to Be. My Judgment Is Supreme.

Fallacy number 1 is the belief, held by many people, that it is perfectly acceptable to view all probabilities as subjective, arbitrary, and completely open to judgment. There is no structural "right answer." The decisionmaker is free to use whatever probabilities he or she wishes. I believe that the easy availability of decision and risk analysis methodology literally beckons for subjective inputs. They are so easy! In reality, most probabilities are neither arbitrary or subjective. For some variables, it is not appropriate to even estimate many probabilities. The phenomena that govern them arise from structural processes whose underlying probabilistic basis is well understood.

As an example, we often hear in stock and commodity markets that "The market is efficient." This means that everything that is known or knowable is already embedded in the price. It is both wrong and unjustifiable to make independent, exogenous, subjective judgments about price or about the market if it is efficient. It is impossible for any individual to outsmart or outthink it. He or she is equally likely to be wrong high or wrong low. Subjective estimates of stock prices or oil prices are systematically incorrect.

If we cannot make subjective estimates of market prices, what are we to do? Figure 1.7 depicts three extremes. Proper and correct price expectations may be forecast by market observations, by structural models and data, or by a survey of outside experts. Market observations are the most

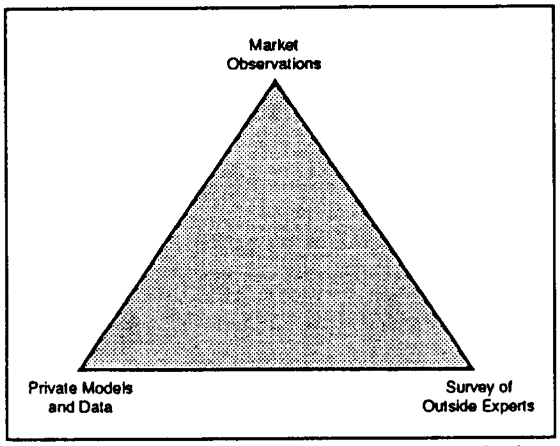

Figure 1.7. Three extremes used to calculate probability.

reliable source of information. For example, everything that is known or knowable about securities that are actively the prices of those securities. No individual can be systematically "smarter" unless he/she has insider information. To assume otherwise is to speculate. Public bodies should not be speculating; they should be hedging, pooling, and mitigating risks.

Surveys of independent external experts regarding future prices in efficient markets are unreliable. In fact, they are utterly hypothetical, mere speculation. No expert can systematically beat the market. All relevant judgments are already embedded in the market. Irrelevant, hypothetical, or abstract judgments have no value. In performing risk analysis, do not waste any time or money with surveys of external experts. They are absolutely worthless. Rather, we recommend using structural models in a way to be described shortly.

In projecting future prices for use in risk analysis, structural models and data are the only respectable alternative to direct observation of market signals. Anything not observable in the market should be structurally modeled using a respectable economic theory (e.g., supply-demand balancing under rational expectations). In building such models, one should take care to simulate the simultaneous pursuit of self-interest by independent, autonomous, economic agents. One should try to represent an efficient market, considering the players, their alternatives (resources), their information (uncertainties), their preferences (objectives), and their interrelationships. One should not simply build a spreadsheet accounting system. One should get fundamental, structural, and explicit about the constituent elements and structure of the market.

In an ideal world, one should operate entirely by market observations, as indicated in Figure 1.8. By so doing, one could hedge all price risk. However, in a non-ideal world for which markets are not totally efficient and for which complete futures markets may not exist, one should operate along the line between market observations and structural modeling of market activities as indicated in Figure 1.9. In evaluation of risk, economic or otherwise, stay away from expert surveys. Instead, choose to combine models with observations. By so doing, one runs the least risk of making the wrong probability assessment and defiling the analysis. The hybrid observation-modeling approach suggested in Figure 1.9 is far, far preferable to the oil price spaghetti in the ANGTS analysis in Figure 1.5. Had such methods been used in 1981, the Alaskan Gas Pipeline fiasco would have been thwarted and over $2 billion and a succession of diplomatic failures with Canada would have been prevented. The message here is harsh: *If you ever see direct subjective estimation of future market prices, consider the analysis to be worthless and incorrect.*

There is another rather frightening aspect of direct subjective estimation of prices and other parameters. There is tremendous room for abuse and bias. In approximately 1985, a government contractor with whom I am familiar was asked to assemble future oil price forecasts and examine whether they "clustered" together depending upon the nature of the organization that offered them. The four types of organizations considered were Banks, Governments, Consultants, and Oil Companies. Indeed, the consultant found that there were four distinct clusters of forecasts for the four distinct types of organizations as shown in Figure 1.10.

Which organizations would you associate with which of the forecast lines? The answer is not at all surprising. The organizations were clustered as shown in Figure 1.11. Notice that banks were at the bottom, the lowest and most conservative oil prices of the group. This is quite understandable. It is

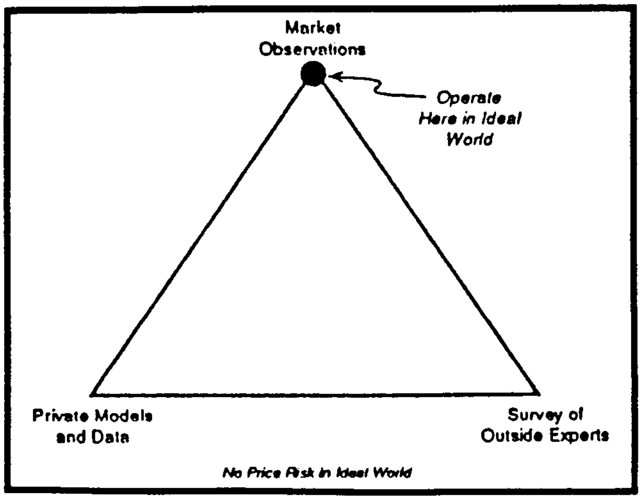

Figure 1.8. Using market observations to calculate risk.

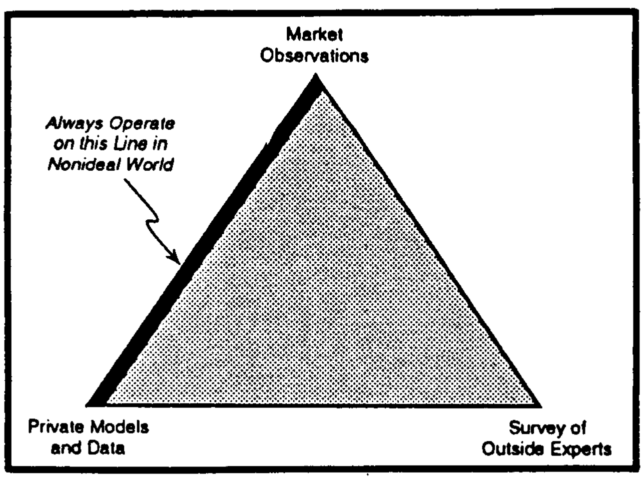

Figure 1.9. Hybrid observation - modeling.

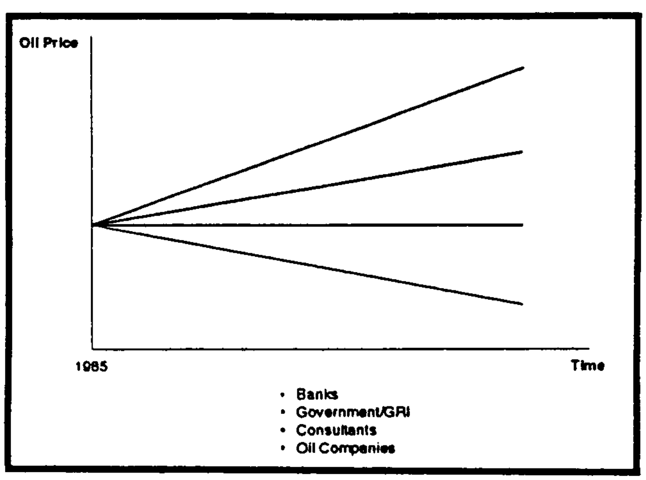

Figure 1.10. Four distinct types of organizations showing four distinct clusters of forecasts.

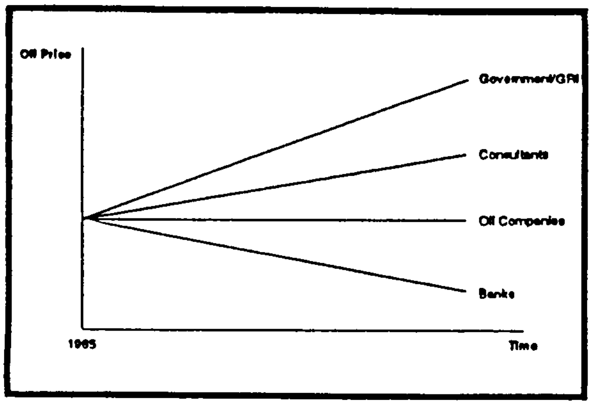

Figure 1.11. Clustered organizations.

their money that is being invested in oil projects. Banks were attempting as a risk mitigation measure to discount future oil prices and thereby discount the value of candidate projects that would be offered them for consideration. They were biasing their estimates low in order to place the burden of proof on project investors.

Second from the lowest were the oil companies. Their equity dollars were at risk and their ability to service debt was also at risk. However, all oil companies have internal advocates for various ventures who would act against the cold, hard-hearted, cynical attitudes of the banks, elevating the aggregate oil price forecast just a little bit. While conservative, producers were not as conservative as banks.

At the opposite extreme, government forecasts are at the highest extreme. Government decisionmakers are motivated to "think high." High future oil prices serve their interests by keeping their profile high. They reasoned: "Who would need a government energy agency if oil prices were rock bottom low?"

Just as one might suspect, consultants fall squarely in the middle. Serving banks, oil companies, and government agencies, consultants are strongly motivated to fall somewhere in the middle. Extreme opinions do not sell consulting work. Iconoclastic prognostications do not foster consulting work. Middle of the road, conventional wisdom, presented with authority and backed by apparent consensus sells consulting work.

In concluding this discussion of the fallacy of arbitrary probabilities, there are two types of biases which can creep into risk analyses of which you should be cognizant. The first type is *motivational bias*, where judgments are colored by the reward and penalty system. This bias is expressed by individuals who have a vested interest in the outcome of an event, such as the project manager for an R&D project, a football coach, or a Congressman who stands to win votes by supporting the Alaskan Natural Gas pipeline system. The second type is *cognitive bias*, where judgments are colored by experience and knowledge. If what you know biases how you think about the world, you may be guilty of cognitive bias. This bias is expressed by individuals, such as surgeons or military generals, whose past knowledge and experience limits their ability to think broadly. "If all you have is a hammer, everything looks like a nail."

Fallacy No. 2 – Probabilities
Are Intuitive; I'll Know
When They Are Right.

Fallacy number 2 is that probabilities are intuitive. "When they are right, I'll know." In reality, probabilistic calculations are extraordinarily counterintuitive. They often surprise us. The right answer is often not particularly intuitive. People are poor judges of probabilistic information. Following are two rather amazing case studies that never fail to underscore just how hard and how counterintuitive probabilities can be.

A Medical Example

Suppose that a woman enters a physician's office for her annual physical. Suppose that the woman is in an age and health category with a medical history such that 1 in 100 similar women develop breast cancer. That is, before any examination, diagnosis, or testing is rendered, the woman is in a population such that there is a 1/100 probability of having breast cancer. (Assume there is no reason to believe that the woman is not representative of her population cohort at large.)

During tactile examination, the doctor detects a small lump in the right breast and orders a needle biopsy (i.e., stick a needle into the area of the lump, withdraw cells, and examine microscopically for cancer cells). The medical literature reports the biopsy test to be 95 percent reliable. That is, for women who actually have breast cancer, the biopsy has proven successful at correctly detecting such cancer 95 percent of the time. That is, the "false negative" rate for women who actually have breast cancer is only 5 percent. The test is right 19 times out of 20. The medical literature also reports that the biopsy has a 10 percent "false positive" rate. That is, for women who are cancer-free, the biopsy test will correctly test negative 90 percent of the time and incorrectly test positive 10 percent. Most people would agree that the biopsy test is quite reliable. The "false positive" rate is only 10 percent and the "false negative" rate is only 5 percent. Not bad!

Figure 1.12 illustrates the four possible scenarios that can occur with the woman. As indicated in the leftmost level of the tree, the woman either has or does not have breast cancer. As indicated in the rightmost level of the tree, the biopsy test is either positive or negative. The four scenarios indicated in the tree can be summarized as follows:

1. Woman has cancer *and* biopsy test positive ("correct positive") with probability 95/10000.

2. Woman has cancer *and* biopsy test negative ("false negative") with probability 5/10000.

3. Woman does not have cancer *and* biopsy test positive ("false positive") with probability 99/1000.

4. Woman does not have cancer *and* biopsy test negative ("correct negative") with probability 891/1000.

The probabilities associated with each of these four scenarios are indicated at the right of the tree in the figure. These probabilities are calculated as the product of the probabilities of each of the two events that comprise the scenario (whether she has cancer and how the biopsy test came out.)

Suppose the doctor commissions the biopsy test, the results come back to the doctor several days later, and the biopsy test result is *positive*. The biopsy test indicates that the woman indeed has breast cancer. After seeing the positive biopsy test result, what is the probability the woman really does have breast cancer? It is tempting to assume that since the biopsy test is 95 percent reliable, the probability the woman actually has breast cancer is 95 percent after the doctor receives the positive test. After all, one might reason, the biopsy has only a 5 percent false negative rate. Such an assumption would imply that the probability the woman has cancer increases from 1 in 100 to 95 in 100 (a 95-fold increase) after the biopsy test result comes in positive. (A surgeon I presented with this example insists that the probability is 95 percent and extreme emergency steps should be taken immediately.) Is 95 percent the right answer after the doctor sees the positive biopsy test result? Or is the right answer 90 percent, one minus the false positive rate? Does the false positive rate have anything at all to do with the final answer, the probability that the woman really has breast cancer? What does the false negative rate have to do with it? Should the woman undergo a radical mastectomy without any more tests or diagnosis?

To calculate the correct answer, we begin by calculating the probability that the biopsy test is positive. Notice that the biopsy test result is positive in scenarios 1 and 3. Therefore, the overall probability that the biopsy test result is positive is the sum of the probabilities for both of those scenarios. Adding the probabilities from scenarios 1 and 3, the overall probability of a positive biopsy test is 1085/10000. Similarly, the biopsy test result is negative in scenarios 2 and 4. The overall probability of a negative biopsy test result is therefore the sum of the probabilities in those two scenarios or 8915/10000. For persons in this health, age, and medical history category, the lab reports positive biopsy results 1085/10000 or just over 10 percent of the time. We have associated these probabilities with the two possible biopsy test outcomes in Figure 1.13.

We now recreate the same four scenarios as above but with the biopsy test outcome occurring first and the cancer outcome occurring second as shown in Figure 1.14. The figure shows the biopsy test outcomes at the leftmost level of the tree and the cancer outcomes at the rightmost level. Notice that the probability the woman has cancer if the biopsy test is positive is indicated by an x and the probability the woman has cancer if the biopsy test is negative is indicated by a y.

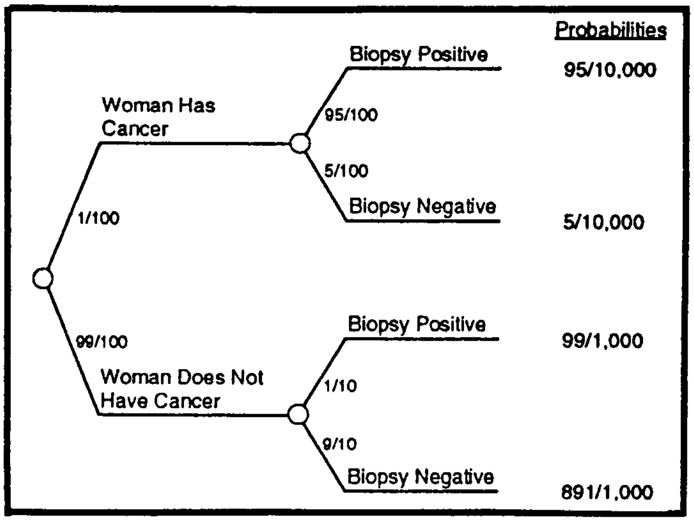

Figure 1.12. Probability of outcome of biopsies.

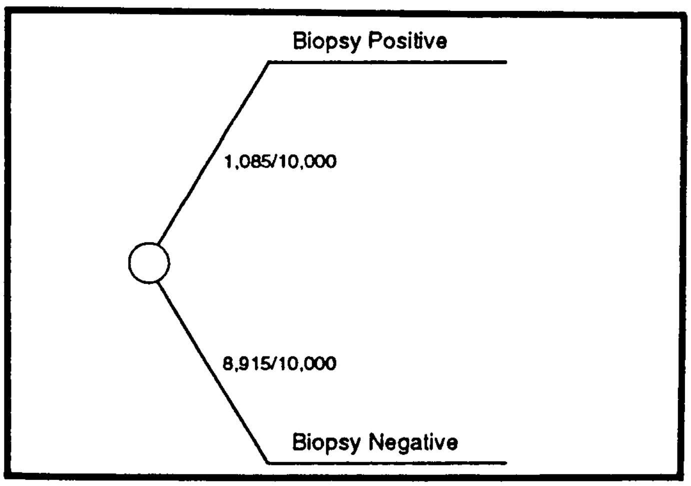

Figure 1.13. Two possible biopsy outcomes.

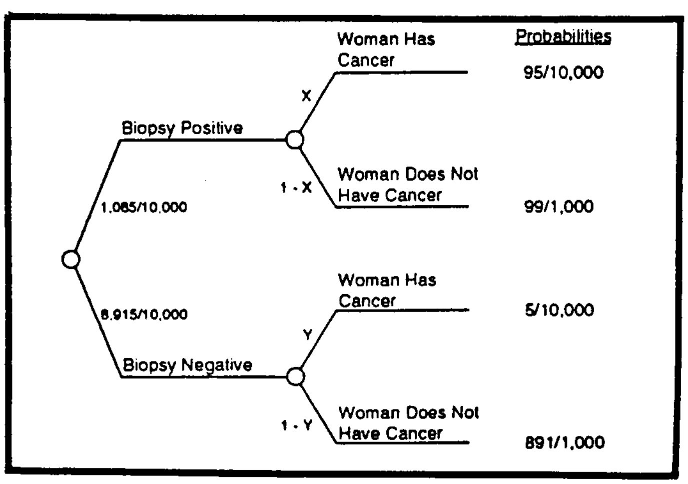

Figure 1.14. Four scenarios for possible biopsy outcome.

In order to calculate x, we notice that the probability the biopsy test is positive is 1085/10000 and the probability that scenario 1 occurs (woman has cancer and biopsy test is positive) is 95/10000. We know that the probability of the overall scenario is the product of the individual event probabilities, i.e.,

$$\{biopsy\ positive\}\{cancer\,|\,biopsy\ positive\} = \{scenario1\}$$
$$\frac{1085}{10000}x = \frac{95}{10000}$$

(We use the {.} notation to designate "probability of.") Solving for x, the probability that the woman actually does have breast cancer given that the biopsy test came back positive, we obtain the rather startling result that

$$\{cancer\,|\,biopsy\ positive\} = \frac{95}{1085} = 0.08756$$

Making the same calculation for y, we can create the probability diagram in Figure 1.15 with the biopsy test outcome occurring first and the cancer outcome occurring second. The diagram contains that rather astounding conclusion that

> *The probability that the woman actually has breast cancer is approximately 9 percent after the test result came back positive!*

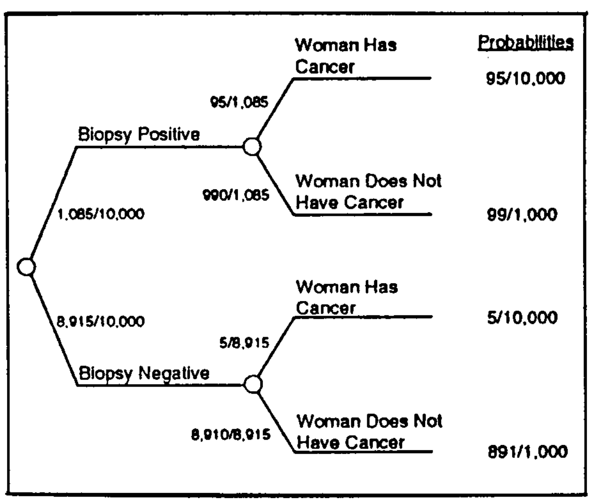

Figure 1.15. Probability of biopsy outcome using risk analysis.

Simply astounding! The positive biopsy test increases the probability that the woman has breast cancer from its initial level of 1/100 to the new level of 0.08756, approximately a 9-fold increase in the probability she has breast cancer. Had the biopsy been negative, her probability of having breast cancer would have been reduced from its initial level of 1/100 to the much lower level of 0.000561, more than a 20-fold reduction.

Are these probabilities intuitive? Who would have guessed the right answer without the analysis? Who would have guessed that the probability the woman really has cancer is below 10 percent *after* hearing that her own biopsy test was positive? Who would have believed it without the analysis? Who would have known how to consider the false negative and false positive possibilities? Who would have recommended immediate radical mastectomy? Who would have recommended additional testing, deferring any decision until after then? How much value does the biopsy test have to the patient, recognizing that it increased her probability 9-fold of actually having breast cancer? Who feels "funny" even after seeing the numbers? I must admit that the example remains enigmatic to me, even though I have known for 15 years or more that the numbers are correct.

Monte Hall's "Let's Make a Deal" Problem

The second probability analysis is equally counterintuitive. Recall the old Monte Hall "Let's Make a Deal" television show. In the show, there were three doors labeled Door Number 1, Door Number 2, and Door Number 3. Behind one of the doors was a "bonanza" prize (e.g., trip to Tahiti, new car). Behind the other two doors were "goats," unattractive, worthless prizes that contestants would not want to win.

To play the game, Monte instructed a contestant to "Pick a door." Suppose you were the contestant and you selected Door Number 1. Monte then selected one of the other doors and showed you what was behind it. Because Monte knew what was behind each of the other two doors, you knew he would always select a door with a goat behind it. Suppose Monte selected Door Number 3 and revealed to you a goat behind it. Following revelation of the goat behind Door Number 3, Monte then asked you the $64,000 question: "Knowing there is a goat behind

Door Number 3, would you like to stick with Door Number 1 or trade it to me for what is behind Door Number 2?"

- What are your chances if you stick with Door Number 1?
- What are your chances if you trade it for Door Number 2?

How might you think about it? I will first present the wrong way and thereafter the right way. The wrong way to think about it is this: "After Monte shows me the goat behind Door Number 3, I know the bonanza is not behind Door Number 3. There are only two doors remaining, and the bonanza must be behind one of the two. Therefore, I reason, there must be a 50-50 chance the bonanza is behind Door Number 1 or Door Number 2. It shouldn't matter if I stick with Door Number 1 or switch to Door Number 2. The probabilities are 50 percent." Dead wrong!

Why is this seemingly obvious reasoning wrong? The answer becomes clear when we consider the sequence of events and the information that is revealed at each step. Consider that you choose first. After you choose Door Number 1, you must assign a 1/3 probability that the bonanza is behind Door Number 1 that you have selected and a 2/3 chance that the bonanza is behind Door Number 2 or Door Number 3. The significant insight is that there is a

- 1/3 probability the bonanza is behind Door Number 1
- 2/3 probability that the bonanza is *not* behind Door Number 1

Monte knows the bonanza is not behind Door Number 3 and shows it to you. You continue your earlier reasoning

- 1/3 probability the bonanza is behind Door Number 1
- 2/3 probability the bonanza is not behind Door Number 1

but you add the new knowledge

- 0 probability the bonanza is behind Door Number 3

Monte's revelation of the goat behind Door Number 3 concentrates your entire 2/3 probability that the bonanza is not behind Door Number 1 or Door Number 2. Monte's revelation eliminates any of your 2/3 probability staying with Door Number 3, concentrating your entire 2/3 probability on Door Number 2. Therefore, after the revelation that the goat is behind Door Number 3, your probability is

- 2/3 that the bonanza lies behind Door Number 2
- 1/3 that the bonanza lies behind Door Number 1

You double your probability of winning by switching to Door Number 2. *Always switch*! The odds are definitely not 50-50; they are 1/3-2/3. Most people find this result highly counterintuitive, even after seeing the foregoing calculation. Yet again, probabilities are for professionals, not amateurs (or Let's Make a Deal contestants dressed in pizza costumes). They are not for subjectivists.

Probability is "tough stuff," both analytically and intuitively. People are poor judges of probability. In conducting risk analysis, please do not leave probabilities to the amateurs. Make sure the professionals do it.

Fallacy No. 3 – I Can Get Just as Good Answers Using Multiple Scenario Analysis.

Fallacy number 3 is that "Analyzing multiple scenarios is just as good as formal risk analysis. Why go to all that trouble of risk analysis?" In reality, scenario analysis can be terribly misleading. In life, decisions are not scenario dependent. Decisions are made in the face of a multiplicity of future scenarios, each scenario governed by a probability. You must live with your decision, a single decision, regardless of which scenario ensues.

To illustrate, suppose I offer you the option to flip a coin at midnight, December 31, 1992, double or nothing for next year's salary. If you call the coin correctly, you will double next year's income. If you call it incorrectly, you will give me all of your income for next year. You have two choices, illustrated in Figure 1.16. You can refuse my offer, choosing instead to routinely receive next year's income (designated I). This is option #1. Or you can accept my overture, getting 2I with probability 0.5 and 0 with probability 0.5. This is option #2.

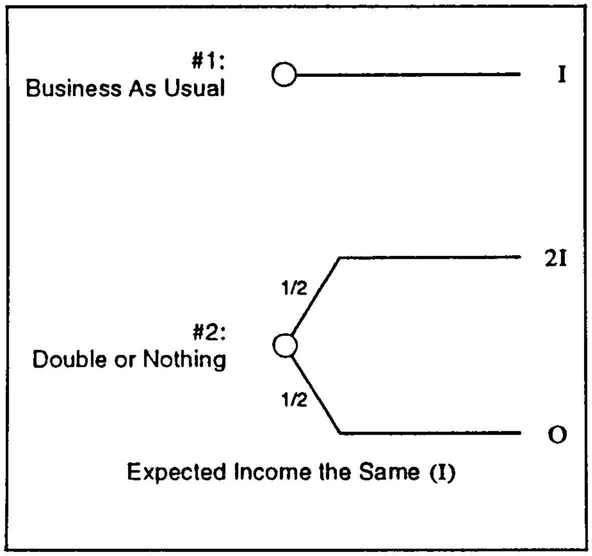

Figure 1.16. Salary prediction.

Notice that both of the alternatives have exactly the same expected value of income next year. On average, your expected income next year is I. Therefore, you must be indifferent between the two options. Is that correct? No difference? Same expected value? Same scenario? Is that the way you feel? Most people do not. The reason the two options are different lies in the answer to the question: Would you act any differently (would you make different decisions) between now and the end of the year if you were going to take option #2 rather than option #1? Would you do anything differently if you knew you were going to flip double or nothing for next year's income at midnight on December 31, 1992? Without a doubt, most people would act quite differently. If you were going to make different decisions under the two options, then the two cannot possibly represent equivalent scenarios. The fact that you would make different decisions means the two scenarios are fundamentally different.

The 1 times I scenario is clearly insufficient by itself to analyze the problem even though both options have 1 times I expected value. Clearly one must consider the 0 times I and 2 times I outcomes as well as the 1 times I outcome to analyze the problem. What decisions would you make between now and the end of the year if you knew you were going to lose the flip and receive 0 times I? Would you do anything differently? What decisions would you make between now and the end of the year if you knew you were going to win the flip and receive 2 times I? Would you behave differently? The answer to both questions is yes. You would behave totally differently. Clearly the 0 times I and 2 times I are fundamentally different scenarios because you would make quite different decisions.

Is it sufficient to analyze the 0 times I and 2 times I scenarios on a stand-alone basis independently? The answer is a resounding NO! The reason is that you must commit to a single decision *before you know which of the scenarios will transpire*. Your decision between now and the end of the year must be common to both the 0 times I and 2 times I scenarios. Your decision will not be optimum in either scenario. In general, your decision will "hedge" against the possibility that you will lose next year's income. Individual analysis of the two scenarios is entirely meaningless because it does not represent the fact that all decisions must be made before the outcome is incurred. You must live with the same decision no matter which of the two outcomes (0 times I and 2 times I) occurs. Individual scenario analysis cannot give you the right answer because you cannot predict the decision you (and others) would really make in the presence of multiple scenarios each weighted by probabilities. Individual, independent scenario analysis simply cannot represent the commonality of decisions across multiple scenarios.

Fallacy No. 4 – If I Can Find Experts with a Sterling Empirical Record of Success, I Will Be OK.

Fallacy number 4 is that accepting the advice of a good expert with a good track record will make everything OK. If a person has repeatedly "called the turn" in the past, he or she can be counted on to be a reputable, reliable expert upon whom you can bet your money. This is entirely fallacious. In reality, the empirical record of experts is largely meaningless. I will offer what I consider to be a rather compelling illustration to argue my point.[3] Consider a basketball gymnasium filled initially with 1000 people. Suppose that at half court, a person successively flips a fair coin. At each flip, every person in the gym who fails to call the coin correctly is asked to leave the gym. Every person who calls the coin correctly is allowed to remain. Consider what would occur after 10 successive flips or so. The gym would contain one to three people whose sagacity at calling coins would be absolutely astounding. Can you picture the brochures the three surviving coin flipping gurus might write:

- See the human computer!
- Ten straight correct calls of the coin!
- If you need to predict coins, here is your man!
- I can definitively *document* that I made 10 consecutive correct calls of the coin flip. My track record was witnessed by 1000 people!
- Never buy consulting services from any of the other 997 people who demonstrably are worse at it than me! You can't afford to go with second best!

If any of the surviving gurus is, God forbid, a "computer nerd" with a model of how to predict coin tosses, so much the better. If you hire him as a coin prognosticator, make sure he brings along his computer model so that you too can correctly predict coin tosses. Pay him whatever he asks for his computer model; it is worth gold.

In spite of what his brochure might read and how many might be duped by his claims, the fact of the matter is that *his success is just plain, dumb luck.* Empirical track records such as this simple example are quite often the result of plain, dumb luck. The person with the track record just happened to be the last guy in the gym. Darwinian natural selection culls out the people who do not have plain, dumb luck, leaving the lucky handful to make outrageous but substantiable claims regarding their track record.

[3]The illustration comes from Burton Malkiel's *A Random Walk Down Wall Street.*

What would happen if you hired this expert to flip coins? Clearly his performance would be no better or worse than anyone else's. For the next flip of the coin, he would have a 50 percent chance of being right, just like everyone else. In the lingo of statisticians, his performance would "regress to the mean." His stellar past performance would not offer one iota of competitive advantage in predicting future tosses of coins. His computer model would be valueless. He would be just like everyone else.

The message is clear. Be wary of the advice of experts no matter what their track record. Rely on modeling, disaggregated structural understanding of the problem, and careful independent thinking. The information you need for economic and environmental analyses is fundamental structural information that can withstand discussion and open debate in the "sunshine," not exhortations by supposed gurus. Putting the complete range of information in the sunshine and discussing it with a broad range of the "best and the brightest" is perhaps the most valuable benefit of risk analysis. You want the discussions in the sunshine so that they regress to the mean before the fact, before you do any analysis, not after the fact.

Fallacy No. 5 – Direct Judgment is Better Than Using Formal, Structural Models.

Fallacy number 5 is the belief that "With risk analysis, I don't need models." Actually, even simple models are very useful indeed in helping estimate probabilities.

To illustrate, ARCO's 1985 study referenced previously began with a comprehensive (but not particularly large) economic model of world oil supply and demand. The model required as input regional supply curves from around the world, regional demand curves from around the world, discount rates, tax regimes, cartel composition and behavior, government policy initiatives, backstop sources, competitive fuel alternatives, and other structural issues. The model combined these disparate pieces of the puzzle into a supply-demand balance complete with a market clearing price and corresponding oil volumes and market shares at that price. In a nutshell, the model found the point where the supply curves and demand curves cross each other.

Using the model, ARCO conducted single variable sensitivity analysis to determine the order of importance of the various input variables. They thereafter associated probabilities with the most important variables and used the model to develop a consequent probability distribution over the oil price. Using their technique, the probability distribution over oil price was not subject to the egregious errors and inaccuracies inherent in Figure 1.5. ARCO used the rule, which I strongly endorse: *Model first. Assign probabilities to model inputs second. Use the model to develop probabilities over model outputs third.* By using this technique, ARCO was able to answer the critical business questions: What is a legitimate upper bound on future oil price (i.e., how high is high)? What are the precursors for high future oil price (what would it take for high price)? What is a legitimate lower bound on future oil price (how low is low)? What are the precursors for low future oil price (what would it take for low price)? What is a legitimate probability distribution between the two bounds?

There is another intriguing example that is relevant here. Suppose you and I are both football fans, but you are a New Orleans Saints fan and I am a San Francisco 49ers fan. Five days before the pivotal Saints-49ers game, we wish to structure a bet. You believe that the probability the Saints will win is 3/5, and I believe the probability the Saints will win is only 1/3. If we agree that I will pay you $100 if the Saints win and you will pay me $87.50 if the 49ers win, who is better off? Should either or both of us be happy? The answer is evident if we each independently calculate the expected value of such a bet. Your expected value is (3/5)($100) + (2/5) (-$87.50) = $25.00. My expected value is (1/3) (-$100) + (2/3)($87.50) = $25.00. Both of us are equally happy with the deal. Both of us thinks his deal is worth $25.00. I wouldn't sell my deal for less than $25.00. You wouldn't sell your deal for less than $25.00.

Much deeper than the insight that both of us can perceive positive expected value from a bet if we assign different probabilities to the outcomes is the notion that a parimutuel betting organization could make substantial money by setting up a betting system. A broker could make substantial brokerage fees by setting up a market. Both of us would be much better advised to examine whatever market or parimutuel betting system exists and betting with the majority rather than operating based on purely subjective probabilities (or wishful thinking about another 2-minute Joe Montana miracle). Both of us would be much better advised to build a structural model of the underlying market or parimutuel betting system rather than operating based on purely subjective probabilities.

This example can be viewed in a Machiavellian way as well. It seems on the surface that it is too good to be true for both of us. Both of us see $25.00 positive expected value from the deal we have. Such perceptions simply do not seem right; how can both of us be winners in such a zero sum situation? In such situations, one or both of us should be suspicious that our probabilities are simply wrong, naive, or inappropriate. One or both of us is simply wrong. Structural modeling rather than subjective hip shooting is called for.

SUMMATION

In conclusion, I have tried to ring the alarm bell about risk and decision analysis, and I have tried to do so outside the emotionally charged arena of environmental risk analysis. Like chemotherapy, risk analysis is powerful but very hard to do right. It is not a panacea. It is dangerous. It is disarming. It has been my intent to help give people elemental insights with which to defend themselves against risk analysis being "amateurized," used incorrectly, or used to advance political agendas. Clients should be vigilant. Only the most sophisticated and correct uses should be allowed in the public domain.

I have tried to illustrate a few "fallacies" to be avoided. For example, don't assume that risk analysis gives you license to use any old probabilities you want. Don't make subjective estimates of prices and other market phenomena. Don't assume the answers will be intuitive; probabilities are hard and often surprising. Don't ascribe so much power to risk analysis that you quit modeling. Don't trust risk analysis implicitly.

Risk analysis is entertaining, stimulating, and personal. In my experience, risk analysis is plain, outright fun. It intrigues people. Risk analysis is simply a means to let you "get the probabilities right." Probabilities may be objective (you can measure them); some may be subjective (you can't measure them). I caution you to always use structural models. Don't hip shoot aggregate possibilities. Disaggregate environmental risk analyses, for example, into transport and consequence. Do not settle for some aggregate effect. People should be challenged if they violate these guidelines.

Dr. Dale Nesbitt is Senior Vice President at Decision Focus Incorporated, Mountain View, California. Dr. Nesbitt earned his B.S. at the University of Nevada at Reno, and his M.S. and Ph.D. degrees at Stanford University. His academic training was focused on engineering-economic systems. Dr. Nesbitt began his career at Xerox Corporation in 1972. He moved to the Decision Analysis Group at Stanford Research Institute in 1974, where he performed a number of risk analyses for government and industry. In 1977 he co-founded his own company, Decision Focus Incorporated, which has performed numerous economic and environmental risk assessments for clients in industry and government.

MINERALS MANAGEMENT SERVICE ENVIRONMENTAL STUDIES PROGRESS REPORTS, I

Session: MINERALS MANAGEMENT SERVICE ENVIRONMENTAL STUDIES PROGRESS REPORTS, I

Co-Chairs: Dr. Robert M. Avent
Dr. Robert M. Rogers

Date: November 5, 1991

Presentation	Author/Affiliation
Minerals Management Service Environmental Studies Progress Reports, I: Session Introduction	Dr. Robert M. Avent and Dr. Robert M. Rogers Minerals Management Service Gulf of Mexico OCS Region
Marine Mammal and Sea Turtle Populations of the North-Central Gulf of Mexico	Dr. Keith Mullin, Mr. Wayne Hoggard, Dr. Ren Lohoefener, Ms. Carol Roden, Ms. Carolyn Rogers National Marine Fisheries Service Mississippi Laboratories and Lt. Brian Taggart National Oceanic and Atmospheric Administration Aircraft Operations Center
Distribution and Abundance of Marine Mammals in the North-Central and Western Gulf of Mexico	Dr. Randall W. Davis Texas A&M University at Galveston, Mr. Larry Hansen National Marine Fisheries Service Southeast Fisheries Science Center, and Dr. Bruce Mate Hatfield Marine Science Center Oregon State University
Behavior and Movements of Sea Turtles in the Western and Central Gulf of Mexico	Dr. Warren E. Stuntz National Marine Fisheries Service
Round Table: The Chemosynthetic Communities Study	Dr. James M. Brooks, Dr. Ian R. MacDonald Geochemical and Environmental Research Group Texas A&M University, and Dr. William W. Schroeder Dauphin Island Sea Lab University of Alabama Marine Science Program

MINERALS MANAGEMENT SERVICE ENVIRONMENTAL STUDIES PROGRESS REPORTS, I: SESSION INTRODUCTION

Dr. Robert M. Avent
and
Dr. Robert M. Rogers
Minerals Management Service
Gulf of Mexico OCS Region

INTRODUCTION

This session on Minerals Management Service (MMS) Environmental Studies was organized to allow MMS contractors an opportunity to present progress reports from their respective studies. In this session these include investigations on protected species and chemosynthetic communities. These studies provide valuable information on these potentially sensitive resources and are useful in formulating stipulations and mitigating measures for the protection of these animals. The studies focus on the distribution, abundance, and community structure of both motile and sessile species. In the case of animals protected under the Marine Mammal Protection Act and/or the Endangered Species Act, behavioral investigations are also important. For chemosynthetic animals and communities, energetic dynamics, life history, and physiological requirements are investigated. The programs described all depart from the traditional MMS-funded descriptive regional studies, in that they focus on target species and rely on advanced technologies such as satellite positioning and research submersibles.

Dr. Robert M. Avent received his Ph.D. in biological oceanography in 1973 from Florida State University. His main fields of interest include marine physiological ecology. He has pursued investigations on the biological effects of hydrostatic pressure, animal zonation, and reef morphology. He is with the Environmental Studies Section, MMS, Gulf of Mexico OCS Regional Office where he came in 1981 from the National Marine Fisheries Service.

Dr. Robert M. Rogers is an oceanographer with the Environmental Studies Section, MMS, Gulf of Mexico OCS Regional Office. He received his B.S. and M.S. degrees in zoology from Louisiana State University and Ph.D. in marine biology from Texas A&M University. His research interests have included the ecology of coastal meiobenthic organisms and trophic interrelationships. He has been involved in the MMS/Bureau of Land Management Environmental Studies Program since 1977.

MARINE MAMMAL AND SEA TURTLE POPULATIONS OF THE NORTH-CENTRAL GULF OF MEXICO

Dr. Keith Mullin,
Mr. Wayne Hoggard,
Dr. Ren Lohoefener,
Ms. Carol Roden,
Ms. Carolyn Rogers
National Marine Fisheries Service
Mississippi Laboratories
and
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From June 1988 through June 1990, cooperative research between the Minerals Management Service (MMS), the National Marine Fisheries Service (NMFS), and the National Oceanic and Atmospheric Administration (NOAA) Aircraft Operations Center was conducted in the north-central Gulf of Mexico. This research resulted in two final reports to the MMS. Lohoefener *et al.* (1990) examined the spatial relationship of sea turtles to petroleum platforms. Mullin *et al.* (1991) reported on the diversity, distribution, and relative abundance of marine mammals on the continental slope. The abstract from each report is presented here.

SEA TURTLES

In 1988 there were over 4,500 petroleum platforms in the north-central Gulf of Mexico. Once a platform is no longer used for petroleum production, federal regulations require that the platform be removed. For platform removals, explosives are commonly used to sever pilings that anchor the platform to the bottom. The use of explosives has the potential to kill or injure marine animals, including sea turtles, in the vicinity of the platform. The five species of sea turtles which occur in the Gulf of Mexico are listed as either threatened or endangered under the provisions of the Endangered Species Act of 1973. The five species are as follows: loggerhead (*Caretta caretta*), leatherback (*Dermochelys coriacea*), green sea turtle (*Chelonia mydas*), Kemp's ridley (*Lepidochelys kempi*), and hawksbill (*Eretmochelys imbricata*).

Anecdotal evidence indicated that at least some individual sea turtles, primarily loggerheads, were commonly found in the vicinity of specific platforms. However, the general relationship of the sea turtle population to petroleum platforms was unknown. From June 1988 through June 1990, we used aerial surveys to estimate sea turtle abundance and to study the spatial relationship between sea turtles sighted near the surface of the water and petroleum platforms. We surveyed seven study areas which sampled the range of water depths (3-200 m) in the oil and gas fields offshore of Louisiana. For each study area we used three types of statistical procedures (Hamill and Wright's method, Kendall's rank correlation, and chi-square analysis) to test the null hypothesis: surfaced sea turtles were randomly located with respect to platform locations. We used line transect methods to estimate sea turtle density for each study area.

During the study, we sighted 316 chelonid sea turtles of which we estimated 92 percent were loggerheads. Most of the sea turtles (78%) were sighted just northeast of the Mississippi River delta in two study areas offshore of Breton and Chandeleur Islands, Louisiana. Sea turtles were present throughout the year but fewer sea turtles were sighted during the coldest months (January and February). East of the river, sea turtle densities were seasonally variable, ranging from 0.92 sea turtles/100 km^2 in winter to 4.83 sea turtles/100 km^2 in spring. Because of the small number of sea turtles sighted in the five study areas west of the river, seasonal density estimates were not made. However, the annual densities in these areas ranged from 0.50 sea turtles/100 km^2 in 13-48 m water depths to 0.11 sea turtles/100 km^2 in 60-120 m water depths. Rather than leaving the north-central Gulf of Mexico in winter, we believe some sea turtles may have brumated or moved to slightly deeper water during cold weather periods. We saw mud trails coming off some loggerheads. These mud trails indicate that they had been brumating by partially burying in bottom sediments. West of the river, sightings of sea turtles in deeper water areas increased slightly in winter. However, this was not observed east of the river.

East of the river, all three statistical tests indicated that, except during winter, offshore of Chandeleur and Breton Islands, sea turtles were positively associated with platform locations (i.e., generally closer to platforms than expected). In winter, sea turtles were randomly located with respect to platform locations. In the study areas west of the river, sea turtles were randomly located with respect to platforms locations. Before the explosive removal of a platform can proceed, current mitigation measures require that no sea turtle can be sighted within 1,000 m of the platform. East of the river, based on the density of sea turtles (corrected for subsurface turtles) and the observed distance distribution of sea turtles to platforms, we estimated the probability of one or more chelonid sea turtles being within 1,000 m of any platform selected at random was great, generally more than 60 percent. West of the river, depending on the study area, we estimated that this probability ranged from 2-7 percent.

We identified 18 petroleum platforms which may have had one or more positively associated chelonid sea turtles at some time during the study. To understand why sea turtles were associated with these 18 platforms, we compared them to other platforms using nine platform characterization variables. Overall, the platforms with associated sea turtles tended to be smaller unmanned platforms that were closer to shore than the other platforms.

Offshore of Breton and Chandeleur Islands, we found chelonid sea turtles preferred more shallow water (generally <20 m) over sandy bottom sediments. West of the river, we did not detect a sea turtle preference for bottom sediments but most were in waters less than 50 m deep.

In addition to shallow water (<200 m) sea turtle studies, we also surveyed deep Gulf waters (>200 m) for cetaceans from July 1989 through June 1990. During these surveys we also sighted 15 chelonid sea turtles. We also sighted 86 non-chelonid (leatherback) sea turtles from June 1988 through June 1990. Twenty-four were sighted in waters less than 200 m.

We concluded that for an area from the mouth of the Mississippi River, west to about 92°W longitude, the current MMS/NMFS mitigation measures should adequately protect sea turtles when explosives are used to assist petroleum platform removals. However, for the area offshore of the Breton and Chandeleur Islands including deeper waters of at least 60 m, special precautions should be taken. The probability will be high that one or more sea turtles may be near any given petroleum platform.

MARINE MAMMALS

At least 29 species of cetaceans occur or have occurred in the Gulf of Mexico (Gulf) including five species listed as endangered under the provisions of the Endangered Species Act. All cetaceans in U.S. waters are protected by the Marine Mammal Protection Act of 1972. Except for data from strandings, opportunistic sightings and limited aerial surveys, very little is known about cetaceans in the Gulf beyond the continental shelf. The continental shelf (<180 m deep) in the U.S. Gulf has been well studied compared to the deep waters (>180 m) and the bottlenose dolphin has been found to be the only species which commonly inhabits most shelf waters. Seaward of the shelf, water depths increase rapidly and the cetacean community becomes more diverse.

Minerals development has occurred widely in U.S. Gulf waters on the continental shelf west of Mobile Bay, Alabama (over 4,500 oil and gas platforms). Plans for development of the continental slope and central Gulf waters are in place and some exploratory activities have already occurred in these waters. Because of their protected status, information on cetacean diversity, abundance, and seasonality is needed in order to assess the potential impact of minerals development. In 1989, the MMS and the NMFS began cooperative aerial surveys of the upper continental slope with the following objectives: (1) determine the species diversity of cetaceans, (2) learn about the temporal and spatial distribution of each species, and (3) estimate the relative abundance of each species.

From July 1989 through June 1990, we conducted aerial surveys each month (except December) in the north-central Gulf. The area studied was centered along the shelf break (180 m) south of the Mississippi River delta and extended from DeSoto Canyon (87°30.0' W) to west of the Mississippi Trough (90°30.0' W). The area studied was about 44 km wide. Water depths ranged from 18 to 2,000 m.

During the study, we sighted at least 15 species of cetaceans. Seven species accounted for 93 percent of the sightings of identified herds. These species included: Risso's dolphin (61 herd sightings), sperm whale (43), bottlenose dolphin (39), Atlantic spotted dolphin (36), dwarf/pygmy sperm whales (32), striped/spinner/Clymene dolphins (24), and pantropical spotted dolphins (23). Beaked whales (Cuvier's beaked whale and mesoplodonts) were sighted nine times and short-finned pilot whales five times. Herds of the following species were sighted once: melon-headed/pygmy killer whales, false killer whale, killer whale, rough-toothed dolphin, fin whale, and sei/Bryde's whale.

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 species 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 the species sighted more than once were sighted throughout the length (east-west) of the study area.

For all cetacean herds sighted, and for each species, we tested the location data for preferences in intervals of water depth and sea floor topography. Cetaceans as a group did not prefer any water depth or topography interval on the upper continental slope. However, cetaceans that were sighted more than 20 times and could be identified to species were partitioned by these two factors. Bottlenose (<300 m) and Atlantic spotted dolphins (<600 m) preferred shallow waters over steep sea floor (a large relative change in water depth). Risso's dolphins preferred waters between 300-

900 m over steep sea floor. Pantropical spotted dolphins (>900 m) and sperm whales (600-1,200 m) preferred deeper waters over less precipitous sea floor (a smaller relative change in water depth). Dwarf/pygmy sperm whales were found throughout the range of waters depths and topographies. Striped/spinner/Clymene dolphins may prefer deeper waters (>1,200 m) but showed no preference for topography. Of the species sighted more than once, beaked whales were sighted at the deepest mean water depth (966 m).

The overall density of cetaceans on the upper continental slope was 0.78 cetaceans/km^2. Because of large average herd sizes (88 dolphins/herd), striped/spinner/Clymene dolphins had the highest overall density (0.22 dolphins/km^2). Pantropical spotted dolphins averaged 72 dolphins/herd and had a density of 0.18 dolphins/km^2. Risso's dolphins, Atlantic spotted, and bottlenose dolphins averaged much smaller herds (<30 dolphins/herd) and densities ranged from 0.05-0.08 dolphins/km^2. The physeterids only averaged about 2 whales/herd and the beaked whales only one, and their densities were much smaller (<0.006 whales/km^2).

Because of its extremely large size (about 20,000 kg), the sperm whale, an endangered species, is an important part of the cetacean community on the upper continental slope. Although they had a small overall density, we estimated that sperm whales made up between 21-44 percent of the total biomass of cetaceans. Sperm whales were found throughout the study area but were concentrated in the region near the Mississippi River delta.

On two days in June 1990, we conducted surveys in deeper waters south of the regular study area. During those two days, we sighted at least eight species of cetaceans including three that were sighted only one to five times during the regular surveys (false killer whale, melon-headed/pygmy killer whale, and short-finned pilot whale). These species may be more numerous in the pelagic Gulf. Pantropical spotted dolphins were the most commonly sighted species. These surveys indicated that the Gulf, beyond the upper continental slope, is also an area of high cetacean diversity and abundance.

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Dr. Keith Mullin (Ph.D., Mississippi State University) is a Fisheries Biologist with the NMFS in Pascagoula, Mississippi. He studied bottlenose dolphins for his Ph.D. dissertation.

Mr. Wayne Hoggard (B.S., University of Tennessee) is a Fisheries Biologist with the NMFS, Pascagoula Laboratory. He has coordinated and conducted sea turtle and marine mammal surveys for the NMFS in the Gulf of Mexico and Atlantic Ocean since 1979.

Dr. Ren Lohoefener (Ph.D., Mississippi State University), formerly an Ecologist with the NMFS, is now an Endangered Species Biologist with the U.S. Fish and Wildlife Service in Phoenix, Arizona.

Ms. Carol Roden (B.A., University of Alabama) and Ms. Carolyn Rogers are Biologists with the NMFS, Pascagoula Laboratory. They specialize in aerial surveys for sea turtles and marine mammals.

LT Brian Taggart (B.S., Florida Institute of Technology) is a NOAA Corps pilot. He has piloted aerial surveys for marine mammals throughout North America.

DISTRIBUTION AND ABUNDANCE OF MARINE MAMMALS IN THE NORTH-CENTRAL AND WESTERN GULF OF MEXICO

Dr. Randall W. Davis
Texas A&M University at Galveston,
Mr. Larry Hansen
National Marine Fisheries Service
Southeast Fisheries Science Center,
and
Dr. Bruce Mate
Hatfield Marine Science Center
Oregon State University

On September 31, 1991 the Minerals Management Service (MMS) awarded a contract entitled "Distribution and Abundance of Marine Mammals in the North-Central and Western Gulf of Mexico" to a scientific team from the Texas Institute of Oceanography (TIO), the National Marine Fisheries Service at the Southeast Fisheries Science Center (NMFS, SFSC), and the Hatfield Marine Science Center at Oregon State University (HMSC, OSU). This 39 month, $3.2 million study will seek new information about the abundance and seasonal movements of marine mammals along the continental slope in the Gulf of Mexico.

To complete this study, TIO has incorporated the extensive expertise in marine mammal biology, bioacoustics, and oceanography from three Texas A&M University System units: Texas A&M University at Galveston, the Department of Engineering Technology, and the Department of Wildlife and Fisheries Science (Table 2.1). The NMFS, SFSC will provide expertise in aerial and ship-based visual surveys of marine mammals. Personnel from the Stennis Space Center (also located at NMFS, SFSC) will provide expertise in the analysis of new and historical oceanographic and remote sensing data from the Gulf of Mexico. To complete the team, scientists from the HMSC, OSU will use recently developed techniques to tag and track sperm whales using satellite telemetry.

PROGRAM OBJECTIVES

The MMS has the responsibility to ensure that oil and gas operations on the Outer Continental Shelf leases in the Gulf of Mexico are conducted in a manner that reduces risks to the marine environment. To meet their responsibilities under the Marine Mammal Protection Act of 1972 and the Endangered Species Act of 1973, the MMS must understand the effects of oil and gas operations on marine mammals. As the oil and gas industry moves into deeper water along the continental slope in their continuing search for extractable reserves, information is needed on the at-sea distribution, movements, behavior, and preferred habitats of cetaceans, especially large and deep water species in the Gulf of Mexico (Table 2.2). This study is designed to produce a first-step estimate of the potential effects of deepwater exploration and production on marine mammals.

The purpose of this study, herein called the GULFCET Program, is to determine the seasonal and geographic distribution and movements of cetaceans in areas potentially affected by future oil and gas activities along the continental slope in the north-central and western Gulf of Mexico. The study is restricted to the area bounded by the Florida-Alabama border, the Texas-Mexico border, and the 100- and 2,000-m isobaths (Figure 2.1). In addition to conducting systematic aerial surveys and shipboard surveys, the GULFCET Program will tag and track a limited number of sperm whales using satellite telemetry. Finally, environmental data from shipboard surveys (acquired during this program and other oceanographic studies in the Gulf) and remote sensing will be used to characterize the preferred habitats of cetaceans in the study area. We will identify those environmental variables that seem most likely to affect the seasonal distribution, abundance, and activities of cetaceans. The ultimate goal of GULFCET is to improve the ability of MMS to assess the effects of oil and gas operations, including oil spill impacts, on the distribution and behavior of marine mammals.

PROGRAM OUTLINE

The goals of this program will be met by a suite of ten tasks. For Task 1, we will conduct a statistical power analysis for the relative abundance of marine mammals in the target area using the most current data. This analysis will ensure an adequate survey strategy for obtaining inter-year comparable information the on relative numbers and distributions of marine mammals. Task 2, obtaining

Table 2.1. List of Principal Investigators (PIs) and Their Affiliations. (In addition to the Program Tasks [see text for a description] listed with each name, all of the PIs will participate in the data analysis, integration of the results, and preparation of the final report [Tasks 8-10]).

Randall W. Davis	Program Manager, Tasks 2 & 4	TIO, TAMUG
Bernd Würsig	Deputy Prgm. Manager, Task 4	TIO, TAMUG
Gerald P. Scott	Prgm. Mgr. for NMFS, Task 4	NMFS, SFSC
Giulietta Fargion	Data Manager, Task 4	TIO, TAMUG
Robert Benson	PI, Task 4	TAMU, DET
William Evans	PI, Task 4	TIO, TAMUG
Larry Hansen	PI, Tasks 1 & 4	NMFS, SFSC
Thomas Lemming	PI, Task 4	NMFS, SFSC
Bruce Mate	PI, Tasks 5 & 6	HMSC, OSU
Nelson May	PI, Task 4	NMFS, SFSC
Keith Mullin	PI, Tasks 1 & 4	NMFS, SFSC
David Schmidly	PI, Task 3	TAMU, WFS

Abbreviations:

TIO, TAMUG	Texas Institute of Oceanography, Texas A&M University at Galveston
TAMU, DET	Texas A&M University, Department of Engineering Technology
TAMU, WFS	Texas A&M University, Department of Wildlife and Fisheries Science
NMFS, SFSC	National Marine Fisheries Service, Southeast Fisheries Science Center
HMSC, OSU	Hatfield Marine Science Center, Oregon State University

Marine Mammal Permits to conduct the work, was initiated immediately after contract award. Task 3 consists of a training program for field observers and the whale tagging team. This training regime will standardize techniques for marine mammal identification and data collection and will provide safety training.

Tasks 4-6 form the major field portion of the program. Task 4 consists of seasonal, aerial, and concurrent shipboard visual and acoustic surveys (Table 2.3) to determine the relative abundance and distribution of cetaceans; aerial observations of cetacean behavior to determine aspects of habitat use; and shipboard and remote sensing data acquisition to categorize preferred habitats and seasonal changes in oceanographic variables such as water temperature, chlorophyll concentration, and turbidity. Tasks 5 and 6 involve tagging sperm whales with radio and satellite telemeters to determine seasonal movements, diving behavior, and preferred habitat. The results from these three tasks will enable us to describe where cetaceans, especially endangered sperm whales, spend their time on a seasonal basis and to describe preferred habitat along the continental slope.

The final four tasks of the program are designed for quality control (Task 7, Scientific Review Board), data analysis (Task 8), data integration (Task 9), and reporting (Task 10). Certain investigators are in charge of data processing and integration, and the Program Manager oversees and takes final responsibility for reporting. However, all of the principal investigators will ensure that data are analyzed and presented in a fashion that allows efficient comparison between the visual surveys, acoustic surveys, behavioral observations, telemetry results, and oceanographic characterizations of the environment.

The results of the GULFCET Program will provide baseline information on the distribution and preferred habitat of cetaceans along the continental

Table 2.2. Cetaceans of the Gulf of Mexico.

Balaenidae	
Right Whale	*Eubalaena glacialis*
Balaenopteridae	
Blue Whale	*Balaenoptera musculus*
Fin Whale	*B. physalus*
Sei Whale	*B. borealis*
Bryde's Whale	*B. edeni*
Minke Whale	*B. acutorostrata*
Humpback Whale	*Megaptera novaeangliae*
Physeteridae	
Sperm Whale	*Physeter macrocephalus*
Pygmy Sperm Whale	*Kogia breviceps*
Dwarf Sperm Whale	*K. simus*
Ziphiidae	
Cuvier's beaked whale	*Ziphius cavirostris*
Blainville's beaked whale	*Mesoplodon densirostris*
Sowerby's beaked whale	*M. bidens*
Gervais' beaked whale	*M. europaeus*
Delphinidae	
Melon-headed whale	*Peponocephala electra*
Pygmy killer whale	*Feresa attenuata*
False killer whale	*Pseudorca crassidens*
Killer whale	*Orcinus orca*
Short-finned pilot whale	*Globicephala macrorhynchus*
Rough-toothed dolphin	*Steno bredanensis*
Fraser's dolphin	*Lagenodelphis hosei*
Common dolphin	*Delphinus delphis*
Bottlenose dolphin	*Tursiops truncatus*
Risso's dolphin	*Grampus griseus*
Atlantic spotted dolphin	*Stenella frontalis*
Pantropical spotted dolphin	*S. attenuata*
Striped dolphin	*S. coeruleoalba*
Spinner dolphin	*S. longirostris*
Clymene dolphin	*S. clymene*

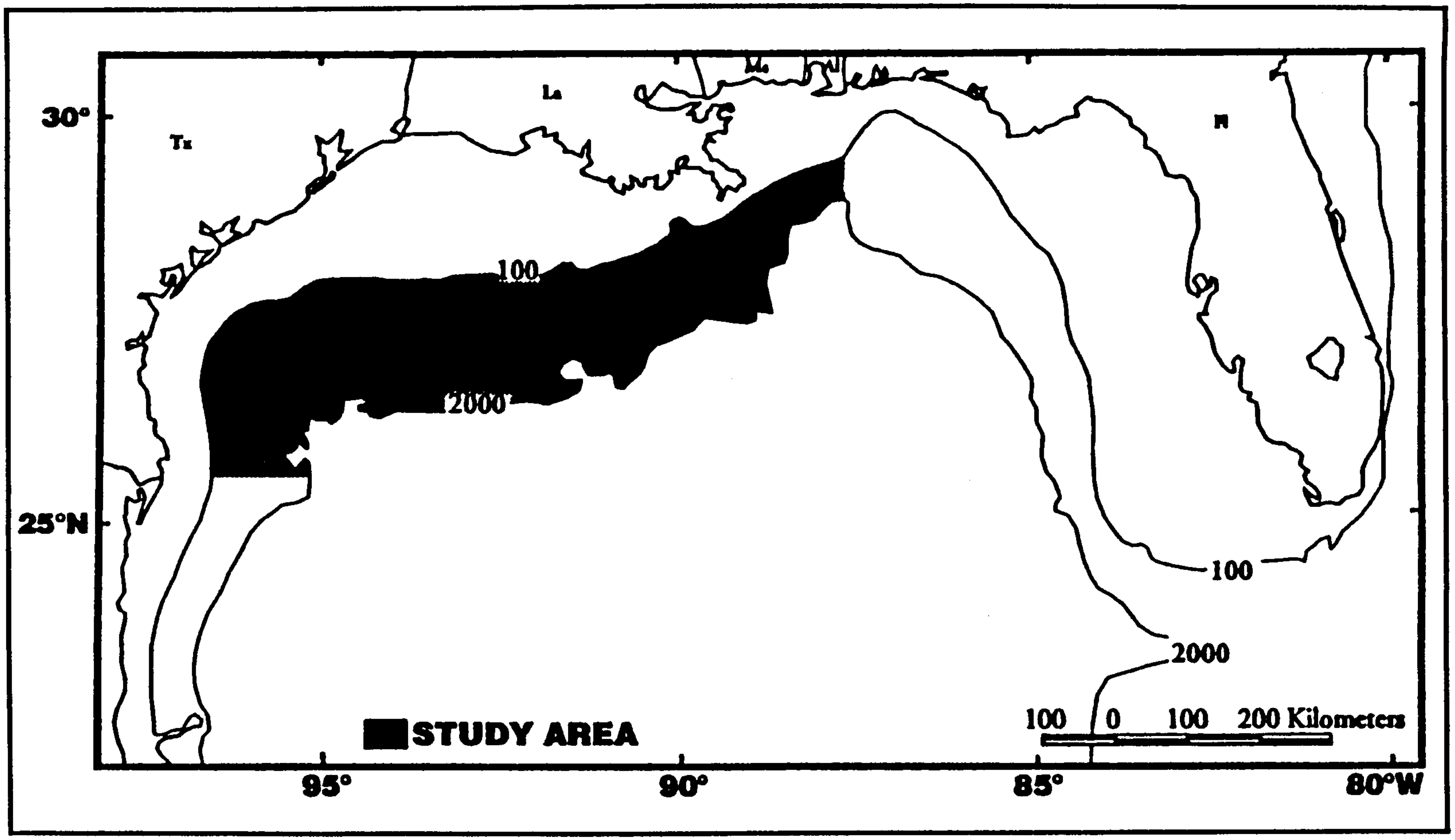

Figure 2.1. The proposed study area between the 100- and 2,000-m isobaths, extending as far east as the Florida-Alabama border, and as far southwest as the Texas-Mexico border.

Table 2.3. Schedule of Aerial and Shipboard Surveys.

	Aerial Survey	Vessel Survey
1992-		
Winter	-	-
Spring	47 day, 100 hr	12 day acoustic, visual; 54 day visual
Summer		12 day acoustic, visual
Fall	47 day, 100 hr	12 day acoustic, visual
1993-		
Winter		12 day acoustic, visual
Spring	47 day, 100 hr	12 day acoustic, visual; 54 day visual
Summer		12 day acoustic, visual
Fall	47 day, 100 hr	12 day acoustic, visual
1994-		
Winter		12 day acoustic, visual

slope. However, there is already some oil and gas exploration and general ship and aircraft activity in the study area. We will assess, on an opportunistic basis, the impact of these activities on cetaceans during our aerial surveys, shipboard surveys, and satellite telemetry of sperm whales. By taking advantage of these "natural experiments" of disturbance, we will obtain useful information on the effects of oil and gas activities on cetaceans.

Dr. Randall Davis is Head of Marine Biology and a member of the Marine Mammal Research Program at Texas A&M University at Galveston. He has studied the physiology and ecology of marine mammals for over 14 years.

Mr. Larry Hansen is a Marine Mammal Biologist at the NMFS, SFSC. He is an expert in the field of marine mammal population biology and has been responsible for recent aerial surveys of cetaceans in the Gulf of Mexico.

Dr. Bruce Mate is a Marine Mammal Biologist at HMSC, OSU. He is an expert in radio and satellite telemetry of cetaceans.

BEHAVIOR AND MOVEMENTS OF SEA TURTLES IN THE WESTERN AND CENTRAL GULF OF MEXICO

Dr. Warren E. Stuntz
National Marine Fisheries Service

I. Study Goal

- To define the nature of any attraction of sea turtles to platforms.

To meet this goal two major objectives have to be met.

- Evaluate the diel and seasonal behavior and movements of sea turtles within the study areas.

- Characterize preferred sea turtle habitat within the study areas.

II. Methods

The main method of data collection will be radio tracking of sea turtles using a retransmitted loran-C tag adapted from a tag designed by the U.S. Department of Agriculture, Forest Service for a study of range partitioning among elk, deer, and cattle. This tracking system has an accuracy of less than 75 m and is automated so that we can track as many as 40 or more turtles simultaneously. Data sent from the tags will include the turtle ID, the duration of the last dive, the duration of the last period spent on the surface, and approximately 10 seconds worth of loran-C data. These data will be obtained each time the turtle surfaces for the life of the tag. The tag will have a battery life in excess of one year. In the situation where a turtle is on the surface for a protracted period the tag will transmit once per hour.

During the summer of 1992 40 large (> 60 cm) turtles will be captured in the Chandeleur Island study area and tagged. These turtles will be tracked for one year. At the end of that time the tracking system will be moved to an area off the Texas coast and the entire study will be repeated.

The study areas will be mapped in terms of sea turtle prey items and the distribution of substrate types. Temperature, dissolved oxygen, and salinity profiles will be made in an attempt to understand something of the prey distribution and surfacing frequency and behavior of the sea turtles. Available data suggest that the area of greatest sea turtle abundance off the Chandeleur Islands (Lohoefener *et al.* 1990) is also an area of high crab abundance (Stuntz *et al.* 1985). Areas in which sea turtles spend a lot of time will be investigated more carefully to attempt to learn what physical or biological characteristics of the environment are attractive or repellant to the tagged turtles.

III. Test of Open Water Sea Turtle Capture Method

Two aspects of this study were sources of concern. First was the possible difficulty of capturing sea turtles in open water for tagging. Sea turtles that are radio tagged and tracked are normally captured during nesting or when incidentally captured in a fishery. For the purposes of this study it is necessary that a random cross-section of the population be captured. The National Marine Fisheries Service (NMFS) personnel from our Galveston laboratory, Dr. Maurice Renaud and Gregg Gitschlagg, have perfected a method of capturing turtles sleeping on platforms at night. Females nest on the Chandeleur Islands and some of them can be tagged after they nest. The other segment of the population is composed of free ranging sea turtles. To enable us to capture them, a purse seine/gill net was built and tested.

This net is 450 m (1,500 feet) in length and 27 m (90 feet) deep. It is set just as a purse seine is set and is recovered using a power block as is done with a normal purse seine. The major difference between this net and a normal purse seine is the mesh size. The mesh size in the body of the net is 36 cm (14 inch) stretch mesh. A smaller mesh net, tested earlier using this same technique, was very successful at surrounding turtles, but failed in capturing them because they would simply crawl up the webbing and over the cork line. With the large mesh in this net, when the turtle encounters the wall of webbing, it becomes entangled and can then be lifted to the surface.

The technique used is to have a spotter plane working in the area of the boat. When the airplane spots a turtle, a dye marker is dropped. The boat comes over to the area and when the turtle again surfaces the boat encircles the turtle. During the past summer a test of this system was completed during which 3 sets were made and 2 turtles captured.

IV. Feasibility Test of Retransmitted Loran-C System (RTL System)

The second area of concern was the RTL system. Prior to beginning construction of a full scale RTL system we felt that it was necessary to test the system under the actual conditions that the system will face during the radio tracking program. To accomplish this, a complete system was borrowed from the U.S. Forest Service. An elk tag was modified for use in salt water and the entire system was installed on a Chevron Platform located in Main Pass block 127A. The accuracy of the system was tested and found to be 16 m east-west and 60 m north-south. A range test was conducted and it was found that reception remained good out to slightly more than line of sight distance (16 km) with the 216.5 MHz frequency being used during the tests. The revised version of this system will be operating at 907 MHz and will thus be restricted more nearly to line of sight. When the tag was placed under a platform as might occur during turtle tracking, the loran signal was lost although the telemetry data, which includes a tag ID and dive information, was still being received when the tag was under the platform.

With the success of the feasibility tests, we have begun the process of building the complete radio tracking system. The target date for beginning installation of the system is March 1992, although that is probably an overly optimistic date. A more reasonable expectation is probably June 1992.

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Dr. Warren E. Stuntz is employed by the NMFS at Pascagoula, Mississippi as a Research Fishery Biologist. His areas of research interest are the behavior and physiology of sea turtles and marine mammals. Dr. Stuntz obtained his B.S., M.S., and Ph.D. degrees in zoology from the University of Wisconsin at Madison.

ROUND TABLE: THE CHEMOSYNTHETIC COMMUNITIES STUDY

Dr. James M. Brooks,
Dr. Ian R. MacDonald
Geochemical and Environmental
Research Group
Texas A&M University,
and
Dr. William W. Schroeder
Dauphin Island Sea Lab
University of Alabama
Marine Science Program

SUMMARY

In this presentation, we will briefly review the scientific and management issues raised by the discovery of chemosynthetic communities in the Gulf of Mexico. We will outline the goals of the recently inaugurated Chemosynthetic Communities Study and the overall Study design. Finally, we will present preliminary study results from recent dives (September 1991) with the submarine *Johnson Sealink* (JSL); these include documentation of the recently discovered chemosynthetic community in the Viosca Knoll 826 lease block.

BACKGROUND

Chemosynthetic species of tube worms, mussels, and clams were discovered in the Gulf of Mexico in 1983, first at brine seeps on the base of the Florida Escarpment at water depths over 3,000 m (Paull *et al.* 1984), and very shortly thereafter at oil seeps on the upper and middle continental slope south of Louisiana (Kennicutt *et al.* 1985). These findings demonstrated that marine communities based on chemosynthesis were not limited to the geologically active hydrothermal vents where they were first discovered (Corliss *et al.* 1979). Subsequent exploration in the northern Gulf of Mexico (Figure 2.2) has documented substantial chemosynthetic communities, which were often larger in area and total biomass than the vent communities, at over 40 locations on the upper continental slope (MacDonald *et al.* 1990). Recent discoveries at 2,200 m depths in Alaminos Canyon (Brooks *et al.* 1990) have extended the potential

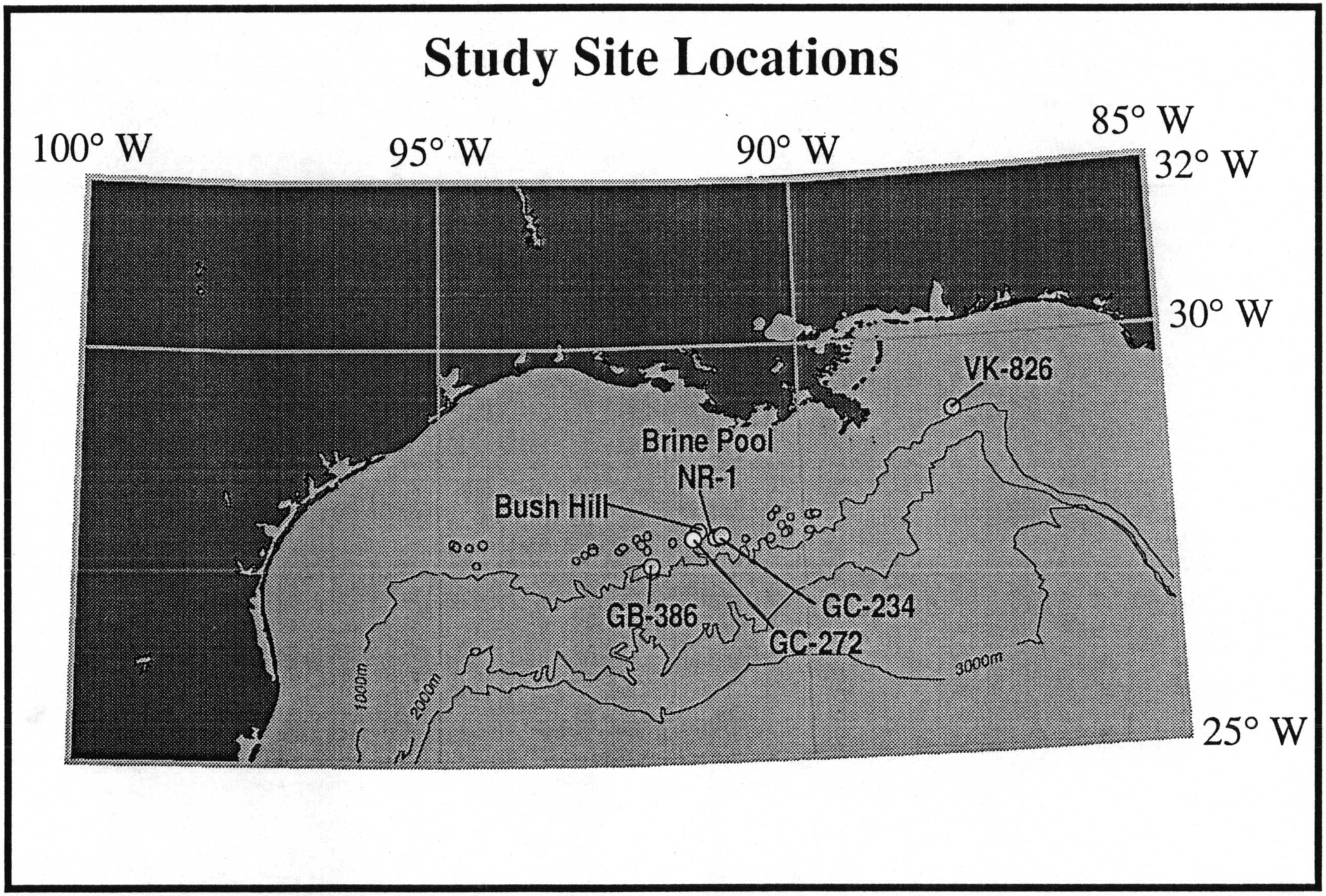

Figure 2.2. Locations of known chemosynthetic communities in the northern Gulf of Mexico. (Presence of chemosynthetic organisms at each site has been confirmed by trawl collection, observations from submarines, or conclusive photo-reconnaissance. Large, labeled dots are the study sites for the Chemosynthetic Communities Study).

depth range of oil seep communities while finds in the Viosca Knoll region extended their geographic range to east of the Mississippi Delta (Gallaway *et al.* 1990).

All of the chemosynthetic species on the continental slope depend on chemical enrichment of the seafloor caused by natural oil and gas seepage (Brooks *et al.* 1987; Childress *et al.* 1986; Kennicutt *et al.* 1988). Together, the Geochemical and Environmental Research Group of Texas A&M University (GERG) and major collaborators at the University of California Santa Barbara, Penn State University, Louisiana State University, and the Dauphin Island Sea Lab have established a productive program of basic research investigating questions such as the following: What are the specific geological, chemical, and ecological processes whereby seeping hydrocarbons support distinct communities? What biochemical and physiological mechanisms allow chemosynthetic species to utilize the chemicals and to tolerate toxic hydrocarbons? How does chemosynthetic community formation affect carbonate geology on the slope? What contribution do the communities make to the overall ecosystem of the Gulf of Mexico? How are seep communities preserved in the fossil record? This work has lead over 25 peer-reviewed publications and to major awards of logistic support, mostly in the form of submarine time, over the past six years.

The advent of energy exploration and production on the continental slope of the Gulf of Mexico creates a potential for damage to chemosynthetic communities. The Minerals Management Service (MMS), acting under provisions of the Offshore Lands Act, has implemented the policy of reviewing geophysical data prior to issuing permits for drilling oil companies to determine the potential for impact on chemosynthetic communities (MMS 1989). In order to increase the knowledge base for making these decisions, MMS awarded the Chemosynthetic Communities Study in July of this year. The Principal Investigators (PIs) are pleased to have been chosen for this work and look forward to a highly productive study.

STUDY OVERVIEW

The project team consists of 12 PIs from five academic institutions under the overall direction of GERG:

- Dr. James M Brooks: GERG, Texas A&M
- Dr. Robert S. Carney: Coastal Ecology Institute, Louisiana State
- Dr. Charles R. Fisher: Dept. of Ecology, Penn State
- Dr. Holgar W. Jannasch: Woods Hole Oceanographic Institution
- Dr. Mahlon C. Kennicutt II: GERG, Texas A&M
- Dr. Eric N. Powell: Dept. of Oceanography, Texas A&M
- Dr. Ian R. MacDonald: GERG, Texas A&M
- Dr. William Sager: Dept. of Oceanography, Texas A&M
- Dr. William W. Schroeder: Dauphin Island Sea Lab
- Dr. Dan Wilkinson: GERG, Texas A&M
- Dr. Carl O. Wirsen: Woods Hole Oceanographic Institution
- Dr. Gary Wolff: GERG, Texas A&M

Figure 2.3 shows the management structure of the project and the areas of responsibility for each investigator.

The work plan comprises 31 months of effort and requires two reports: a review and synthesis of existing data and literature; and a final report that integrates data collected and analyzed over two field seasons. The synthesis phase of the program will make use of extensive data and material collected by the project team during previous investigations of the Gulf of Mexico seeps. In particular, extensive video and seismic survey data are available from cruises with the U.S. Navy Submarine NR-1. Also, extensive collections of tissue, water, and sediment samples have been made by the project team from the JSL submarine. Finally, several energy companies have expressed willingness to share proprietary data in support of the study.

The field phase of the project will consist of two 10- to 20-day cruises with the JSL submarine (the first of which was completed on 28 September 1991) as well as additional collections from surface vessels. The National Undersea Research Program has allowed dive time awarded to the investigators to be

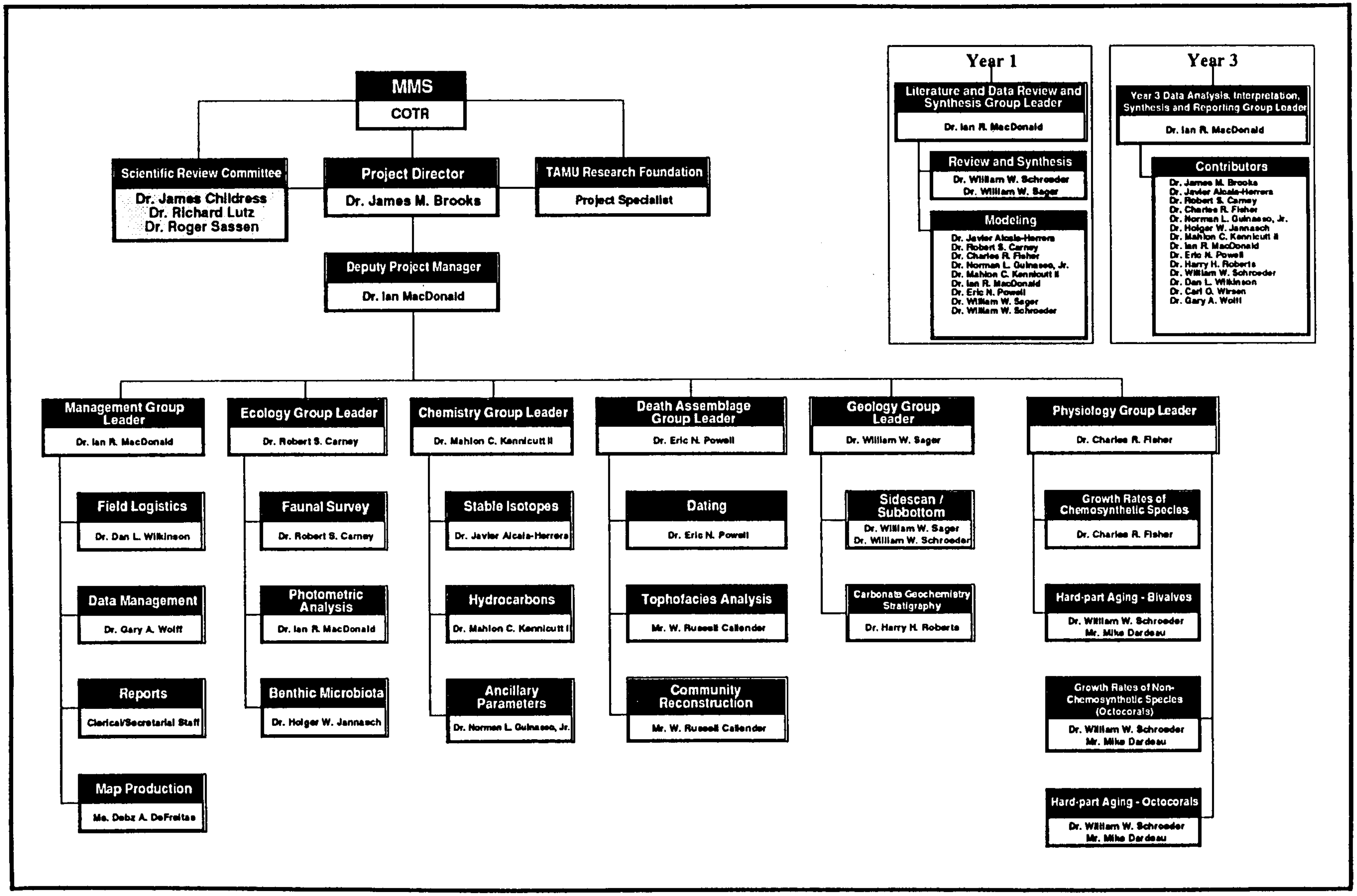

Figure 2.3. Organizational structure for the Chemosynthetic Communities Study.

applied toward the goals of the MMS study and thereby significantly increased the available dive time. Collections will be made at permanent stations established in a minimum of six sites where chemosynthetic communities have been documented (see Figure 2.2). The sites were chosen to represent--within the resources available for the study--the faunal, geographic, and geologic diversity known to characterize the Gulf of Mexico seep communities.

Sampling design for geochemical parameters is intended to establish the threshold levels of key chemical parameters associated with the distinct faunal clusters that are characteristic of seep communities. For example, tube worms, which metabolize sulfides, occur in large bush-like clusters; we will therefore collect water samples at the exterior and interior of a tube worm cluster and compare sulfide levels. Likewise, short sediment cores will be collected within and away from beds of mussels or clams; pore fluids from these cores will be analyzed for indicators of seepage such as extractable oil, total CO_2, and chlorinity.

Geological characterization of the seeps is built chiefly around analysis of existing NR-1 and industry survey data--supplemented by opportunistic reconnaissance with the JSL. Our intention here is to map the faults and seepage features and compare these with the distribution of seep fauna. Additionally, comparison of available geophysical data with the distribution of seep fauna will allow us to evaluate various geophysical tools as methods for remote detection of chemosynthetic communities.

The overall objective of biological sampling is to develop a spatial and temporal model describing community formation, senescence, and death. This has several related tasks: determine growth rates of the principal chemosynthetic species, quantify the diversity of both the heterotrophic and chemosynthetic fauna, and test for natural variation in distribution and/or behavior at the spatial scale of individual faunal clusters. Additionally, we will be examining long-term trends in community formation by means of the paleo-record. For the growth studies, we have developed a variety of unique mark, release, and recapture techniques. We will calculate diversity among the benthic macrofauna using sediment grab samples collected at proximate and remote locations with respect to faunal clusters. We will test for short-term change by use of time-lapse camera deployments and by photogrammetric comparison of individual faunal cluster over a one-year time course. We will also undertake a limited study of the microbiota of seeps to identify the free-living bacteria at a genus level and to verify their chemoautotrophic capacity.

SYNOPSIS OF FIELD EFFORTS DURING CRUISE I

- The PIs made dives at 6 chemosynthetic sites and collected samples at 23 fixed locations and collected 40 water column samples, 170 pore fluid samples, 90 sediment core sections, 70 tissue samples for stable isotope analysis, and 40 macrofauna samples. This sample array more than meets the goals specified in the proposal for the Year I cruise.

- Samples of orange and white microbial mats were collected at Bush Hill. Analysis indicates that the pigmented bacteria, generally collected over the oiliest sediments, were morphologically identical to the white mats, but did not exhibit significant chemosynthetic activity. The white mats exhibited very high CO_2 uptake rates that were inhibited at higher temperatures.

- Several *in situ* experiments were deployed to study short-term (1-2 year) change in the chemosynthetic communities. These included growth studies: four clam enclosures containing 26 marked clams, 30 banded tube worms, and 400 marked mussels, as well as a time-lapse camera deployments of 14, 6, and 5 days, and a time-lapse deployment that will remain in place until retrieval next year.

- Length-weight series were collected for tube worms, mussels, and both species of clam. These data will be used for biomass determination for faunal aggregations and for development of condition indices for the animals.

- Photographic documentation of the sampling sites was accomplished through extensive video tape records of dive and sampling processes. Photomosaics were taken at nine stations; these stations will be re-photographed during next year's cruise to determine rates of change in the aggregations.

- A current meter was deployed at 27°44.9'N and 91°12.7' (GC235) in a water depth of about 550 m. It is scheduled to remain in place through February 1992 and will provide valuable information concerning bottom water flow and temperature in the region of four of the six community sites.

- A conductivity, temperature, depth cast was taken in Brine Pool NR-1. The instrument showed unexpectedly high temperatures (17.5° C) and unexpected depth for the pool (>10 m).

RESULTS FROM VIOSCA KNOLL 826

Three JSL submersible dives were undertaken to investigate the recently discovered chemosynthetic community at Viosca Knoll 826. Located on the upper DeSoto Slope, 115 km south of coastal Alabama at 29°09.5'N and 088°01.0'W, this site represents the first chemosynthetic community associated with hydrocarbon seep activity reported east of the Mississippi River delta. The areas surveyed were generally on the upper flanks of a low-relief mound that rises between 45 to 90 m above the surrounding sea floor to a minimum water depth of 428 m. The northern dive site has an overall moderate slope, locally ranging from flat terraces to hummocky terrain with occasional steep slopes. The slope increases to the west in the northwest corner. Bottom sediments are clays and silty clays with authigenic carbonate deposits, in the form of crusts, with fractures and fissures, boulders and rubble found throughout. The southern dive site has a steep to very steep muddy slope that has small terrace-like features with exposed authigenic carbonate outcrops. The southwest corner of the mound is extremely steep sided with at least one terrace area comprised of large, mostly irregularly shaped blocks of authigenic carbonates. Living chemosynthetic fauna are represented by vestimentiferan tube worms (*Lamellibrachia* sp. and *Escarpia* sp.) and possibly lucinid clams. Several zones of disarticulated bivalve shells (lucinid and vesicomyid) were also observed. Conspicuous heterotrophic fauna include the ahermatypic scleractinian coral *Lophelia prolifera*,the soft coral *Callogorgia* sp., the antipatharian coral *Leiopathes glaberrima*, the asteroids *Odontaster setosus* and *Sclerasteriaas contorta*, the bivalve *Acesta bullisi*, and a large galatheid as yet to be identified.

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Dr. James M. Brooks, Senior Research Scientist and Project Manager, has had extensive experience in marine environmental projects. As Director of the GERG, he manages a research and service group consisting of 60 to 70 personnel that handles over $6 million of funding annually. Dr. Brooks has over 100 referred publications relating to a wide spectrum of geochemical and environmental areas. He is currently conducting marine environmental and basic research for such agencies as the National Science Foundation (NSF), Office of Naval Research, a 17-company oil industry consortium, MMS, U.S. Fish and Wildlife Service, Texas A&M Sea Grant, NOAA (2 contracts), and American Petroleum Institute. His other recent projects include studies for the NOAA (OMPA), Gas Research Institute, Offshore Operators Committee, and the NMFS. He is currently Project Director for the Gulf of Mexico portions of the NOAA *"Status and Trends Mussel Watch Program"* and the MMS *"Mississippi/Alabama Marine Ecosystem Study."* His other environmental related work includes research at the Gulf of Mexico, Puerto Rico, and DWD-106 industrial waste dumpsites for three years for the Ocean Dumping Program, involvement for two years with the NOAA (NMFS) Buccaneer Oil and Gas Field environmental assessment study, studies around the Ixtoc-I well blowout for AOML, and a three-year study for NOAA (OMPA) of volatile organics in Gulf of Mexico coastal ecosystems. He is currently conducting the hydrocarbon component of an American Petroleum Institute on the *"Fate and Effects of Drilling Fluid and Cutting Discharges in Shallow, Nearshore Waters."* Other environmental projects have included research and baseline measurements at the Strategic Petroleum Reserve brine disposal sites in the Gulf of Mexico for NOAA; studies of the effects of drilling mud effluents and baseline measurements in the Flower Garden area in the Gulf; baseline studies of hydrocarbons for Bureau of Land Management and MMS at south Texas, MAFLA, and slope study areas; inputs of organic compounds from offshore platforms, river runoff, etc. in the northwest Gulf of Mexico for NOAA and NSF; and sublethal effects of industrial wastes on phytoplankton for NOAA.

Dr. Ian MacDonald, Project Coordinator, has over 12 years of experience in marine ecology including extensive field and sea-going projects. He combines field experience as a marine biologist in the Mediterranean Sea, the Bering Sea, and the Gulf of Mexico with a strong background in research, technical writing, and data management. Principal research interests have included fisheries science and benthic ecology. His current research interests have applied photographic techniques for study of the spatial distribution of chemosynthetic organisms at deep-sea petroleum seeps, remote-operated-vehicle surveys of deep hard-bottom communities, and residency behavior of sea turtles at energy platforms. These studies have required development of reliable field methods and data-archiving procedures for photographic materials as well as innovative analytical techniques.

Dr. William Schroeder, Data Synthesist, has 25 years of experience in marine ecology including extensive field and sea-going projects. Principal research interests have included fisheries science and benthic ecology. His current interests include development of aging techniques for soft corals and clams.

SCOPING SOCIOECONOMIC CONCERNS AND ISSUES IN THE GULF OF MEXICO REGION

Session:	SCOPING SOCIOECONOMIC CONCERNS AND ISSUES IN THE GULF OF MEXICO REGION
Co-Chairs:	Mr. John Greene Ms. Linda Castaño-Vélez
Date:	November 5, 1991

Presentation	Author/Affiliation
Scoping Socioeconomic Concerns and Issues in the Gulf of Mexico: Session Introduction	Mr. John Greene and Ms. Linda Castaño-Vélez Minerals Management Service Gulf of Mexico OCS Region
Oil and Gas Related Social and Economic Issues and Concerns of the State of Florida	Ms. Deborah L. Tucker Executive Office of the Governor Tallahassee, Florida
The Concerns of the State of Louisiana, Involving the Socioeconomic Impacts of Outer Continental Shelf Activities	Dr. Robert Gramling Center for Socioeconomic Research University of Southwestern Louisiana
Oil and Gas Related Social and Economic Issues and Concerns of the State of Mississippi	Mr. J. I. Palmer, Jr. Mississippi Department of Environmental Quality
Presentation to Minerals Management Service Information Transfer Meeting	Mr. Walter Rosenbusch Governor's Energy Office Texas General Land Office
Socioeconomic Advantages to Outer Continental Shelf Activities in the Gulf of Mexico	Mr. B. Jim Porter Louisiana Mid-Continent Oil and Gas Association

SCOPING SOCIOECONOMIC CONCERNS AND ISSUES IN THE GULF OF MEXICO REGION: SESSION INTRODUCTION

Mr. John Greene
and
Ms. Linda Castaño-Vélez
Minerals Management Service
Gulf of Mexico OCS Region

There has been increasing concern throughout the coastal states of the Gulf of Mexico about the social and economic impacts of the offshore oil and gas industry. The history of the oil and gas industry has involved cycles of increased activity followed by periods of decreased activity (the so-called "boom-bust cycle"). Expansion of oil and gas activity to the Gulf of Mexico Outer Continental Shelf (OCS) has increased the commitment of some coastal areas of the Gulf of Mexico to oil and gas exploration and production enterprises. Levels of extremely high or extremely low activity may result in stresses placed on public services, infrastructure, community cohesion, and other factors of social and economic interest.

The present session was developed to work within the framework of the Information Base Review process. It was expected to serve as preliminary scoping of social and economic issues and concerns from the states which rim the Gulf of Mexico. The participants of the session included representatives from most of the Gulf of Mexico States as well as a representative from the oil and gas industry. The different perspectives brought to the session from the participants highlight the variety of concerns about social and economic issues which can be found in the Gulf of Mexico OCS Region today.

Mr. John Greene received his B.A. in anthropology from the University of New Orleans in 1979. From 1980 to 1988, Mr. Greene worked for the Archaeological and Cultural Research Program of the University of New Orleans, as well as performing private consulting. While working as a research associate, Mr. Greene completed classwork for an M.S. in geology at the same university. Mr. Greene has authored or co-authored over 20 research reports on the archaeology, geology, and history of southeast Louisiana.

Ms. Linda Castaño-Vélez is an economist with the Leasing Activity Section of the Minerals Management Service Gulf of Mexico OCS Region. Prior to her association with the Minerals Management Service, Ms. Castaño-Vélez worked as a planning engineer and as a forecast analyst for Entergy Corporation in New Orleans. She earned a B.S. degree in engineering from Tulane University in 1984.

OIL AND GAS RELATED SOCIAL AND ECONOMIC ISSUES AND CONCERNS OF THE STATE OF FLORIDA

Ms. Deborah L. Tucker
Executive Office of the Governor
Tallahassee, Florida

People come to Florida to enjoy the warm, sunny weather, beautiful beaches, abundant fresh and salt water recreational opportunities, low taxes, and strong economy. With 11,000 miles of shore along the Atlantic Ocean and Gulf of Mexico, nearly 10,000 lakes and streams, a rich diversity of flora and fauna unique to the United States and year round temperatures that average 71° F throughout much of the peninsula, Florida is a "sure bet" place to live, visit, and invest.

Florida's natural attractiveness has brought phenomenal growth over the past 40 years. Our population has grown on an average of 900 new residents each day since 1983 and approximates 13 million today. The State's population is projected to be nearly 16 million by the year 2000, and nearly 20 million by 2020. Additionally, in 1990 Florida hosted some 41 million visitors.

Florida's yearly $183 billion economy is fueled mainly by tourism, services, trade, and government. All are growth related and considered to be environmentally <u>clean</u> industries. Florida's environment and economy are directly linked.

Tourism is Florida's largest industry. According to the U.S. Travel Data Center, spending by travelers in Florida totaled $24.36 billion in 1989, ranking Florida second only to California in tourism expenditures.

The estuarine and nearshore marine habitats of the Florida Panhandle, where most oil and gas activities are expected to occur, are some of the greatest natural and economic assets of the region. The nearshore Gulf of Mexico waters and the adjacent continental shelf off the Panhandle play a vital role in the health and productivity of the region.

The ecological importance and sensitivity of the area is tremendous. Coastal habitats and areas of environmental concern include salt marshes, tidal flats, barrier beaches, submerged seagrass meadows, and open bay waters. These ecosystems contain nursery grounds for many economically important species. In addition, these areas provide habitats, rookeries, nesting areas, and calving grounds for several endangered and threatened species, including various marine turtles. Saltmarshes and seagrass beds play a vital role in the healthy economy of the area. The economic value of an acre of marsh, for example, has been estimated at 4 to 5 times that of the most productive farmland.

In recognition of this sensitivity, the State has designated some 21 "Areas of Special Management." In addition, there are many federal holdings including the Gulf Islands National Seashore, St. Vincent Island National Wildlife Refuge, and the Apalachicola River and Bay National Estuarine Sanctuary.

The Florida Panhandle is one of the most rapidly developing regions in the entire State. Coastal cities such as Panama City, Destin, and Pensacola are the center of this growth. Many Panhandle commercial interests, especially fishing and tourism, are highly dependent upon the maintenance of relatively unaltered habitats. People are especially attracted to the clear, blue Gulf of Mexico waters and the white, sandy beaches of the western Panhandle. In addition, many of the estuaries harbor important commercial species, such as oysters, fish, and shrimp, that provide a livelihood to many who live there. The residents of many small Panhandle coastal communities derive practically all their incomes from the seafood industry. The destruction or alteration of the natural coastal setting would seriously inhibit tourism.

The economy of the Panhandle, like the remainder of the State, is directly tied to its warm climate, clean waters, and unspoiled natural resources. Recreation, tourism, retirement, and commercial and recreational fishing are major economic activities of the area.

Recent commercial fishery landings for Florida's west coast were valued at approximately $132 million annually. Processed fishery products exceeded $350 million. Recent fishery landings for Apalachicola alone was valued at approximately $12 million.

The recreational fishing industry brings in millions of dollars annually. Recreational saltwater boat fishing continues to be a popular activity among both residents and tourists. Some 27 percent of residents participated in this activity in 1987, while saltwater fishing is the third most popular resource-based activity - nearly 10 percent of visitors to the State participate in saltwater boat fishing. In the region from Wakulla County westward to the Florida/Alabama border, resident anglers number over 200,000 and produced expenditures of over 67.5 million dollars. For the same region, tourists anglers number over 400,000 with approximately $169 million in expenditures.

The tourist industry generates billions of dollars annually for the regional economy. Bay and Escambia Counties ranked third and fourth, respectively, in the top 10 county destinations of auto visitors to Florida in 1990. The area from Dixie County westward to the Florida/Alabama border ranked third of seven State tourist regions most frequently visited by tourists - hosting over 7 million visitors in 1990. In the same year, tourist development tax collections totaled over $2.7 million for Escambia and Okaloosa Counties alone.

The above descriptions clearly point to the need to maintain the health of the ecological systems which support the economics of the region. Although much economic data is known for the area to aide in determining the economic effects of oil and gas operations, there has been little or no study of the sociological effects of Outer Continental Shelf (OCS) development.

A host of socioeconomic impacts can be associated with programs or actions affecting environmental quality. These include such parameters as changes in population size and composition, impacts on employment, impacts of crime and public safety, effects on education and other social services, changes in housing and community structure, and fundamental changes in lifestyle and the quality of life. As difficult as it is to assess environmental risks and cumulative impacts, examining and then explaining social impacts proves to be even more difficult. To complicate matters further, social impacts from the same activity may vary from location to location.

Yet, the National Environmental Policy Act and the Outer Continental Shelf Lands Act, as amended, clearly intend that socioeconomic impacts be considered in analyses of the project. The question is not one of "whether", but rather "when", "under what circumstances", "to what degree" and "how."

Social impacts are critical in determining and understanding the political acceptability of a project. Impacts on community lifestyles, cultural norms, and economic effects are often at the root of public opposition to projects such as the OCS program. Complicating the analyses is the fact that the aspect of social impact analyses often varies depending upon whether a state or federal agency is making the assessment.

What maybe important or significant to the State or especially local entities may not have the same degree of importance to the federal government, i.e., the Minerals Management Service (MMS) mandate is to lease for oil and gas to the economic benefit of the nation as a whole. Yet, both environmental and economic effects and risks are often felt at the local level and people are not generally willing to accept risks (no matter how small) if their quality of life is not significantly improved.

It is important to understand the specific social and economic issues and concerns at the local level regarding the activity being considered. Although much can be learned from study of the socioeconomic effects of the same activity to another region, extrapolation of all information to another region often proves to be inadequate. Most importantly, people's concerns, whether one thinks they are valid or not, are real and must be dealt with. To do that we have to have the necessary information.

To borrow from Dr. William Freudenburg, "in the social sciences, just as in the biological and physical sciences, the way to answer a question is by looking at it systematically, building on relevant information, not just assertion. We don't have the base of evidence we need."

The National Research Council's report, "The Adequacy of Environmental Information for Outer Continental Shelf Oil and Gas Decisions: Florida and California", had two major conclusions regarding the specific area studied off of Florida:

- traditional social and economic analyses have been inadequate; and

- significant types of social and economic impacts have been ignored.

While these conclusions were reached while addressing OCS activities off southwest Florida, the same are likely for the remainder of the eastern Gulf of Mexico.

In response to the very real potential for development and production on the OCS off the Florida panhandle, the State requested that a study entitled the "Northeast Gulf Social and Economic Study" be funded by the MMS. The objectives of this study are:

- to synthesize existing relevant data on the social and economic impacts of oil and gas activities;

- to identify the socioeconomic components of the human environment necessary in determining impacts. These include a range of demographic and economic features and activities such as population size and composition; birth, death, and mortality rates; patterns and rates of immigration and emigration; areal extent; dominant economic activities; economic diversity with special attention to tourism, fishing, and other marine and coastal usages; employment and unemployment patterns and rates, household income; land use patterns; transportation routes; traffic patterns and capacities; tax bases;

and government services including education, creation and maintenance of infrastructure, police protection, recreation facilities, etc.;

- to determine what activities (especially cumulative) can produce impacts to the northwest Florida area, including those which have already occurred from leasing and exploration and those which may be expected from development and production;

- to determine how specific activities might affect the human environment including (1) incidence, (2) consequence, (3) time and space, (4) cumulative potential, (5) susceptibility to mitigation, and (6) interactions between different dimensions of impacts; and

- to determine how impacts from OCS oil and gas activities are distributed to various elements of the human environment (i.e., residents, producer, and governments).

In a recent analysis of the OCS Natural Gas and Oil Resource Management Comprehensive Program, 1992-1997, Florida concluded:

- The eastern Gulf of Mexico may not be worth the time, efforts, and expense for leasing and recovery given that the potential amount of the resource is relatively small;

- Net economic value, which is a measure of expected revenues less private costs of production, is so relatively low in the eastern Gulf of Mexico, that leasing and attempting recovery may be high compared to the risks of accidents, spills, and environmental damage; and

- Recognizing that net social value is computed from net economic value less social costs, it may be wise to delay leasing and recovery of oil and gas resources in the eastern Gulf of Mexico given that the benefits to society are so relatively small compared to other areas under consideration.

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Ms. Deborah Tucker, a Senior Governmental Analyst with the Florida Governor's Office, serves as a technical and policy advisor to the Governor regarding the OCS oil and gas activities. Ms. Tucker is State's representative to the OCS Policy Committee and the Gulf of Mexico and South Atlantic Regional Technical Working Groups and has worked with the OCS program in Florida for over 10 years.

THE CONCERNS OF THE STATE OF LOUISIANA, INVOLVING THE SOCIOECONOMIC IMPACTS OF OUTER CONTINENTAL SHELF ACTIVITIES

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The State of Louisiana is not anti-Outer Continental Shelf (OCS) development.

- As probably everyone here knows there are over 3,800 production platforms on the Gulf of Mexico OCS (over 99% of the production platforms on the total U.S. OCS), of which the overwhelming majority are off Louisiana.

- Offshore oil, both in State waters, and on the OCS, evolved in Louisiana, and there is understandably a considerable amount of local pride associated with the promotion and support of one of the, if not the, most massive development scenarios the planet has ever seen.

- Indirectly, OCS leasing has been responsible for tens of thousands of jobs in Louisiana.

- And directly, the 8(g) funds (the State's share of the three to six miles offshore leases) have contributed to education in the State.

- All of this needs to be acknowledged up front!

In addition, both the State and the scientific community have been remiss in examining the full range of effects of this massive development scenario. When economic times are good, the natural tendency is to avoid a close examination of what the future holds.

And, quite frankly, the tools to address these issues from the perspective of social impact assessment did not exist until recently. Social impact assessment as a self-conscious discipline emerged out of the requirements of the National Environmental Policy Act (NEPA) 1969. Because NEPA required assessment of potential impacts prior to development, this became the focus of social impact assessment. It is only recently we have began to realize that social impact assessment must also look at the effects of development while it is happening, and after it has occurred; not only in order to assess the accuracy of our predictions, but also to understand the cumulative effects of major development projects.

Until recently, there was little understanding of how different types of development led to different results. We now realize that there are special circumstances surrounding extractive development, particularly in rural areas.

Because extractive enterprises (such as OCS development) cannot necessarily locate near existing development (they must locate in proximity to the resource), and thus take advantage of shared labor supplies and support sectors, they must often re-build the local rural environment (social, economic, and physical) to provide support for the extractive activity. This re-building of the environment has several consequences. First the specialized development (social, economic, and physical) surrounding the extractive activity is often not transferable to new activities, thus flexibility is lost. Second, the creation of the new support sectors may use up or destroy local resources. Third, the existence of high paying jobs in the extractive sector makes the competition for labor keen, and thus the introduction of alternative economic activities difficult. Finally, movement into jobs associated with the extractive sector of the economy means abandonment of traditional occupations. Over the course of a generation this can mean knowledge is lost, skills are not passed on, and the physical infrastructure associated with traditional occupations decays. When the extractive activity ceases or declines, the local area is more specialized than before the activity started, there is less of the local resource base available, and traditional occupations may not be available.

Within this altered environment, if we take an ecological perspective, the question is not whether human social and economic systems will adapt to these changes (because inevitably they will), but rather what the extent and consequences of the adaptation will be. Both the time frame for the development activity and the extent to which it dominates the local economy are important variables in determining the extent of adaptation.

The offshore/OCS development in the Gulf of Mexico is one of the most massive developmental scenarios the planet has seen. From the marshes of southern Louisiana, petroleum activity moved by the 1930's into the shallow protected waters of the Gulf of Mexico. By the mid 1940's, the technology had evolved to allow drilling on (what was later defined as) the OCS. Through the first OCS lease sale in 1954 (spurred on by the 1973/1974 oil embargo) until 1982, offshore activities and the support sectors for those activities grew steadily in the Gulf of Mexico. Thus, for over half a century (two generations) offshore development and support activities expanded to become a mainstay of the Louisiana coastal economy.

In addition to replacing traditional economic activities for long term residents, the growth associated with offshore development attracted in-migration to fill jobs in the expanding labor market. Using time series data available for the last 20 years, it is possible to statistically explain over 95 percent of the variance in total employment in a number of coastal parishes in Louisiana, using only the price of oil on the world market, and the world rig count as predictor variables (Gramling and Freudenburg 1990). Thus, offshore oil and gas activities in coastal Louisiana have not only been around for two generations, but have come to almost completely dominate the coastal economy.

Under these circumstances social and economic systems adapted, and did so at a variety of levels.

- At the individual level people made career decisions based on the expectation that past trends would continue. Seventeen year olds dropped out of high school to gain and use (often esoteric) skills in the support and fabrication sectors surrounding offshore activities. Those who graduated, frequently pursued specialized types of skills (associated with the offshore and support sectors) at the expense of other skills, or more flexible higher education.

- At the small business level, businesses specialized. Mechanic shops became marine diesel repair facilities (with considerable investment in tools and equipment to make that transition). New specialty businesses opened to take advantage of the growing opportunities (offshore catering services, hot shot drivers, etc.). Both of these trends happened in an economic environment that was stimulated to the point that good business practices were not necessary for success. With profit margins high enough, inventory control, billing, machine and equipment layout, etc., could be marginal, and still enterprises prospered. This too is an adaptation.

- Adaptation occurred at the regional level also as the interaction between the resources associated with human and social capital, skills, knowledge, experience, teamwork, networks of supply and distribution, and the physical capital of buildings equipment, and other physical infrastructure developed over time.

The end results of this is what is called overadaptation (Freudenburg and Gramling in press), or a situation where the investment patterns, in both human and financial capital, have been such that it is difficult for the coastal social and economic systems to respond to opportunities other than those associated with offshore petroleum extraction.

Crude oil prices fluctuated between 1982 and 1985, and in late 1985 the bottom fell out of the world oil market. Unemployment in some coastal parishes went from long established levels in the 4 percent range (essentially no unemployment) to over 20 percent throughout 1986 and much of 1987. These overadapted coastal social and economic systems were unable to respond to the drastic changes, business failures were common, and the preliminary 1990 census figures show that out-migration from many coastal parishes has been high.

At this point in time there are two fundamental realities the State of Louisiana faces:

- Coastal Louisiana is overadapted in the extreme; and

- In the long run, the oil will run out.

The State wants to prevent the latter as long as possible, in order to address the former, and wants the Department of Interior/Minerals Management Service (MMS) to help do this. The focus, then, of the State's concerns is on cumulative impacts. There are two fundamental ways MMS can help:

- The MMS could help through a more carefully controlled development process. What Louisiana wants, and needs, is some control over the boom/bust cycle; some moderating procedure; some legal/policy structure that inhibits extreme swings from boom to bust and back again in response to erratic oil price fluctuations. Since we have no control over the vagaries of the world oil market, our best chance of moderating these destructive cycles is to limit the areas in the Gulf of Mexico that are available for the expansion of OCS activity during the inevitable, but unpredictable, periods of high price per barrel oil. Under a more controlled and smaller scale leasing schedule, we might not be left entirely at the mercy of what has historically been an extremely and increasingly unstable world oil market. Present area-wide leasing policies, however, leave us completely exposed to the workings of the boom/bust cycle as a consequence of oil price shifts.

  Put simply, by opening up virtually all of the Gulf of Mexico OCS for leasing, and holding such lease sales semi-annually, as MMS has done and proposes to continue doing, the stage is set so that in periods of extreme and sudden oil price inflation, such as have often occurred, exploration, development, and production can almost immediately expand into the huge vacuum of minimally developed leases in the central and western Gulf of Mexico regions, and bring on another uncontrolled and uncontrollable oil "boom". Our painful experience, and social scientific research, show that the more extreme the boom, the more devastating will be the effect of the following, inevitable, oil price moderation, or "bust". To seek another boom without some kind of legal or policy moderation is to seek another unmoderated bust with all of its accompanying social and economic devastation.

- The MMS could help through support of impact mitigation to help coastal social and economic (and physical, but that is beyond the scope of this presentation) systems to adapt to a changing environment. If funding becomes available, a model for such a program exists, in MMS's University Initiative Program. It is not the content, but rather the structure of the program that provides a model for quick response, and locally-generated proposals. There are three elements to the model:

  - The initiatives program provides for proposals for projects to come from outside of MMS. In the case of the initiatives program, these proposals come from scientists at universities. Under an OCS impact mitigation program, those eligible to propose projects would have to be broadened to include coastal communities and organizations. The definition of appropriate projects would also have to be broadened to include such things as maintenance of physical infrastructure (paving a road to a major offshore support facility), and program development (e.g., development of a new curricula for a vocational technical school) and evaluation (e.g., five years later - did the new curricula work?).

  - The proposed projects go to a state agency which has the proposals externally reviewed. The proposals are then ranked on the basis of the reviews by a steering committee, and a "short list" is developed. Those proposals remaining on the short list are given an opportunity to respond to reviewer comments.

  - Representatives from MMS and the state agency meet to decide which of the projects are funded, based on the reviews and the funds available. The state agency administers the project.

- This process has a number of advantages:

  - Projects are proposed at the local level in response to local need.

  - Local proposals and external reviews free MMS from the necessity to maintain the far-reaching type of expertise that would be necessary if the program was run directly through the agency.

- Administration of the projects is funded through the same funds as the projects. This means that as funding levels go up or down, administrative cost automatically follow the trend. In short, project(s) administration does not become a line item on anyone's budget. If there are no funds one year, there are no administrative costs.

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Gramling, R. and W.R. Freudenburg. 1990. A closer look at "local control": communities, commodities, and the collapse of the coast. *Rural Sociology* 55(4):541-58.

Dr. Robert Gramling is the Director of the Center for Socioeconomic Research at the University of Southwestern Louisiana. He received his Ph.D. in sociology from Florida State University. Dr. Gramling's principle research interests include socioeconomic impact assessment, microsociology, and the sociology of marriage and the family. He is particularly familiar with the south Louisiana "cajun" culture, and has conducted and published research on the impacts of offshore oil and gas, and OCS activities on the people and communities of Louisiana.

OIL AND GAS RELATED SOCIAL AND ECONOMIC ISSUES AND CONCERNS OF THE STATE OF MISSISSIPPI

Mr. J. I. Palmer, Jr.
Mississippi Department of
Environmental Quality

No presentation was made at the Information Transfer Meeting. Mr. Palmer requested that the following letter be read and entered into the Proceedings.

Mr. John Greene
Archaeologist/Anthropologist
United States Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Boulevard
New Orleans, Louisiana 70123-2394

Dear Mr. Greene:

This letter summarizes our telephone conversation this afternoon about your Information Transfer Meeting tomorrow in New Orleans. I regret that the State of Mississippi will not have a representative to participate in the work session considering social and economic issues related to Outer Continental Shelf oil and gas activities, but I very much appreciate the opportunity to comment on one particular aspect of this matter in writing.

We in the Department of Environmental Quality are not social scientists. Our statutory responsibilities focus on the environmental and managerial aspects of oil and gas exploration and production. So, I cannot speak with authority about the various social and economic impacts, including "trickle-down effects," which inevitably result from off-shore oil and gas activities. However, regardless of the variety and magnitude of these impacts, I would like to address the issue of funding the many efforts required to cope with such impacts.

State and local governments everywhere are struggling for revenues. While funds required to deal with pressures caused by off-shore oil and gas activities could be generated through taxation, that is the least attractive funding source for elected officials these days. Similarly, user fees and other exactions are also available, but they, too, have their limits.

Around 1979, Congress amended the Coastal Zone Management Act, as I recall, to provide a mechanism to compensate states for impacts caused by off-shore oil and gas operations. The Coastal Energy Impact Program (CEIP) was needed and well intended, but existed only at the whim of Congress through their annual appropriations process. I have not inquired about the CEIP in many years, and am not even sure that the program still exists. In addition to the problem of hinging support for coastal states on the caprice of Congress, the CEIP also suffered from the basic formula upon which funding distributions were made. The concept of areal "adjacency" was very difficult to administer, giving rise to various controversies among adjacent coastal states, thus making the whole program a real mess.

During the lengthy process of settling the "8(g)" controversy through Congressional amendment of the Outer Continental Shelf Lands Act, several coastal states attempted to inject into the resolution of this problem the issue of compensation for on-shore impacts attributable to off-shore oil and gas operations. Unfortunately, I don't believe this effort was successful, but it would have provided for distribution of a percentage of off-shore revenues directly to affected coastal states, rather than through the difficult and circuitous CEIP process.

Having been personally away from these issues for several years now, I am somewhat stale on the current status of both the 8(g) and CEIP programs. My purpose in bringing these issues to your attention is simply to suggest to those attending your meeting tomorrow that various mechanisms to assist coastal states in their efforts to cope with the on-shore effects of off-shore operations have been instituted in the past. Unfortunately, they were terribly flawed. However, I believe that the basic construct of these programs should be revisited to see if the positive aspects of these initiatives are salvageable.

Again, I regret not being able to personally attend your conference and participate in the discussion of these very important issues. Hopefully, I will have another opportunity to do that in the future.

Sincerely,

J. I. Palmer, Jr
Executive Director

JIP,Jr./ch

PRESENTATION TO MINERALS MANAGEMENT SERVICE INFORMATION TRANSFER MEETING

Mr. Walter Rosenbusch
Governor's Energy Office
Texas General Land Office

Presentation Summary not submitted.

Mr. Walter C. Rosenbusch, Deputy Land Commissioner in the Texas General Land Office, oversees a program area which is directly responsible for the management and administration of public acreage related to mineral development and revenue, and dedicated to support education in Texas. Previously, Mr. Rosenbusch has held positions at the Texas General Land Office such as Royalty Audit Manager and Division Director of Royalty Management & Compliance. He received his BBA in accounting from the University of Texas at Austin in 1979, and studied oil and gas accounting at the University of St. Thomas at Houston. Mr. Rosenbusch is a member of the Institute of Internal Auditors, Natural Gas Marketing Association of Houston, and is Chairman of the Royalty Management Committee of the Western States Land Commissioners Association. He has recently been appointed by the Governor's office to the Interstate Oil Compact Commission.

SOCIOECONOMIC ADVANTAGES TO OUTER CONTINENTAL SHELF ACTIVITIES IN THE GULF OF MEXICO

Mr. B. Jim Porter
Louisiana Mid-Continent Oil and Gas Association

There are some obvious advantages to continuation of oil and gas development in the Gulf of Mexico. It is necessary to mention a few items as a foundation for other points.

REVENUES

Revenues from Outer Continental Shelf (OCS) activities go into the general treasury and help to finance the numerous services offered by the federal government. These revenues have been in excess of $6.5 billion in some years and have averaged more than $2 billion annually for the past several years. The federal government can only increase these revenues by expanding offshore development and not limiting it.

ENERGY SECURITY

The Gulf of Mexico is the only place in the lower 48 where any significant new oil and gas exploration is taking place. As you know, the United States imports nearly 50 percent of its daily crude oil supplies from foreign countries. Without increased domestic production, that number could increase to as much as 75 percent in 20 years, according to a recent report by the Office of Technology Assessment.

If OCS activities are curtailed to any extent, our dependence on foreign oil will increase. The United States balance of payment will worsen. Local economies dependent upon the oil and gas industry will be subject to even greater instability. This is not only because of the cyclical nature of the industry, which is the result of shifting wellhead prices, but because of the political instability in foreign countries. Nearly 270 million barrels of oil or 70 percent of our total annual offshore production comes from the Gulf of Mexico. More than three trillion cubic feet of natural gas comes from the Gulf of Mexico each year, again representing nearly 70 percent of the United States offshore production effort. If we fail to develop new reserves, our ability to replace foreign oil in a time of crisis or emergency becomes even more precarious.

To maintain the necessary level of production, new reserves have to be developed. New exploratory wells have to be drilled. New areas must be opened for development and access to existing areas such as the Gulf of Mexico must be maintained.

As President of the Louisiana Mid-Continent Oil and Gas Association, my comments are primarily concerned with Louisiana, but much of what I say can be carried over to other states.

ENVIRONMENTAL CONCERNS

Some areas such as Florida and California oppose offshore drilling because of the fear of oil spills. The serious oil spills that have taken place in the United States have been from tankers and not production platforms. Statistics clearly show that pipelines are the safest way of transporting oil from offshore production facilities to onshore facilities. Yet, by limiting offshore development, we increase imports and therefore increase tanker traffic.

Many environmental groups oppose the opening of ANWR to exploration and production activities. The ANWR is a valuable natural resource that needs proper management. We also contend that the oil and gas that lie under that frozen ground are also essential natural resources that must be managed and properly utilized.

Other environmental concerns are often voiced and there is a need for environmental awareness. The petroleum industry takes every precaution to prevent the spoiling of beaches or fouling of waters. Accidents do happen and industry responds as quickly as it can. Its success record is excellent, but often ignored by opponents.

Instead of elaborating on federal revenues, national energy security or environmental matters, which are integral facets when discussing offshore development, our purpose is to discuss the socioeconomic impacts of offshore development in the Gulf of Mexico.

NO CONCLUSIVE PROOF

Although countless studies and papers have been offered which address these issues, none offer any conclusive proof to justify a curtailment of offshore development or a curtailment of the current areawide leasing program.

There is no evidence to prove that limiting lease sales would eliminate or at least stabilize the boom-bust cycles that take place in south Louisiana and, therefore, lessen the socioeconomic impacts on the people and governing agencies.

OBSERVATIONS

To help understand the impacts of the offshore industry, let me offer the following observations.

The oil and gas industry in Louisiana is the single largest employer in the private sector. More than 100,000 direct jobs are generated by the industry in this state and many of those are directly related to OCS activities. It is estimated that each oil and gas industry job results in three to five spin-off jobs.

Thus, to maintain these jobs it is necessary that OCS activities in the Gulf of Mexico continue and be enhanced.

In regard to the socioeconomic impacts, there are many fallacies being put forth which are based upon incorrect assumptions, inaccurate information or incomplete data. I wish to address some of those points.

We frequently hear about the millions upon millions of dollars spent for schools, highways, hospitals, and other public facilities in south Louisiana because of the presence of OCS activity.

There is no base-line data on which to formulate these assumptions. Instead, they use a what-if scenario. These figures are based on the assumption that if OCS activities had not developed in south Louisiana, the region would have remained stagnant, apparently showing no population growth, no in-or-out-migration, and no demand for expanded services. You can not assume such things.

Coastal Louisiana was not a virgin wilderness before the advent of the offshore oil and gas industry. The area was settled, it was developed, and it was populated. Numerous industries including lumbering, trapping, fishing, and tourism have developed in coastal Louisiana, just as the offshore oil and gas industry. Because of the area's location and network of waterways, the boat building and fabrication industry might have developed even without the offshore oil and gas industry.

TAXES ON INDUSTRY

Instead of claiming that state and local governments were forced to pay for these facilities, it would perhaps be more accurate to say that the oil and gas industry and its related industries, boats, fabricators, caterers, supply companies, and others have paid the bill for these items. It is readily admitted that the coastal communities did not receive any direct revenues from actual OCS production. However, the on-shore resources of the companies involved in OCS activities are subject to local ad valorem taxes.

Most schools and public facilities are built through the dedication of property taxes and sales taxes. In Louisiana property taxes are paid by industry, since the state has an extremely high homestead exemption. The bulk of the sales taxes is paid by the industrial segment. In coastal Louisiana the biggest industries are the oil and gas companies, the fabricators, and related industries. These companies have paid the taxes that built the schools and hospitals.

Many public facilities, such as the hospital and jail in Morgan City, were constructed in part with Coastal Energy Impact funds, which were funds made available to the state and the coastal communities to help offset the impact of offshore development.

While it does not relate directly to our discussion today, it is important to note that coastal parishes received 10 percent of the state royalties for oil and gas production on state owned-land and water bottoms. This includes the offshore area within the jurisdiction of Louisiana. These funds are used to pay for roads, drainage improvements, recreational facilities, and other government-financed projects. Many school boards supplement their funding base with mineral revenues derived from oil and gas leases on lands owned by school boards and on 16th section lands.

Numerous federal programs have financed various improvements in these areas. Many of these programs are the result of the former federal revenue sharing programs and the Coastal Energy Impact Assistance Program already mentioned. Again, both of these programs were dependent at least in part upon the revenues derived by the federal government from oil and gas activities in the form of bonuses, lease-rental fees, and royalties. The Federal Land and Water Conservation Fund received approximately 71 percent of its fund from revenues resulting from OCS activities. These funds have been used to acquire more than five million acres of federal, state, and local parks and conservation areas and to develop more than 25,000 community and state recreational facilities.

BOOM-BUST CYCLES

The coastal communities have been impacted by the boom-bust cycles of the oil and gas industry. As a result of this, industry has put additional demands on various governmental services.

This demand, according to most studies, is one of the problems associated with the in-migration of people taxing the services offered by the various municipalities, parishes, and the state.

Rather than blame industry, it might be proper to suggest that this failure to provide the needed level of service is a result of the inability of government, government at all levels, to respond quickly to the changing needs of the populace. This is not an attempt to place blame. Government, because of its nature, must, in most cases, move slowly. I would recommend that all levels of government look for ways to respond to short-term demands that strain the services it provides.

It is admitted that local governments and the state government, despite the best intentions, are not always able to respond to the increase demands. Therefore, the industry does support the sharing with the coastal states and parishes a portion of the federal revenues derived from offshore bonuses, rentals, and royalties.

Another issue often raised deals with how the industry's boom cycles result in an in-migration of people, who then leave when the boom cycle is over. The in-migration is blamed for increased housing costs, housing shortages, and other related matters. This is simply supply and demand, the cornerstone of the free economic system, at work. If the demand for any commodity increases, being it bread, cars, or houses, and the supply remains stagnant, then the price for the available supply will increase.

The argument is then made that when the boom cycle ends, people are left without jobs and then leave the area, resulting in a housing glut and depressed real estate values.

If you examine any industry you will find the same scenario. Maybe it is not as vividly portrayed as in the oil and gas industry, but it has happened in virtually all areas.

If automobile sales slump, a car manufacturer shuts down a production facility, laying off hundreds of assembly line workers, who may or may not be rehired later.

A defense contractor fails to get a contract or finishes a job at a particular facility and hundreds are laid off.

The U.S. government decides to close a military base and the impact on the surrounding area is devastating, as we will soon see in Alexandria.

Many communities in the northeast have been severely impacted when the local steel mills closed.

These are unfortunate situations and perhaps ways could be found to lessen the impact of these things, but as an industry we do not believe that curtailing activities in the Gulf of Mexico is the way to reduce the impacts.

The boom-bust cycle is not a new development or something unique to the oil and gas industry. Any industry that is impacted by global political issues as much as this industry is going to have up and down periods. We as an industry have no control over Middle East politics. Thus to lessen those impacts at the local level, the economy of south Louisiana must be diversified.

LIMITING LEASING NOT THE ANSWER

A paper presented to this body at its 1990 meeting suggests that controlled leasing of mineral rights could minimize social costs to the individuals and communities. Leasing less area, the paper stated, over longer periods of time would result in more stable economic and employment conditions.

The economic fitness of south Louisiana, the growth and decline of the workforce, and other related items are a function of well head oil prices and not leases. If you graph the wellhead price of oil and the level of oil and gas industry employment in Louisiana, you will see similar trends. The trends are not exactly the same because some offshore workers do not actually reside in Louisiana. However, if you compare the number of leases sold to the employment trends, you will see there is no correlation. Simply stated, there is no pattern.

Leases sold one year may not be subject to exploration and production activities for several years later. During this period, the federal government is collecting rental fees that it would not otherwise receive.

If anything is to be said about the current leasing method, it is that it has helped to stabilize the south Louisiana economy. Along with the areawide leasing program, the current minimum bid policy of Minerals Management Service has come under attack.

BID LEVELS

The decline in the average bid is not a recent occurrence or the result of the areawide leasing program or the $25 per acre minimum bid. This decline, like the decline in employment, is a direct result of oil prices.

The amount of money a company bids for an OCS lease is related to a number of factors, the most important of which is the prospective future price of oil and gas. It is no coincidence that future price expectation, as well as bid levels peaked in 1980, three years before the areawide leasing program started and have declined since then.

Although the economy of coastal Louisiana may not be anything like it was in the early 1980's, it has in the past few years showed some stability.

According to a recent economic study, the Louisiana Economic Outlook, by Dr. Loren Scott, Dr. James Richardson, both of Louisiana State University, and Dr. A.M.M. Jamal of Southeast Louisiana University, employment is projected to grow on an average between 2 and 2.5 percent in two areas traditionally impacted by OCS activity, Lafayette and the Houma-Thibodaux area, over the next two years.

Areawide leasing provides a steady stream of attractive prospects, resulting in a stabilization within the industry. While the level of activity is not near the boom period level, the industry activity has increased slightly in recent years and the offshore construction industry has also stabilized.

More oil and gas is being found as companies pursue innovated exploration strategies, which would perhaps not be feasible under a limited leasing program.

Also, the industry's move into deepwater Gulf of Mexico can be attributed to areawide leasing and advance technology. This move is necessary as near-to-shore reserves decline in productivity.

The current leasing program is sound and workable.

INTERNATIONAL POLITICS

It is also important to remember that the boom period of the 1980's is a direct result of the global increase in oil prices which is directly attributable to actions by the Organization of Petroleum Exporting Countries (OPEC). Regardless of what the industry would have done, the price of oil would have still increased because OPEC controls the majority of the free world's oil. The federal government was quick to take advantage of this increase with the passage of the ill-advised Windfall Profits Tax, which has since been repealed.

The OPEC does not offer the same level of influence today. However, conditions in the Middle East are so unstable, oil prices can be impacted by the slightest action there, as has been seen in recent years.

OTHER ISSUES

Regardless of the level of activity in the Gulf of Mexico, there are some issues that will continue to be raised. For example, there may be some sociological impacts resulting from employees working seven days on and seven off. Such a schedule is not for everyone. But such problems are not unique to the oil and gas industry.

Is the seven-on, seven-off cycle more disruptive to family life than people who do shift work and, therefore, work odd hours of the day? Is it more disruptive than the lifestyle migratory workers in Florida and California who have to travel large distances to find work? Is it more disruptive than the salesman who must spend several days on the road, being in a different city every night? Is it more disruptive than a construction worker who must be away from home for extended periods of time?

Our social and governmental institutions perhaps need to look at these issues and see how we as a people can adapt. Already, one university, Nicholls State University in Thibodaux, offers classes on a seven-on, seven-off schedule to accommodate offshore workers.

We certainly need to be aware of the sociological and economic impacts of any endeavor we undertake. Government, industry, and social agencies must be able to adapt to change. But when we look at impacts, we must not look only at the negative side.

We must not look at just how much the oil and gas industry has cost us. We must look at what we have gained. We must look at the energy that has been supplied, the jobs that have been created and still exist today. We must look at the revenues provided to the federal government in the form of bonuses, rentals, and royalties. We must look at the local revenues generated through local taxes and money spent on goods and services purchased in south Louisiana.

As a people, we change. As one of the papers presented to this conference in 1990 noted, prior to the advent of the offshore development, many in south Louisiana made their living trapping, fishing, and shrimping. The same history can be found in other states, where industries other than offshore oil and gas industry exist. It is natural for people to look for other employment alternatives and livelihoods. The developing offshore oil and gas industry has offered this alternative to the people of Louisiana and other coastal states.

It is not a perfect industry, but no industry is. However, the offshore oil and gas industry is a very good industry, and an industry that when properly viewed has had more positive than negative impacts.

Mr. B. Jim Porter is President of the Louisiana Mid-Continent Oil and Gas Association, which is the largest trade group representing all petroleum interests in Louisiana. He is the former Secretary of the Louisiana Department of Natural Resources. Mr. Porter holds a B.S. in chemistry and physics from the University of Central Arkansas and an M.S. in radiation physics from the University of Arkansas. Mr. Porter has extensive experience in fields involving natural resources, energy, and the environment.

DEVELOPMENT POTENTIAL OF HARD MINERAL RESOURCES IN THE EXCLUSIVE ECONOMIC ZONE OF THE NORTHERN GULF OF MEXICO

Session:	DEVELOPMENT POTENTIAL OF HARD MINERAL RESOURCES IN THE EXCLUSIVE ECONOMIC ZONE OF THE NORTHERN GULF OF MEXICO
Co-Chairs:	Mr. Gary Rutherford Mr. T. Gerald Crawford
Date:	November 5, 1991

Presentation	Author/Affiliation
Development Potential of Hard Mineral Resources in the Exclusive Economic Zone of the Northern Gulf of Mexico: Session Introduction	Mr. Gary Rutherford and Mr. T. Gerald Crawford Minerals Management Service Gulf of Mexico OCS Region
Characterization of the Development Potential of Ship Shoal Sand for Beach Replenishment of the Isles Dernieres: An Introduction	Dr. Mark R. Byrnes and Dr. Charles G. Groat Louisiana Geological Survey Center for Coastal, Energy, and Environmental Resources Louisiana State University
Dredging Technology for Mining Hard Minerals Resources in the Exclusive Economic Zone	Mr. Thomas W. Richardson U.S. Army Engineers Waterways Experiment Station Coastal Engineering Research Center
The Gulf of Mexico Task Force – A Federal-State Cooperative	Mr. T. John Rowland Minerals Management Service Office of International Activities and Marine Minerals
Geologic Framework and Sand Resources of Ship Shoal, Northern Gulf of Mexico Exclusive Economic Zone	Dr. Shea Penland and Ms. Karen E. Ramsey Louisiana Geological Survey Center for Coastal, Energy, and Environmental Resources Louisiana State University
An Evaluation of Physical Environmental Impacts of Sand Dredging on Ship Shoal	Dr. Mark R. Byrnes and Mr. Praveen Patnaik Louisiana Geological Survey Center for Coastal, Energy, and Environmental Resources Louisiana State University

(Continued)

Session: DEVELOPMENT POTENTIAL OF HARD MINERAL RESOURCES IN THE EXCLUSIVE ECONOMIC ZONE OF THE NORTHERN GULF OF MEXICO (continued)

Presentation	Author/Affiliation
Physical and Economic Evaluation of Onshore Sand Resources	Ms. Karen E. Ramsey Louisiana Geological Survey Center for Coastal, Energy, and Environmental Resources Louisiana State University
Economics of Sand Mining at Ship Shoal	Mr. T. Gerald Crawford and Mr. Robert F. Kelly Minerals Management Service Gulf of Mexico OCS Region
Environmental Studies for Evaluation of Marine Mining Impacts	Mr. Barry S. Drucker Minerals Management Service Office of International Activities and Marine Minerals
Characterization of the Development Potential of Ship Shoal Sand for Beach Replenishment of the Isles Dernieres: Conclusions and Recommendations	Dr. Mark R. Byrnes and Dr. Charles G. Groat Louisiana Geological Survey Center for Coastal, Energy, and Environmental Resources Louisiana State University

DEVELOPMENT POTENTIAL OF HARD MINERAL RESOURCES IN THE EXCLUSIVE ECONOMIC ZONE OF THE NORTHERN GULF OF MEXICO: SESSION INTRODUCTION

Mr. Gary Rutherford
and
Mr. T. Gerald Crawford
Minerals Management Service
Gulf of Mexico OCS Region

The erosion of Louisiana's coastline and subsequent land loss has been on everyone's mind and especially in Louisiana in recent years. In Louisiana are 40 percent of the nation's wetlands where 80 percent of the nation's wetlands loss occur. Beach replenishment and barrier island restoration are possible solutions to this dilemma. The Exclusive Economic Zone Gulf of Mexico Task Force, represented by scientists from Minerals Management Service and state agencies of Texas, Louisiana, Mississippi, and Alabama investigated several areas for sand resources. The Ship Shoal/Isles Dernieres area was recommended based on resource abundance and quality. The purpose of this session is to provide to us an analysis of the environmental, geologic, engineering, and economic considerations of sand dredging in the Ship Shoal/Isles Dernieres area where the use of sand is probable for beach replenishment and barrier island rejuvenation.

Mr. Gary Rutherford is a geologist in the Minerals Management Service (MMS), Gulf of Mexico OCS Region, Leasing and Environment Section. Prior to his employment with MMS, he worked seven years in the oil industry, five years of which he was a petroleum geologist with Gulf Oil Exploration and Production Company. He received his B.A. in geology from the University of Tennessee and his M.S. in geology from the University of New Orleans. He is an active member of the American Association of Petroleum Geologists.

Mr. T. Gerald Crawford is a supervisor of the Resource and Economic Analysis Unit in the Geological and Geophysical Section of Resource Evaluation in the Minerals Management Service, Gulf of Mexico OCS Regional Office. He received his B.S. in petroleum engineering from Louisiana State University in 1972. He began his career in the Federal Government with the U.S. Geological Survey (USGS) in 1972, and has been involved with resource assessment, bid adequacy, and fair market value determinations within the USGS/MMS since then.

CHARACTERIZATION OF THE DEVELOPMENT POTENTIAL OF SHIP SHOAL SAND FOR BEACH REPLENISHMENT OF THE ISLES DERNIERES: AN INTRODUCTION

Dr. Mark R. Byrnes
and
Dr. Charles G. Groat
Louisiana Geological Survey
Center for Coastal, Energy,
and Environmental Resources
Louisiana State University

As part of ongoing investigations related to non-fuel mineral resource targets in the Exclusive Economic Zone (EEZ) of the northern Gulf of Mexico, the EEZ Gulf of Mexico Task Force has assembled and analyzed existing data bases for identifying potential hard mineral resources in the northern Gulf of Mexico (Gulf Task Force, 1989). The task force consists of representatives from the Minerals Management Service and members from state agencies in Texas, Louisiana, Mississippi, and Alabama. The most prominent offshore hard mineral resources identified in phase I of the study were sand and shell. As a result of these investigations, several target areas for sand resources were identified and further studies were proposed on selected resource areas. After reviewing preliminary information from proposed study sites, the Gulf of Mexico Task Force recommended a concentrated effort on one site with the greatest potential for near-term leasing. The papers in this session present the results of that study in terms of detailed resource identification, physical environmental impacts of dredging, and economic feasibility.

Whereas the primary objective of the phase I Gulf Task Force study was to prepare a preliminary assessment of the occurrence and economic potential of non-fuel mineral resources in the EEZ offshore Texas, Louisiana, Mississippi, and Alabama, the primary goal for phase II was to provide an analysis of the geologic, engineering, environmental, and economic considerations associated with sand dredging and placement in the Ship Shoal/Isles Dernieres area where the near-term use of sand is likely for barrier island restoration and beach replenishment. This area was chosen based on results from a preliminary evaluation of resource abundance and quality, data availability and the necessity for further data collection, proximity to areas for resource utilization, and likelihood of resource utilization. Ship Shoal, a large sand shoal approximately 15 km seaward of the Isles Dernieres barrier island system in Louisiana (Figure 4.1), was an ideal site for this study because initial results indicated a very high quality sand deposit that contained about 1.2 billion cubic meters of material seaward of one of the most rapidly migrating barrier shorelines in Louisiana (long-term rates of change ranging from -10 to -15 m/yr (McBride *et al.* 1991)). Significant quantities of data existed for characterizing the geologic framework of the shoal (only a limited field effort was needed to provide necessary detail about the geologic history of the shoal), and nearshore wave climatology was available for analysis of physical environmental impacts of dredging. In addition, sand resource compatibility with deteriorating sand beaches landward of the shoal make it a likely source of material for coastal restoration and protection against accelerating rates of wetland loss.

Five specific tasks were designed to evaluate Ship Shoal as a potential near-term leasable sand deposit for coastal erosion control in Louisiana. High-resolution seismic profiles and vibracore data provided the primary information for identifying the sedimentologic characteristics and geometry of the shoal. A preliminary analysis of existing dredging technology for application at Ship Shoal was assembled for domestic operations. The physical environmental impacts of dredging on the shoal were estimated using a wave refraction model to test resultant effects on the shoreline landward of the borrow area. An evaluation of available upland sand resource targets for quantity of material and cost was accomplished for comparison with offshore site characterization. Lastly, an economic analysis for two potential project conditions on Ship Shoal addressed the economic viability of this resource.

The results of this study were developed through a cooperative effort between the Louisiana Geological Survey, the U.S. Army Corps of Engineers, Waterways Experiment Station's Coastal Engineering Research Center, and the Office of Resource Evaluation for the Gulf of Mexico OCS Region, Minerals Management Service. A prototype methodology was established for evaluating near-term leasable sand resources for coastal erosion control or construction aggregate.

PROJECT OVERVIEW

During the initial stages of the study, significant effort was spent coordinating activities of the five different tasks to ensure a coherent final product that would meet project objectives. Although Ship Shoal was the area under consideration, certain aspects of the analyses required more limited spatial constraints to provide specific recommendations regarding dredging sites as related to physical environmental impacts and projected cost estimates. The geologic framework study provided background information on the regional history of shoal development, including sand size characteristics, sand volumes for specific portions of the shoal, and historical migration rates. These data were integral components for optimum site selection regarding dredging scenarios, physical environmental evaluations, and project cost estimates. Potential dredging alternatives were investigated relative to environmental limitations, such as water depth and travel distance, and operating costs.

Based on the results of these two tasks and a cursory investigation of the location of oil and gas infrastructure on the shoal, two dredging scenarios were chosen for testing the effect of resource extraction on wave propagation patterns and resultant shoreline impacts. The 1 million and 10 million cubic yard (yd^3) sand dredging scenarios were tested based on the range in quantity of sand used for past coastal erosion control projects in the

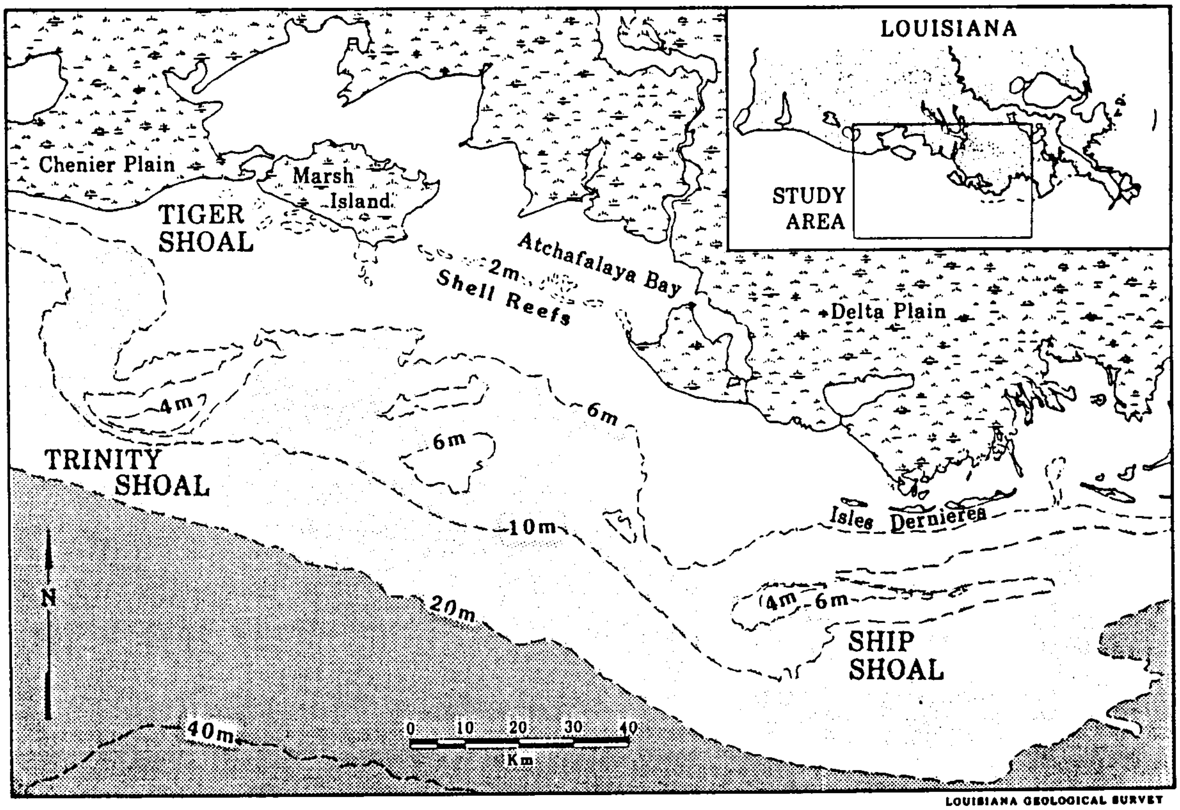

Figure 4.1. Index map of Ship Shoal/Isles Dernieres study area offshore of the southwestern Mississippi River delta plain (Penland *et al.* 1986).

northern Gulf of Mexico. For example, sand volumes associated with beach replenishment at Grand Isle, Louisiana, range from hundreds of thousands of cubic yards to approximately eight million yd^3. Ship Shoal lease block 88 was chosen as the specific site for simulated dredging because oil and gas operations were not present, and it was located along the leading edge of the shoal where sand deposits were thick and water depths were ideal for dredging. Water depths over the shoal from a 1986 survey were used to create a grid of variable bathymetry for wave refraction analysis, and water depths at specific positions in lease block 88 were increased to simulate sand dredging for the two volume scenarios. Information from these tasks provided the foundation for a detailed economic analysis, using Monte Carlo simulation techniques, of expected costs associated with sand dredging at Ship Shoal and subsequent placement on the Isles Dernieres for coastal erosion control. These estimates were compared with upland sand deposits in terms of quantity of material and delivery costs to evaluate the economic feasibility of using sand dredged from Ship Shoal for coastal restoration. The following papers will present specific results for each task.

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DREDGING TECHNOLOGY FOR MINING HARD MINERALS RESOURCES IN THE EXCLUSIVE ECONOMIC ZONE

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There is no "best" dredging technology for offshore hard minerals mining. Factors such as thickness of minerals deposit, water depth, exposure to wave climate, transportation distance, equipment availability, required production rates, environmental constraints, and scale of operation influence which equipment is more suited for a particular site. However, dredging equipment can be categorized into groupings that share common general characteristics, and these characteristics can be illustrated by discussing them relative to specific potential projects.

An offshore hard minerals mining operation consists of at least three steps: recovery, transportation, and unloading or delivery. In addition, depending on the mineral being mined and its intended use, a fourth step of processing may be required. The most common types of dredging recovery equipment are the simple grab dredge, the ubiquitous hydraulic pipeline dredge, and the self-contained trailing suction hopper dredge.

Transportation of dredged material is usually accomplished by a barge, a pipeline, or by the dredge itself in the case of the hopper dredge. Unloading at the delivery site can be by dumping, mechanical conveyance, or hydraulic pumpout. Processing may be as simple as fines removal at the recovery site by hopper overflow, washing at the delivery site for concrete aggregate, screening to obtain desired size distributions, or more complicated jig or hydrocyclone technology to separate denser or lighter material.

A feasibility study of sand recovery from Ship Shoal, Louisiana, illustrated some of the characteristics of available U.S. dredging technology. The shoal is large in size, relatively thin, in shallow water, and a significant distance offshore. Wave climate at the site is not severe, although exposure to sudden storms and lack of nearby safe harbors can pose risks to equipment survivability. For a project to recover 1 million per cubic yard (yd^3) of sand from Ship Shoal and deliver it to Isles Dernieres, Louisiana, for barrier island restoration, two types of systems using existing equipment appeared feasible. The first, a large tug-propelled hopper dredge, with direct pumpout capability and a dedicated pumpout connection, was estimated to cost from $3.50 to $7.00 per yd^3. The second system, which would consist of two smaller self-propelled hopper dredges and a hydraulic pipeline dredge, could range from $6.50 to $13.00 per yd^3. The wide range of estimated costs is due to a number of factors, including variability in bidding climate, sensitivity to fuel prices, and lack of comparable previous United States projects.

Marine aggregate mining is a large industry overseas, especially in Japan (75 million tons per year) and the United Kingdom (15 million tons per year). Of these two countries, the United Kingdom has the most homogeneous dredging situation, with three or four companies dominating the market and using similar types of equipment. The United Kingdom aggregate dredging fleet includes modern and technically sophisticated equipment, with one company alone having invested $70-80 million in new dredges in the last five years. The most recent equipment has been designed and built in the Netherlands, and several Dutch dredging companies have aggregate mining subsidiaries in the United Kingdom.

Depending on the scale of operation and intended use of the mined material, several developments may be possible that could lower the delivered cost in the United States of marine hard minerals over the long term. As a modest first step, improved designs for open-water pumpout from existing hopper dredges can make this capability more widely available. At a much higher level of investment, large floating or "walking" hydraulic pipeline dredges can significantly reduce the amount of minerals production lost due to wave and weather conditions. For sites where transportation distances make pipelines unfeasible, such equipment can also serve closer to shore as dedicated rehandlers for delivery. However, just as the marine aggregates industry in the United Kingdom grew gradually over time from some small shallow-water dredges in the 1950's supplying local needs to a present fleet of more than 40 vessels with a total hopper capacity of almost 100,000 yd^3 serving much of western Europe, such improvements are more likely to come as a response to an expanding marine minerals market rather than a higher-risk venture to compete with existing material sources.

Mr. Thomas W. Richardson is Chief of the Engineering Development Division of the U.S. Army Engineers, Waterways Experiment Station's Coastal Engineering Research Center. His technical interests include development and field testing of dredging and sand bypassing equipment and techniques; design, construction, and monitoring of sand bypassing systems; and general coastal engineering studies. He has authored more than 20 reports and papers on these topics, and has received the Department of the Army Research and Development Achievement Award for his work. He holds a B.S. degree in civil engineering from The Citadel, an M.S. degree in civil/ocean engineering from the University of Miami, and a Diploma in hydraulic engineering from the International Institute for Hydraulic and Environmental Engineering in Delft, The Netherlands.

THE GULF OF MEXICO TASK FORCE – A FEDERAL-STATE COOPERATIVE

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The Minerals Management Service (MMS) under the Department of the Interior initiated joint studies by federal and state agencies to assess the potential of mineral resources in the Exclusive Economic Zone (EEZ)/Outer Continental Shelf (OCS). The Office of International Activities and Marine Minerals (INTERMAR) previously referred to as the Office of Strategic and International Minerals (OSIM) was established in 1983 to develop a leasing and regulatory program for administering marine mineral exploration and development in the EEZ/OCS. The Gulf of Mexico Task Force was established in December 1986 by agreement among the Secretary of the Interior and the governors of Alabama, Louisiana, Mississippi, and Texas. This Gulf of Mexico Task Force is composed of representatives of MMS and the directors of the Geological Survey of Alabama, Louisiana Geological Survey, Mississippi Mineral Resources Institute, and the Texas Bureau of Economic Geology. The coordination activities are conducted by the Louisiana Geological Survey.

The initial and primary objective of the Gulf Task Force was to prepare a preliminary assessment of the occurrences and economic potential of the non-fuel resources in the EEZ offshore Alabama, Louisiana, Mississippi, and Texas. Although the EEZ extends 200 nautical miles from the Gulf of Mexico shoreline, the initial assessment was restricted to the zone extending from the shoreline out to the 200 m depth contour. The consensus of the Task Force was that further distance offshore would present unfavorable economic considerations and possible technology and mineral extraction difficulties.

During the initial project, Gulf of Mexico Task Force members examined data bases consisting of high resolution seismic reflection profiles, vibracores, surface sediment samples, and foundation borings from all available sources. An extensive list of references and a bibliography of relevant literature were also compiled. Based on the results of that inventory, types and areas of the mineral deposits of potential economic value were identified; however, identification was subject to the quality and quantity of available, pertinent data. The available data bases were determined to be generally inadequate to conduct detailed site-specific resource assessment and market analysis. The Task Force members made recommendations regarding the nature and extent of the data required for detailed economic analyses. The Gulf of Mexico Task Force recommended that evaluation of potential non-fuel minerals continue in the OCS offshore Alabama, Louisiana, Mississippi, and Texas.

Preliminary indications were that heavy mineral placers of potential economic interest occur in several areas of the Gulf of Mexico. However, the heavy mineral investigations cited by the Task Force report have not evaluated the heavy minerals as a potential economic resource. Existing vibracores in potentially prospective areas should be examined for heavy minerals to identify geographic locations where concentrations are significantly high to be of economic interest. Laboratory analyses were recommended to determine the mineral components within the heavy mineral concentrations. Also recommended was new vibracore field work to be accomplished, as needed, to evaluate further heavy mineral potential of selected sites. Exploration models should be developed and tested. Further recommended was that these activities should be funded by the individual states and federal programs aimed at resource assessments and other fundamental marine geological activities.

The principal conclusion of the report was acknowledgment of sand as the most abundant offshore resource. Among the other recommendations was a request by the Gulf Task Force that a project be undertaken concerning offshore sand resources. The Task Force cautioned that abundance of onshore sand resources along with a depressed market dictate that the primary immediate use of sand would be for nearby beach and barrier island nourishment projects. Many sand resource targets were identified by state and U.S. Geological Survey reports. However, Ship Shoal, one of those resource targets, was located offshore Louisiana in proximity to the Isles Dernieres. The Isles Dernieres are a rapidly eroding barrier island chain on the coast of Louisiana. The Isles Dernieres have been the subject of research regarding the protection of coastal wetlands and the tremendous coastal land loss rates of the Gulf of Mexico coast in general and Louisiana in particular. The geology, physical dimensions, and sediments of Ship Shoal had been characterized by the U.S. Geological Survey and the Louisiana Geological Survey at a level sufficient for a site-specific analysis.

Thus, the primary objective of the Gulf Task Force for the past 18 months was focused on the evaluation of Ship Shoal sand resources as a source of material for barrier island nourishment. Following presentations by Mark Byrnes, Shea Penland, and Karen Ramsey in this Information

Transfer Meeting session, I will discuss the details and results of that project.

Separately funded projects are scheduled for 1991-1992, for Alabama, Texas, and Louisiana/Mississippi with cooperative reporting and information transfer through the Task Force. Alabama will examine offshore sand resources for use as beach nourishment material. Texas will conduct an assessment of the feasibility of development of portions of Heald and Sabine Banks for beach nourishment and barrier island sand needs off Texas. Louisiana and Mississippi will cooperate in a further detailed examination of Ship Shoal and conduct a joint reconnaissance for shell resources from offshore both States. As a result of diminishing onshore supplies, expressions of industry interest have been received from offshore states regarding offshore shell deposits for use as roadbed material.

Mr. John Rowland has been employed since 1988 by the INTERMAR, Minerals Management Service in Herndon, Virginia. Prior to INTERMAR and since 1978, Mr. Rowland has had essentially continual professional involvement with marine sedimentary mineral resources with both the Bureau of Mines and the Geological Survey, Conservation Division. He has an M.S. degree in geological oceanography from Old Dominion University. After graduating from Old Dominion University, he completed additional graduate work in engineering science. Since 1984, Mr. Rowland has been licensed as a Professional Geologist with the Commonwealth of Virginia.

GEOLOGIC FRAMEWORK AND SAND RESOURCES OF SHIP SHOAL, NORTHERN GULF OF MEXICO EXCLUSIVE ECONOMIC ZONE

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INTRODUCTION

Ship Shoal is the most eastern member of a group of Holocene inner-shelf shoals located in Louisiana offshore of the southwestern Mississippi River delta plain. It is a shore-parallel, well-sorted sand deposit located 15 km offshore of the Isles Dernieres (roughly 50 km long) near the 10 m bathymetric contour. The shoal ranges from 5 to 6 km wide in its central area and 8 to 12 km wide at the eastern and western ends, with a relief of 3 to 7 m east to west along its crest axis. Penland *et al.* (1986, 1988) have documented that Ship Shoal is a marine sand deposit formed by the erosion of a submerged barrier shoreline that has migrated 1.5 km landward since 1853. Over 2,000 line-km of high-resolution seismic reflection data and 50 offshore vibracores have been collected by the Louisiana Geological Survey, U.S. Geological Survey, and Minerals Management Service in support of this study. In addition, borings from other state and federal agencies and private industry were collected, analyzed, and cataloged into a single data base in order to assess Ship Shoal sand resources.

REGIONAL SETTING

The morphology of the Louisiana delta plain and inner-continental shelf reflects the combined effects of sea-level rise, with transgressive and regressive sequences formed from delta building and subsequent abandonment processes of the Mississippi River. Apart from the Modern delta complex located in deep water near the shelf edge, Holocene Mississippi River sediment has accumulated in shallow water. The delta building process consists of a prodelta platform, followed by distributary progradation and bifurcation, resulting in delta plain establishment. This process continues until the distributary course is no longer hydraulically efficient. Abandonment occurs in favor of a more efficient course, initiating the transgressive phase of the delta cycle. The abandoned delta complex subsides, and coastal processes rework the seaward margin, generating a sandy barrier shoreline backed by bays and lagoons (Kwon 1969; Penland *et al.* 1981; Penland *et al.* 1988). Today, the delta plain can be divided into two distinct geomorphic regions, active and abandoned deltas. Delta building is restricted to the Modern delta complex and the Atchafalaya delta complex. The four remaining complexes, the Maringouin, Teche, St. Bernard, and Lafourche, are abandoned. In addition, the Plaquemines delta of the Modern complex is abandoned.

Ship Shoal is one of the largest and most prominent inner-shelf shoals offshore Louisiana. The shoal has a landward-oriented asymmetry and slopes westward. The change in shoal-crest asymmetry and orientation westward is concurrent with a decrease in water depth over the crest and an increase in shoal relief. The landward-oriented asymmetry of Ship Shoal suggests that it is migrating onshore (north-northwest) and onto a bathymetric protuberance that extends southeast out of the Caillou Bay and Point Au Fer area as defined by the 6-m isobath (Penland *et al.* 1986).

SEDIMENTARY FACIES

On the basis of lithology, texture, sedimentary structures, faunal assemblages, and stratigraphic position, seven major sedimentary facies were identified. The first facies is located within the upper 5 m of the shoal and is characterized as a very well sorted, well rounded quartz sand with horizontal to sub-horizontal laminations. Facies 1 contains 99 percent sand that coarsens upward within the unit from 0.13 mm at the base to about 0.16 mm at the top. Facies 2 is a massive, moderately sorted, very fine to fine sand (0.12 to 0.15 mm) with faint low-angle and planar laminations. This unit ranges in thickness from 1.2 to 3.4 m and underlies Facies 1. Facies 3 is characterized by poorly sorted, very fine-grained sand (0.10 to 0.13 mm) with interbedded layers of silty clay. Lenticular to wavy bedding is common and sand content is about 50 to 75 percent. This unit represents the lower extent of Ship Shoal.

Below the basal contact of the shoal lies a fine-grained unit 0.5 to 1.5 m thick of poorly sorted medium silt. Grain size in this unit ranges from 0.02 to 0.05 mm (coarse to medium silt). Just below this unit lies a 1 to 9 m, coarse silt to very fine sand facies. Sand content in this deposit varies drastically from 28 percent to 98 percent sand. Ripple cross-beds grade into low-angle horizontal laminations. Facies 6 is characterized by interbedded silt and sand. Grain size analysis indicates poorly to moderately sorted fine grained deposits (0.008 to 0.03 mm). This unit coarsens upward and ranges from 1.2 to 4.6 m thick. Sand content is relatively low (19 to 27%). However, the frequency, thickness, and percentage of sand increases upward. Facies 7 is a massive, silty clay with laminated and ripple beds and less than 5 percent sand.

ENVIRONMENTS OF DEPOSITION

Facies 1 through 3 characterize the sand shoal, with Facies 1 representing the crest of the shoal, Facies 2 the central body or shoal front, and Facies 3 the shoal base. The shoal contains approximately 1.2 billion m^3 of sand. Shoal crest deposits contain 112 million m^3 of sand and represent a unit within the zone of active normal and storm wave processes. Evidence for this is the presence of symmetrical ripple laminations which reflect the influence of oscillatory wave motion on surface deposits. The shoal crest is subject to the highest relative energy levels due to its relief above the surrounding shelf. In addition, well-rounded sand particles are indicative of sediment that has been reworked extensively. Water depths range from 2.7 m in the west to 7.0 m in the east.

The shoal front environment contains an estimated 430 million m^3 of sand. It reflects deposition on the upper depositional slope between the 4- and 6-m isobath at the western end of the shoal, and the 8- and 10-m isobath in the east. Because of the increase in depth, it is a lower-energy environment than the shoal crest. Consequently, more burrowing activity is present in this very-fine sand facies relative to shallower shoal crest deposits. The lower sand facies or shoal base environment represents the area landward of the shoal front where advancing sand is deposited during migration of Ship Shoal. This region lies between the 8- and 9-m isobath at the western end of the shoal and the 11- and 12-m isobath at the east. Because the shoal base is below the fair-weather wave base for this region, more burrowing is observed. This deposit is estimated to contain 640 million m^3 of material.

A discontinuous sand sheet extends seaward from the shoal marking its retreat path (Williams *et al.* 1989). Landward migration of Ship Shoal allows sediment transported from the leeward slope to be retained within the Ship Shoal sand body. This sediment is exhumed and reworked when Ship Shoal has migrated a distance equivalent to its width. At its present rate of migration (10 to 15 m/yr), the sand body is reworked completely every 500 to 1,000 years. This pattern of shoal retreat and storm-dominated transport generates a remnant sand sheet on the continental shelf. Sand eroded from the seaward slope of Ship Shoal during a storm may be redeposited offshore, blanketing the retreat path. This fine sand layer ranges between 0.09 and 0.13 mm and contains occasional graded and flaser bedding.

The facies under the shoal represent relatively fine-grained environments that have limited practical value in terms of sand resources considering the large quantity of overlying sand.

SAND RESOURCES

Ship Shoal contains an estimated 1.2 billion m^3 of borrow material ranging from very fine to medium sand. Approximately 112 million m^3 of sand is within the shoal crest, 430 million m^3 is within the shoal front, and an estimated 640 million m^3 of sand is found within the shoal base. An additional 123 million m^3 of sand is estimated within the underlying distributary channel deposits. This tremendous amount of material makes Ship Shoal an excellent source for minable sand provided it is economically and environmentally feasible. The amount of available material, along with the compatibility of grain size with the Isles Dernieres barrier islands, make Ship Shoal an excellent source of beach replenishment material for coastal erosion control.

In order to adequately target sand resources for erosion control, it is first necessary to determine the characteristics of the native beach material. Native material is sediment which is actively affected by beach processes such as waves, tides, and wind. Determining the composite average characteristics of the existing beach material is important because any new material added to a beach will be subject to natural selective winnowing and distribution by shoreface processes. Finer particles will be moved offshore and lost to the system and coarser particles will be transported slightly shoreward creating a slightly steeper beach. However, any coarse material transported offshore during storms may not be returned to the beach during post-storm periods. Other factors to consider are the longshore transport characteristics of the project site and the adjacent coast.

Because it is virtually impossible to target a borrow site with the exact composition of the native beach, it is important to consider an overfill factor to compensate for the winnowing processes. James (1975) developed criteria to indicate probable behavior of borrow material on a natural beach. This overfill factor, R_A, is the estimated number of cubic meters of fill material required to produce 1 m^3 of beach material when the beach is in a condition compatible with the native material.

Vibracore data indicate the Isles Dernieres contain native sand ranging from 2 to 3 phi (0.13 to 0.25 mm). Based upon James (1975) overfill criteria, sand characteristics of the Isles Dernieres and Ship Shoal indicate an overfill factor of 1.03 for replenishment of the Isles Dernieres system (McBride *et al.* 1989). This infers that for every cubic meter of beach replenished on the Isles Dernieres, 1.03 m^3 of sand would be required from the Ship Shoal sand body, making it an ideal sand source.

SUMMARY

Ship Shoal is a shore-parallel sand body 15 km offshore with an estimated 1.2 billion m^3 of minable material. The quantity of sand, along with the compatibility of sand characteristics from Isles Dernieres, indicate Ship Shoal to be an excellent source for beach replenishment material. Should it prove economically feasible to utilize this resource, the amount of sand present in Ship Shoal alone could satisfy requirements for beach replenishment and maintenance of the Isles Dernieres for the foreseeable future.

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Ms. Karen Ramsey is a research geologist at the Louisiana Geological Survey. She received her B.S. in geology from Nicholls State University in 1983 and has been involved with coastal research including studies on sea-level rise, nearshore sand resources, subsidence, coastal erosion, and related issues for the past eight years. Currently, Ms. Ramsey has been involved with the EEZ program for the past three years assessing hard mineral resources offshore Louisiana.

AN EVALUATION OF PHYSICAL ENVIRONMENTAL IMPACTS OF SAND DREDGING ON SHIP SHOAL

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Given the results of the geologic characterization and dredging feasibility studies for Ship Shoal, an analysis of physical environmental impacts was performed to determine the likelihood of resource use for coastal erosion control. This includes identifying incident wave characteristics, their impact on shoal morphodynamics, the patterns of wave movement associated with ambient conditions, and resultant change in wave transformation due to potential dredging activities. A common means of evaluating changes in wave propagation patterns for actual and hypothetical situations in response to changes in bathymetry is to perform wave refraction analysis. The two primary data sets needed to perform this type of analysis include a time history of incident wave processes, for characterizing the local wave climate, and bathymetry. Quantitative understanding of wave transformation is essential for discerning future patterns of coastal erosion in response to changing nearshore bathymetry, such as those associated with removal of material for beach replenishment. If changes in the area used as a borrow source cause adverse effects on the area being replenished (e.g., increased erosion due to wave focusing), alternative sources need to be considered.

SITE SELECTION

A number of criteria were used in choosing a potential borrow site. First, it was decided to avoid existing oil and gas infrastructures. Second, the amount of sand extracted from the site should be reasonable relative to past or existing project specifications in the northern Gulf of Mexico. Finally, dredging should take place in an area that would be most cost effective while working with the natural evolution of the shoal. After a cursory examination of all lease blocks on Ship Shoal, it was determined that block 88 was the most likely candidate. The area includes the leading edge of the shoal that contains a thick sequence of clean sand with no structures. The quantity of material removed for testing was 1 million and 10 million cubic yards (yd^3), volumes consistent with past beach replenishment projects in Louisiana. In both cases, extraction of sand from the shoal face was performed in a way to minimize abrupt changes in shoal morphology, thereby reducing the impact on wave propagation.

WAVE TRANSFORMATION MODELING

An estimation of wave transformation from a nominal depth of 11.6 m (38 feet) to a position seaward of the barrier coastline in 4 m (13 feet) of water was made by application of the Regional Coastal Processes Wave Model, RCPWAVE (Ebersole *et al.* 1986). The RCPWAVE was specifically designed for use in projects with large spatial extent, such as the Ship Shoal study area. The model bathymetry grid is rectangular and is oriented in an east-west direction. The cell size of the grid (250 m alongshore by 125 m cross-shore) was selected in order to maximize resolution of any irregularities in the longshore breaking wave field which may be induced by unusual bottom features.

Wave height and period, and surface wind direction were used as process variables in the wave transformation numerical model. Data from a station just seaward of Ship Shoal in about 11.6 m (38 feet) water depth on a Conoco platform (28.7°N, 91.0°W), were deemed most appropriate for the study because they reflect natural changes in wave propagation from deep water to the seaward edge of the bathymetry grid, and it is within close proximity to the immediate study area. For the 6.5 year period of record, average wave height range from 2.4 to 4.7 feet and wave period remained relatively constant around 5 to 6 seconds. Average wave angle of approach was always out of the south-southeast except for the month of July when waves were on average out of the south-southwest. A total of 36 model runs for ambient conditions and both dredging scenarios were made using average monthly wave conditions.

Wave rays for pre-dredging bathymetry associated with average wave conditions for all months showed the same general trend; the shallowest portion of Ship Shoal causes convergence of wave rays in the western portion of the study area. This condition is accentuated during winter and spring when average wave heights are greater and angles are steeper, and reduced between June and August when waves mainly are approaching from the south. In no cases do waves break over the shoal crest; however, extreme storm conditions were not evaluated and it is likely that under these conditions, waves would collapse.

For both dredging alternatives, sand was removed from the grid numerically by increasing water depths over a selected portion of the lease block. For the first dredging scenario, extraction of 1 million yd^3 of sand from the leading edge of the shoal in lease block 88 caused insignificant changes in wave refraction patterns. Removal of this quantity of material affected about 3.9 percent of the lease block area. The most noticeable change relative to ambient conditions was a slight divergence of wave rays (a decrease in wave energy focusing) just shoreward and to the west of the excavation site. Changes in wave refraction patterns associated with extraction of 10 million yd^3 of sand was slightly more noticeable but still showed relatively little influence (Figure 4.2). Although this is a significant amount of sand, only 17.9 percent of the lease block area was impacted. Again, a greater degree of divergence was associated with imposed bathymetric changes (a positive result) although slightly greater convergence was indicated just east of the dredged area.

SUMMARY

Comparisons of pre- and post-excavation scenarios indicate very little change in wave approach patterns relative to pre-dredging conditions. Divergence of wave rays was the most prominent impact, although small areas of convergence were illustrated on a few of the wave ray diagrams. This suggests that the conditions tested pose little to no effect on the physical environment present at the site prior to extraction. It is expected that changes in wave approach related to major storm events may have a greater influence on the imposed extraction scenarios.

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PHYSICAL AND ECONOMIC EVALUATION OF ONSHORE SAND RESOURCES

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An important aspect of the procedure for assessing the feasibility of near-term leasing at Ship Shoal for sand resources is an evaluation of alternative sources of material and their associated delivery costs. This comparison with the cost structure of offshore dredging will determine the viability of an operation of this kind. Onshore sand resources in coastal Louisiana can be divided into three general deposit types: (1) sand deposited from currents along the floodplain of bayous, creeks, and rivers in the Florida parishes, (2) silty sand deposits from the Mississippi and Pearl river beds, and (3) sand from beach ridges derived from delta reworking. Sand along the bayous and creeks of the Florida parishes are generally restricted to Pleistocene deposits and recent alluviums. Grain size varies depending on the stream gradient during the time of deposition, but is generally very coarse sand and gravel. Deposits in the Mississippi River are usually very fine- to fine-grained sand, silt, and mud which may be used for beach nourishment, but with high overfill ratios to compensate for the presence of significant quantities of fine-grained material. Beach ridges are beach strand lines formed in the presence of prograding headlands separated by coastal mudflat deposits. Sand found in beach

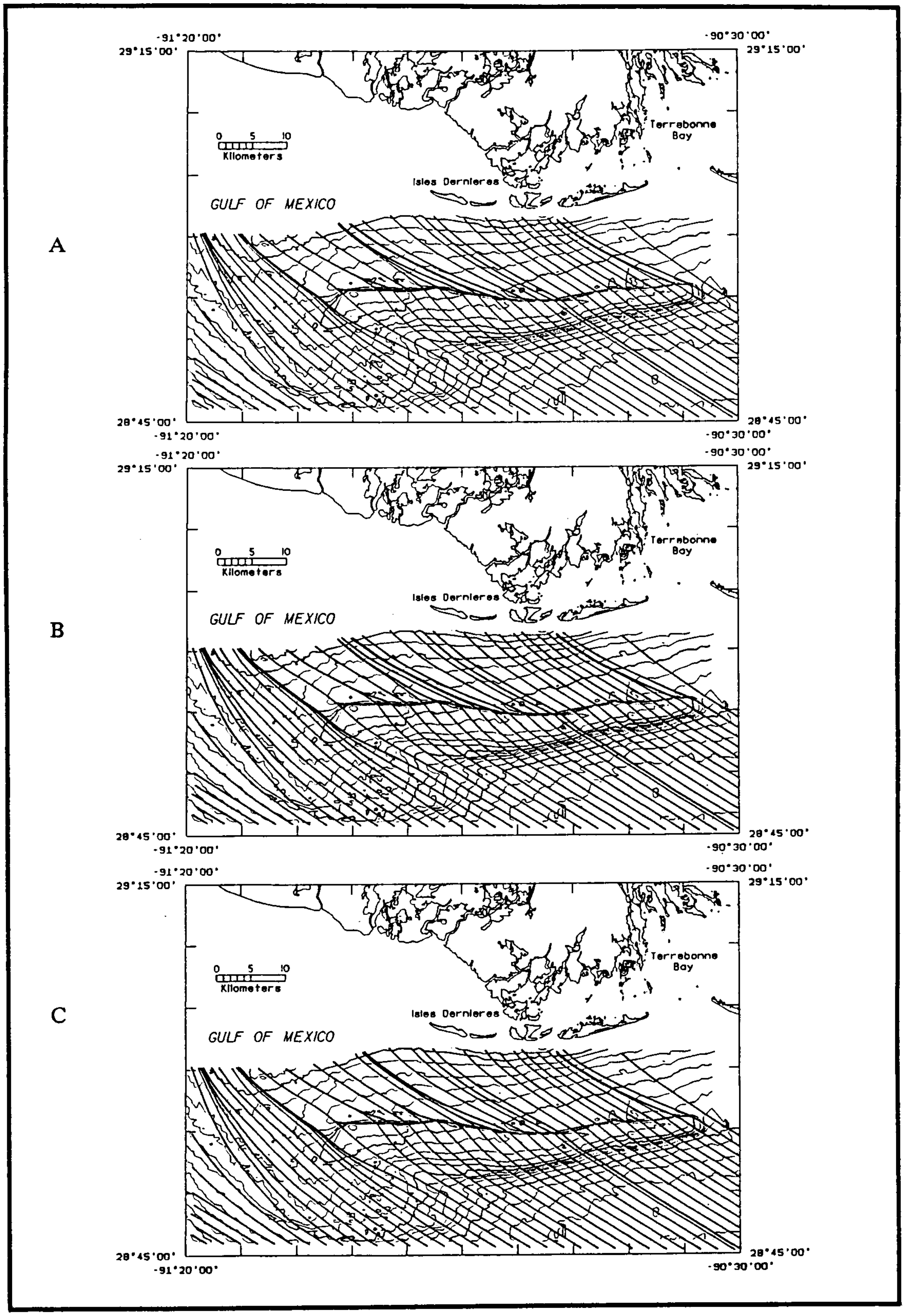

Figure 4.2. Wave ray diagrams for pre-excavation (A), 1 million yd^3 (B), and 10 million yd^3 (C) dredging scenarios.

ridges are generally fine-grained and mixed with shells and silt.

RESOURCE CHARACTERISTICS

Point bar deposits in the Florida parishes of Louisiana are a prominent source of sand and gravel mining in southeastern Louisiana. Dredging in this region is generally restricted to gravel and coarse sand for construction purposes, such as concrete highways, and for commercial use, such as cosmetics and glass. Along the Amite River, sand bodies range from 2 to 4 m thick, and can be up to 6 m thick near the center of the alluvial fill. This sediment is generally coarse to medium, poorly-sorted sand with roughly 3 m of silt overburden. Sand derived from these regions is usually a secondary product from gravel mining and stockpiled at the pit. Quoted cost estimates for sand from the stockpiles loaded onto a truck and shipped to Baton Rouge range from $2.50 to 3.00 per cubic yard (yd^3) at the Pit to $5.00 to 7.00 per yd^3 for sand and transportation to the Mississippi River in Baton Rouge. An additional barging cost would then have to be included for transportation down the river to the nourishment site. In addition, sand companies in this area have quoted a maximum of 1 million yd^3 of sand at the borrow pit. However, several operators indicated they could obtain sand from other sources (river sands from dredging companies along the Mississippi and Pearl Rivers) to increase the volume to 4 to 5 million yd^3.

There are a few dredging companies that operate along the Mississippi River. "The Yard", a company located in Port Allen between miles 240 and 220, is capable of dredging and barging bottom sediment from the Mississippi through the Intracoastal Waterway (approximately 5 miles from dredge site) to the barrier islands. Another source of sand along the Mississippi River occurs in point bar deposits at Sixty-Mile Point near the town of Nairn. Brown and Root (1988) studied the Sixty-Mile Point sand source for beach nourishment of Shell Island. The sand resource was estimated at 7.8 million yd^3, provided a maximum depth of excavation could be obtained. However, these point bar sand deposits contain 1.4 million yd^3 of mud overburden (Brown and Root 1988). Nairn Enterprises quoted a price of $0.94 per yd^3 (not including delivery) in the same area from their dredge site with no overburden. T.L. James is another company with dredging interests in the Mississippi and Pearl Rivers. Dredging costs are estimated at $2.00 per yd^3 near Nairn but barging costs skyrocket to $20.00 to $25.00 per yd^3 due to down time of the dredges between runs to the island and back.

The closest source of sand near the Isles Dernieres occurs along the Caminada-Moreau headland in Lafourche Parish. Gerdes (1982) obtained vibracores and borings from the Caminada-Moreau beach ridge plain which indicated that the sand unit of the ridges range from 0.5 to 1.0 m on Plaisance Ridge with additional 3.5 m of sand described as the upper to lower shoreface. The mean grain size for sand on the Plaisance ridge is 0.125 mm. Borrow pits in this area have reserves of at least 2 million yd^3 of fine- to very fine-grained sand. Even if all this sand could be mined from the ridge, it represents a minor contribution necessary for coastal restoration. Cost estimates from existing borrow pits are quoted at $3.50 per yd^3 for sand at the pit and $6.00 to 7.00 per yd^3 delivered to the Isles Dernieres.

PERMITTING

Permits are required to dredge in a Louisiana waterway or wetland area. The permit process is complex and may require more than one permit, certification, or license. A federal permit from the U.S. Army Corps of Engineers (USACE) is required if mining or dredging operations are conducted outside of the coastal zone; one is required from Coastal Management Division (CMD) if the borrow area is within the coastal zone. Each permit application undergoes a lengthy review process. The Louisiana Department of Transportation and Development reviews applications and comments on the navigation and flood control impacts of a project; the Louisiana Department of Wildlife and Fisheries considers impacts to the environment, state lease areas, and refuge areas; and the Louisiana Department of Health and Hospital (DHH) reviews the effect on public health. Permit applications and guidelines are available from the USACE, New Orleans District.

SUMMARY

Thirteen sand mining companies have been identified in coastal Louisiana for obtaining sand to replenish the barrier islands offshore of Terrebonne Parish. The difficulties in obtaining sand from an onshore source arise in transporting the sand to the islands. Cost estimates range from \$3.50 to 8.00 per yd^3 depending if the sand is transported to Baton Rouge or down to the coast. An additional barging cost would then have to be considered for transportation to the islands. Another difficulty which arises in obtaining sand in this area is the volume of sand required for replenishment. Companies estimate a maximum of only 1 million yd^3 of material available at any one location. Sand dredged from the Mississippi River can be obtained at a lower cost than that obtained for smaller rivers in south Louisiana since the dredging and loading onto the barge can be done at the same time. However, it still becomes a costly operation considering the distance from the dredge source to the replenishment site.

The best resource for onshore sand appears to be derived from the beach ridges near the coast of Louisiana. Sand in this region is compatible with the parent material found on the barrier islands, and barging costs are lower due to close proximity to the islands. Cost estimates for ridges for the Caminada-Moreau beach ridge plain are \$3.50 to 4.00 per yd^3 at the pit with an estimated additional cost of \$6.00 to 7.00 per yd^3 for delivery to the replenishment site. However, the estimated maximum sand volume in this area is roughly 2 million yd^3 of material.

REFERENCES

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Gerdes, R.G. 1982. Stratigraphy and history of development of the Caminada-Moreau beach ridge plain, Southeast Louisiana. M.Sc. Thesis. Dept. of Geology, Louisiana State University, Baton Rouge. 185 pp.

Ms. Karen Ramsey is a research geologist at the Louisiana Geological Survey. She received her B.S. in geology from Nicholls State University in 1983 and has been involved with coastal research including studies on sea-level rise, nearshore sand resources, subsidence, coastal erosion, and related issues for the past eight years. Currently, Ms. Ramsey has been involved with the EEZ program for the past three years assessing hard mineral resources offshore Louisiana.

ECONOMICS OF SAND MINING AT SHIP SHOAL

Mr. T. Gerald Crawford
and
Mr. Robert F. Kelly
Minerals Management Service
Gulf of Mexico OCS Region

As part of the consideration to utilize offshore sand deposits for beach nourishment, an economic analysis was performed for two recommended methods of mining the Ship Shoal sand deposit for use in rebuilding the Isles Dernieres. The economic analysis was accomplished through the use of a mathematical model referred to as QUIKSAND. This computer model was designed by the Branch of Resource Assessment within the Offshore Resource Evaluation Division of Minerals Management Service. The purpose of the model is to calculate the value of the resources contained in deposits of sand and gravel on the Federal Outer Continental Shelf (OCS) to a prudent investor or to an educated seller.

The model uses the basic Monte Carlo simulation technique whereby the probability distribution of pertinent variables are sampled over many trials yielding results which are derived from an averaging process taken over the number of trials. This technique provides a means to handle a series of subjective judgments about each individual variable. The method explicitly recognizes the probabilistic nature of all variables affecting the evaluation and calculates a large number of possible outcomes based upon random samples from input probability distributions.

Much of the geologic and engineering data (e.g., areal extent and thickness of the resource, recovery factors, production rates, product prices, costs, etc.) used to evaluate a venture is known with varying degrees of uncertainty. Providing a single number for the resource economic value is somewhat misleading since it provides no insight as to the relative uncertainty involved. The Monte Carlo technique provides a range of resource economic values (Net Present Worth, NPW) for the venture with the probability of each value occurring being a direct consequence of the data uncertainty.

ECONOMIC ANALYSES

The cost and engineering parameter values used in the model were obtained from a report entitled "Dredging Aspects of Aggregate Mining From Ship Shoal, Louisiana" prepared by Thomas A. Chisholm of the U.S. Army Engineers, Waterways Experiment Station, Coastal Engineering Research Center, Vicksburg, Mississippi. This report also discusses two recommended methods of mining the Ship Shoal sand deposit. The two recommended methods are outlined as follows:

1. Utilize an existing 16,000 cubic yard (yd^3) hopper barge dredge using a direct pump-out discharge through a single point mooring buoy and a submerged pipeline to transport the sand onto shore.

2. Utilize two (2) existing 1,300 yd^3 hopper dredges to mine the sand and dump it at some point close to shore where a pipeline dredge would rehandle the sand and transport it onto shore through a pipeline.

Within the above referenced report, the costs identified with each of these methods is expressed as a cost/cubic yard based on placing 1,000,000 yd^3 of sand along approximately 5 miles of the 21 mile-long Isles Dernieres Barrier Islands. These costs were modified in order to accommodate the cost parameter requirements of the QUIKSAND Model. The following cost parameters: operating cost per dredge in dollars per cubic yard, barge or pipeline cost in year "N", mobilization/demobilization cost in year "N", dredge towing/storage cost, and the transportation cost of commodity in dollars per cubic yard were the operating cost parameters used in the model to determine the economics associated with each recommended mining method.

Because the model is evaluating the economics of sand mining Ship Shoal for use in the Isles Dernieres, a number of geologic parameters characteristic of the sand deposit (e.g., sand body thickness at the dredging site, percent sand, amount of overburden, overfill ratio) were used in conjunction with engineering parameters (e.g., operating days, dredge rate) to make a realistic assessment of operating costs. In addition, pertinent economic parameters are used as input to the QUIKSAND economics model and are related to the discount and inflation factors.

MODEL RESULTS

The mean range of values that is calculated represents a present worth value either above or below the economic break even point when the commodity price is varied for any particular set of conditions. In this way, the model is not used to establish a present worth for a certain commodity price but is used to establish the minimum commodity price at which the dredging project is economically feasible. The economic analysis for each proposed dredging method was performed for two volume considerations: 1 million and 10 million yd^3 dredged from the northeast half of Ship Shoal Block 88. Method 1 generated a commodity price of \$5.19 per yd^3 for dredging 1 million yd^3 of sand and \$3.10 per yd^3 for dredging 10 million yd^3 of sand utilizing one 16,000 yd^3 hopper barge dredge with a direct pump-out discharge. Method 2 generated a commodity price of \$8.45 per yd^3 for dredging 1 million yd^3 of sand and \$6.36 per yd^3 for dredging 10 million yd^3 of sand utilizing two 1,300 yd^3 hopper dredges and a pipeline dredge.

An alternative scenario is proposed that depends on technology suited for open water projects. Because this equipment does not exist in the United States, capital outlay associated with design and construction would be large. However, if a long-term dredging operation could be sustained, cost analyses based on an initial investment of \$26 million suggest that the project could be economically viable resulting in an average commodity price of \$8.35 per yd^3 over a 14-year period for 100 million yd^3 of sand.

Mr. T. Gerald Crawford is a supervisor of the Resource and Economic Analysis Unit in the Geological and Geophysical Section of Resource

Evaluation in the Minerals Management Service (MMS) Gulf of Mexico OCS Regional Office. He received his B.S. in petroleum engineering from Louisiana State University in 1972. He began his career in the Federal Government with the U.S. Geological Survey (USGS) in 1972, and has been involved with resource assessment, bid adequacy, and fair market value determinations within the USGS/MMS since then.

Mr. Robert F. Kelly holds a B.S. in electrical engineering from Tulane University. He has been with the U.S. Geological Survey/Minerals Management Service since 1971. He has held various positions relating to Field Operations. Since 1987, he has held the position of Staff Petroleum Engineer within the Resource and Economic Analysis Unit in the Minerals Management Service, Gulf of Mexico OCS Regional Office, Resource Evaluation.

ENVIRONMENTAL STUDIES FOR EVALUATION OF MARINE MINING IMPACTS

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Office of International
Activities and Marine Minerals

INTRODUCTION

As the potential for further exploration and possible development of offshore sand and gravel, shell, placer, and other minerals on the U.S. Outer Continental Shelf (OCS) increases, environmental considerations will generate a need for technical information and studies to aid the Minerals Management Service (MMS) in making prelease or postlease decisions and to ensure that offshore mineral development is accomplished in a safe and environmentally sound manner. The MMS Office of International Activities and Marine Minerals (INTERMAR) is developing and procuring, through the MMS Environmental Studies Program (ESP), contracted-for projects to provide some of this needed information. This paper describes ongoing and planned environmental studies to support future decisions regarding possible marine mineral leasing and development activities.

ENVIRONMENTAL STRATEGY

The INTERMAR is currently gathering environmental information in several distinct, but related methods. The overall strategy with respect to environmental issues is to operate in a forward thinking manner and to use the time available now to better understand the environmental implications of marine mineral development in order to facilitate better decisions and, if possible, to develop solutions to the environmental problems which may confront us. The current efforts of several of the existing Federal-State mineral task forces are being redirected towards the identification of environmental issues, as well as developing action plans to address issues of concern to the Federal and State governments and the public. The expertise of the Marine Minerals Technology Center of the University of Mississippi and Sea Grant are being utilized to help examine and to develop environmentally sound technology to aid in the extraction of marine minerals as a source of material for beach renourishment, construction aggregate, or industrially important components. Finally, studies to provide needed environmental information are being conducted using funds provided by the MMS ESP; this studies initiative is discussed in detail below.

ENVIRONMENTAL STUDIES INITIATIVE

The MMS ESP has produced, and continues to produce, a significant amount of scientific and technical information, some of which may be applicable to environmental analyses and decisions related to marine mineral activities on the OCS. The ESP information database covers technical subjects such as ocean currents and pollutant transport mechanisms, air and water quality, distribution and abundance of commercially or ecologically important and endangered species, oceanographic hazards, arctic hazards, and social, cultural, and economic conditions in coastal areas. Wherever and whenever possible, existing or planned oil and gas environmental studies will be utilized or contracts amended to provide environmental information for decisions relating to marine mineral development.

With the understanding, however, that the current subject content of the MMS ESP cannot provide all of the information required, beginning in Fiscal Year 1991, ESP funds are being utilized to support the Agency's marine minerals program. Two general categories of studies are likely to be undertaken:

- Generic studies to examine the effects of particular types of mining operations on various aspects of the physical, chemical, and biological environments. Studies examining various types of mitigation techniques may also be undertaken. Such information would be used for decisionmaking for all proposed offshore mining operations of a similar nature.

- Site-specific environmental studies in areas where offshore mineral activity is proposed or where mining appears feasible in the near future.

The INTERMAR has embarked on an initial effort to develop several generically-oriented environmental studies. These studies will be designed to provide information to assist in making initial programmatic offshore hard mineral leasing decisions at both the Headquarters and Regional levels, as well as furnishing generic information useful during preparation of Regional lease sale-specific documents; these efforts are described below. Site-specific studies will be formulated for areas in which near-term lease sales are indicated.

MARINE MINERAL ENVIRONMENTAL LITERATURE SEARCH STUDY

The purpose of this recently awarded study is to survey, analyze, and synthesize existing literature regarding the potential environmental impacts of marine mineral activity on the environment and to have the information summarized in a single manuscript. Continental Shelf Associates of Jupiter, Florida, will have the overall management responsibility for the 15-month, $135,000 project. The principle consultants on the study are Drs. Michael J. Cruickshank and Charles L. Morgan of the University of Hawaii who have been involved for many years in research and development concerning marine mining technology and environmental impact analyses. The final results are due approximately in December 1992.

The search is not specific to sand and gravel, or placer mining, but is oriented to include all types of mining activities of offshore minerals. In addition, foreign, as well as domestic, literature sources are to be evaluated, since a good portion of the environmental work known to have been undertaken to date has occurred in foreign waters. This information is necessary to adequately assess the current level of knowledge regarding the potential environmental effects of marine mineral development on the marine, coastal, and onshore environments of specific regions or areas and to identify possible data gaps in advance of proposed mineral exploration and development activities.

Information to be accessed includes factors such as the following: impacts of marine mineral extraction and development on water quality and the seabed, on benthic and water column organisms and habitats, on recreational and coastal facilities; effects relating to the possible offshore disposal of waste material; and the effects of offshore and onshore processing and tailings disposal. General environmental analyses, as well as laboratory, field, and modeling studies, are included in the literature search. The information synthesis is designed, not only to provide an overall picture of the extent of environmental information available, but also to identify mitigating measures which can be implemented during offshore operations in order to minimize or preclude potential adverse impacts to the environment. Potential models that the MMS could use to predict the fate of material disturbed or discharged during actual operations are also to be identified and analyzed.

BENTHIC REPOPULATION STUDY

Marine minerals that are most likely to see commercial development in the near-term include sand and gravel and placer minerals. Sand and gravel resources are presently being evaluated as a source of material for construction aggregate and beach nourishment material; placer deposits are known to contain various amounts of important industrial minerals such as ilmenite and rutile. These minerals are likely to be harvested using traditional offshore dredging techniques.

The immediate consequences of marine mineral development, such as dredging for sand and gravel, placer minerals, or other offshore mineral deposits, will likely involve some degree of destruction or disruption to the habitat of benthonic invertebrate or other benthic organisms which lie within the path of the mining operation; sessile, non-mobile, or slow-moving organisms may be especially susceptible to impact. This population is generally a source of food for many water column-dwelling species. There also exists the risk of changes to the spawning grounds for fish or other marine species that spawn on the sea bottom, as well as long-term changes in the sea bottom population due to changes in the zones of distribution of different substrata and the subsequent modification of relations between the biological populations living in them. Modifications in bottom sediment grain sizes caused by mineral development operations which disrupt the seafloor sediments also may result in subsequent changes in the makeup of seafloor communities.

A cursory survey of the existing literature base appears to indicate that, of the studies intended to detail the environmental effects of offshore dredging and mining, a relatively small percentage have focused on the seafloor impacts or mining site itself. The studies that have been conducted have placed primary emphasis on the extent and character of sediment resuspension induced by the mining operation, the impacts of turbidity plumes induced by surface discharges from the mining vessel, and the influence of these materials on local pelagic fish populations or the benthic communities found in the areas adjacent to the area being dredged or mined. Little information appears to exist regarding the degree to which possible changes in seabottom substrates, an example being modifications in grain sizes of bottom sediments possibly induced by a mining activity, affects benthic communities and their ability to repopulate after being directly affected by a mining or dredging operation.

For Fiscal Year 1992, INTERMAR is developing a statement of work for a study designed to evaluate and gain insight into the long-term effects of seabed mining operations and the degree to which benthic organisms may repopulate the seabed after a mining activity takes place in a coastal or shallow open-ocean area. The study will entail coordination with a planned dredging activity, preferably on the U.S. East Coast, in an area composed of sandy substrate in order to approximate conditions similar to those which would be found in an area likely to undergo mining for sand and gravel resources, and where near-term prospects for mineral recovery appear favorable. If possible, the study area will be in waters of sufficient depth to simulate conditions found in the open-ocean.

Prior to dredging within the project site, the current status of the seabed in the area to be dredged will need to be assessed in relation to resident benthic seabed communities. This will involve a review of the existing literature, as well as field work such as biological and physical sampling and possibly video observations of the seabed within the selected project site. Periodically, sampling will be conducted in the study area and the photographs and specimens from the seabed stations will be collected in order to assess the degree to which repopulation is occurring. These observations would be continued for approximately 2 to 2.5 years, at which point the overall degree to which repopulation has occurred will be evaluated, and any changes in seabed or fish populations within the study area will be noted. The results of the study should be applicable to other planning areas and other areas of potential U.S. OCS hard minerals mining activities, particularly those areas that exhibit similar bottom substrates and benthic community compositions as would be found within the study area.

FUTURE STUDIES

The INTERMAR will continue to develop generic studies for funding consideration in future fiscal years. Site-specific studies will be developed in areas that warrant closer scrutiny.

For Fiscal Year 1993, INTERMAR will propose a study to put together an integrated team of qualified marine mining engineers, marine biologists, physical oceanographers, and other marine scientists in order to undertake an extensive and detailed analysis of marine mining technologies, presently available or proposed, and to estimate and evaluate the degree of potential impact to the marine and onshore environments associated with each extraction technology. Mitigation methods would then be examined to ascertain the degree to which these impacts can be lessened or eliminated altogether during offshore mineral development activities. This study would be designed to build upon the knowledge base compiled during the marine mining literature search study.

In addition, depending upon the results of the model analysis phase of the literature search study, INTERMAR will submit for Fiscal Years 1993 - 1994 funding, a study to develop a numerical model to evaluate the impacts of the benthic plume generated during a marine mining operation on bottom and near-bottom dwelling organisms.

Mr. Barry S. Drucker is a physical oceanographer and marine geologist and is currently a staff member of the Minerals Management Service's Office of International Activities and Marine Minerals where he is charged with developing environmental studies in support of the Agency's marine minerals programs. He has an undergraduate degree in geology and oceanography from the City University and a graduate degree in marine geology and physical oceanography from Long Island University.

Mr. Drucker's prior employment includes work as a marine geologist with the U.S. Naval Oceanographic Office's Hydrographic Department, Coastal Surveys Group and as an oceanographer with the Bureau of Land Management's New York Outer Continental Shelf Office, Environmental Assessment Group, as well as the Minerals Management Service's Atlantic OCS Office. He has also served as the physical oceanography studies coordinator with the Minerals Management Service, Environmental Studies Branch.

CHARACTERIZATION OF THE DEVELOPMENT POTENTIAL OF SHIP SHOAL SAND FOR BEACH REPLENISHMENT OF THE ISLES DERNIERES: CONCLUSIONS AND RECOMMENDATIONS

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and
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A five part methodology was applied to assess the geological, engineering, and economic feasibility of sand mining at Ship Shoal for coastal erosion control. Approximately 1.2 billion cubic meters of clean quartz sand with no overburden has been identified. Using existing dredging technology, the most economical borrow area would be along the leading edge of shoal migration, where water depth and shoal thickness are greatest. Prior to evaluating potential physical environmental impacts of dredging on the shoreline landward of the shoal, a specific area of study was selected to avoid existing oil and gas infrastructure. Lease block 88 was an ideal location because structures and pipelines were not present and it was located along the leading edge of the shoal. Wave refraction analysis, using a 6.5-year record of wave data, indicated no adverse impacts for 1 and 10 million cubic yard (yd^3) scenarios. Given this information, a Monte Carlo simulation model was used to evaluate the economics of a proposed project. Results suggest that both dredging scenarios and volume requirements were economically feasible relative to alternate upland sources. In addition, a severe limitation for upland sources is a general lack of sand. The most economical situation would be a 10 million yd^3 dredging volume with a 16,000 yd^3 hopper barge using a direct pump-out discharge through a single point mooring buoy and a submerged pipeline to transport the sand to shore (\$3.10 per yd^3). However, 1 million yd^3 could be supplied to the Isles Dernieres for about \$5.19 per yd^3 with the same technique. The primary drawback to this analysis is that only one system of this kind is currently available for operation. Consequently, it is likely that prices would be higher than estimated but not higher than estimates proposed for the more common alternate technique (two 1,300 yd^3 hopper dredges).

A number of recommendations have been formulated relative to the results of this study. They include:

- The information generated from this study should be presented in a workshop format to assess interest and/or concern from local, state, and Federal agencies, industrial representatives, and private groups in using this sand resource as proposed.
- If there is sufficient interest in using sand from Ship Shoal, selection of specific potential leasing sites should proceed with consideration for resolving conflict with oil and gas operations.
- A detailed geological and physical environmental analysis should be performed at selected sites to better define resource and environmental parameters on shoal morphology and shoreline processes.
- Site specific analysis of the potential impacts of nearshore dredging activities on the ecosystem of the area should be performed.
- The methodology developed in this study should be applied to other sites and potential projects along the Gulf of Mexico coast.

Dr. Mark Byrnes is Chief of the Coastal Geology Section at the Louisiana Geological Survey and Assistant Research Professor at Louisiana State University. He received a B.A. from Millersville University (1978) and a Ph.D. in oceanography from Old Dominion University (1988). Dr. Byrnes spent 3-1/2 years as a research physical scientist at the U.S. Army Coastal Engineering Research Center investigating barrier island sedimentation processes and developing models for simulating shoreline response to waves and water level. Currently, he is conducting research on coastal geology and hard mineral resources, coastal processes and geomorphology, shoreline mapping and the application of geographic information systems, and wetland loss in the northern Gulf of Mexico.

Dr. Charles G. Groat is State Geologist and Director of the Louisiana Geological Survey (LGS). He is project director for the Wetlands Mitigation Study being conducted by the Louisiana Department of Natural Resources through LGS and the Coastal Management Division, with assistance of the Louisiana State University Sea Grant Legal Program. Dr. Groat, a geologist, holds a Bachelor's degree from the University of Rochester, a Master's degree from the University of Massachusetts, and a Ph.D. degree from the University of Texas.

PRODUCED WATER: DISPOSAL TECHNOLOGIES/REGULATIONS

Session: PRODUCED WATER: DISPOSAL TECHNOLOGIES/REGULATIONS

Co-Chairs: Ms. Gail Rainey
Dr. Pasquale F. Roscigno

Date: November 5, 1991

Presentation	Author/Affiliation
Produced Water: Disposal Technologies/ Regulations: Session Introduction	Ms. Gail Rainey and Dr. Pasquale F. Roscigno Minerals Management Service Gulf of Mexico OCS Region
Status of the State of Louisiana Produced Water Regulation	Mr. Douglas Hale Louisiana Department of Environmental Quality
U.S. Department of Energy's Produced Waters Research Program	Dr. Brent W. Smith U.S. Department of Energy
Status of Proposed Effluent Limitation Guidelines	Dr. Lee Gibson U.S. Environmental Protection Agency
A Review of Technology for Cleaning Produced Water	Dr. Charles A. Petty Michigan State University
Current Status of Membrane Treatment for Produced Water Discharges	Mr. Ken E. Arnold Paragon Engineering Services, Inc.
Marathon's Operating Experience with the Use of Ceramic Membranes for the Filtering of Produced Water	Mr. Peter J. Oswald Marathon Oil Company Gulf Coast Region
Offshore Operators Committee Study of Flotation Systems	Dr. Michael T. Stephenson Texaco Inc.
Changes in Exxon's Grand Isle Produced Water Disposal System	Mr. Lawrence D. Ziems Exxon Company, USA

PRODUCED WATER: DISPOSAL TECHNOLOGIES/REGULATIONS: SESSION INTRODUCTION

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and
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At this time, several Federal regulatory actions affecting produced water discharges from Gulf of Mexico oil and gas industry operations are in the process of being undertaken by the U.S. Environmental Protection Agency. Regulations limiting produced water discharges in coastal areas have also been newly promulgated by the State of Louisiana. This session was initiated to provide information on the effect of these regulations on current produced water disposal practices. In particular, we will focus on different technologies available to industry that could serve industry capabilities to meet these more stringent contaminant discharge requirements.

Information presented today will provide the Minerals Management Service (MMS) with a better understanding of future volumes, characteristics, and disposal mechanisms for Outer Continental Shelf (OCS)-generated produced water. This information will serve in our risk assessment of the environmental consequences of our leasing program.

Ms. Gail Rainey is an oceanographer with the Office of Leasing and Environment of the MMS, Gulf of Mexico OCS Region Office. Her primary expertise and interests include oil spill sources, fate processes, and petroleum contamination of coastal and offshore waters. She received her M.S. in chemical oceanography from Louisiana State University.

Dr. Pasquale F. Roscigno has recently moved to MMS from the U.S. Fish and Wildlife Service. He attended Fordham University in New York City and received his doctorate in estuarine ecotoxicology. He has done research on the impact of metal contamination on benthic community structure in Gulf of Mexico estuaries and has served as Chief Scientist on two American-Soviet cruises to the Bering Sea. He is working for MMS' Office of Leasing and Environment in New Orleans.

STATUS OF THE STATE OF LOUISIANA PRODUCED WATER REGULATION

Mr. Douglas Hale
Louisiana Department of
Environmental Quality

The Department of Environmental Quality's Office of Water Resources has recently promulgated water quality regulations (LAC 33:IX.708) concerning the effluent standards for operations which explore for and produce oil and natural gas. Included in these standards, which became effective March 20, 1991, is a section which covers discharges of produced water. Produced water is defined as liquid and suspended particulate waste material generated by the processing of fluids brought to the surface in conjunction with recovery of oil or natural gas from underground geologic formations or with underground storage of hydrocarbons.

In April of 1989, the Department of Environmental Quality required that a radioactivity measurement, acute toxicity test, and chronic toxicity test be conducted using test methods approved by the administrative authority on representative samples of all existing produced water discharges that flow to the surface waters of the State. The results of the radioactivity analysis and the average daily discharge rate (barrels per day) were submitted to the Office of Water Resources by August 20, 1989. The results of the toxicity analyses and the average daily discharge rate (barrels per day) were submitted by February 20, 1990.

The section of the regulations covering produced water is divided into four segments. These segments address discharges to freshwater areas; discharges to intermediate, brackish, and saline water areas inland of the territorial seas; discharges to the territorial seas; and requirements pertaining to radioactivity and toxicity analyses of produced water.

The standards covering the discharge of produced water to freshwater areas are divided into the following five parts:

i. All produced water discharges must be specifically identified in a valid LWDPS permit.

ii. The discharge of produced water directly onto any vegetated area, soil, or intermittently exposed sediment surface is prohibited.

iii. There shall be no discharge of produced water to lakes, rivers, streams, bayous, canals, or other surface waters of the State in areas regionally characterized as upland.

iv. There shall be no discharge of produced water to freshwater swamp or freshwater marsh areas or to natural or man-made water bodies bounded by freshwater swamp or freshwater marsh vegetation unless the discharge has been specifically authorized in accordance with an approved schedule for discharge termination, or the discharge has been authorized by a valid LWDPS permit reflecting a discharge directed to a major deltaic pass of the Mississippi River or to the Atchafalaya River, including Wax Lake Outlet, below Morgan City.

v. A schedule for discharge termination shall not be approved for a surface discharge initiated after the promulgation of this regulation. The operator of a facility having a produced water discharge in existence on the date of promulgation of these regulations shall be subject to the prohibition against surface discharge of produced water unless the operator establishes that surface discharge is the only immediately available alternative and that the produced water discharge termination schedule is limited in term to the period necessary to provide an alternate waste-handling method. A compliance schedule that would delay compliance beyond July 1, 1992, will not be approved.

The standards covering the discharge of produced water to intermediate, brackish, and saline areas inland of the territorial seas are divided into the following 10 parts:

i. All produced water discharges must be specifically identified in a valid LWDPS permit.

ii. The discharge of produced water directly onto any vegetated area, soil, or intermittently exposed sediment surface is prohibited.

iii. There shall be no discharge of produced water to natural or man-made water bodies located in intermediate, brackish, or saline marsh areas after January 1, 1995, unless the discharge or discharges have been authorized in an approved schedule for elimination or effluent limitation compliance.

iv. Each operator of a facility with a produced water discharge in existence on the date of promulgation of these regulations shall submit a schedule within six months after promulgation detailing a time frame for achieving compliance with the restrictions imposed by this Subparagraph. The compliance schedule shall be prepared in conformance with the following guidelines:

(a) An operator conducting three or more produced water discharges shall submit for approval a schedule of compliance that will result in phased elimination or compliance with applicable effluent limitations for all produced water discharges by January 1, 1995. The schedule is expected to call for termination of discharge or compliance with applicable effluent limitations for approximately one-third of the discharges existing on the date of promulgation by January 1, 1993; for two-thirds of the discharges by January 1, 1994; and for full compliance by January 1, 1995.

(b) An operator conducting no more than two produced water discharges shall submit for approval a schedule of compliance that will result in phased elimination or compliance with applicable effluent limitations for all produced water discharges by January 1, 1995. One discharge is expected to be eliminated or conducted in compliance with applicable effluent limitations by January 1, 1994.

(c) An operator conducting a single produced water discharge shall eliminate surface discharge or conduct the discharge in compliance with applicable effluent limitations by January 1, 1994.

(d) Facilities with a total produced water discharge of 250 barrels/day or less and a maximum oil production of 100 barrels/day or the monetary equivalent in natural gas, as of the effective date of this regulation, will be provided an additional year to comply with the requirements of this Subparagraph.

(e) Operators discharging to the open waters and at least one mile from any shoreline in Chandeleur Sound, Breton Sound, Barataria Bay, Caminada Bay, Timbalier Bay, Terrebonne Bay, East Cote Blanche Bay, West Cote Blanche Bay, or Vermilion Bay from production originating in these areas will have two years after the effective date of these regulations or one year after completion of the U.S. Department of Energy's (DOE) study concerning Louisiana coastal bays, whichever comes first, to show on a case-by-case basis that their particular discharge should be exempt from these regulations, if the DOE study, after scientific peer review, shows minimal acceptable environmental impacts.

v. Requests for an extension of the compliance period beyond the January 1, 1995, deadline will be considered if submitted with the original compliance schedule and if the following conditions are met:

(a) The operator establishes that surface discharge is the only immediately available and economically feasible alternative, that continued discharge does not represent gross potential for unacceptable environmental degradation, and that the produced water discharge termination schedule is limited in term to the period necessary to provide an alternate waste-handling method.

(b) The proposed extension would not extend the date of discharge termination or effluent limitation compliance beyond January 1, 1997.

vi. A compliance schedule will not be required for a surface discharge initiated after the promulgation of these regulations; however, produced water discharges authorized after the date of promulgation but before December 31, 1992 must be eliminated or conducted in compliance with applicable effluent limitations by January 1, 1995. Produced water discharges authorized after December 31, 1992 must achieve compliance with applicable effluent limitations on the date of discharge initiation.

vii. The following effluent limitations establish the quantity or quality of pollutants or pollutant properties that may be discharged by a facility subject to this section:

Pollutant or Pollutant Property	Discharge Limitation
Benzene	0.0125 mg/l daily maximum
Ethylbenzene	4.380 mg/l daily maximum
Toluene	0.475 mg/l daily maximum
Oil and Grease	15 mg/l daily maximum
Total Organic Carbon	50 mg/l daily maximum
pH	6-9 standard units
Temperature	(as per LAC 33:IX.1113.C.4)
Total Suspended Solids	45 mg/l daily maximum
Chlorides	Dilution required at a ratio of 10:1 (ambient water: produced water). All other prescribed parameters must be within acceptable limits prior to dilution.
Dissolved Oxygen	4.0 mg/l daily minimum
Toxicity (Acute & Chronic)	1 Toxicity Unit
Soluble Radium	60 picocuries/l (2.2 becquerels/l)
Visible Sheen	No Presence

The numerical limitations listed above are to be construed as minimum effluent standards and should in no way be considered authorization to induce a violation of ambient water quality standards.

viii. Surface disposal of de minimis quantities (less than one barrel per day) of produced water may be authorized on a case-by-case basis. Effluent limitations for de minimis discharges will be established on a case-by-case basis in accordance with the provisions of the LWDPS permit authorizing the discharge, but will at a minimum require that the effluent be treated to a point at which the discharge does not generate a persistent visible sheen.

ix. There shall be no discharge of produced water within the boundaries of any State or Federal wildlife management area, refuge, park, or scenic stream or into any water body determined by the Water Pollution Control Division (WPCD) to be of special ecological significance.

x. Produced water shall not be discharged within 1,300 feet (via water) of an active oyster lease, live natural oyster or other molluscan reef, designated oyster seed bed, or sea grass bed. No produced water shall be discharged in a manner that, at any time, facilitates the incorporation of significant quantities of hydrocarbons or radionuclides into sediment or biota.

The standards covering the discharge of produced water to the territorial seas are divided into the following five parts:

i. All produced water discharges must be specifically identified in a valid LWDPS permit.

ii. Surface disposal of produced water into open waters of the Gulf of Mexico within the area defined as the territorial sea may be authorized on a case-by-case basis in accordance with the provisions of the LWDPS permit authorizing the discharge.

iii. The discharge of produced water directly onto any intermittently exposed sediment surface is prohibited.

iv. Produced water shall not be discharged within the boundaries of any State or Federal wildlife management area, refuge, or park or into any water body determined by the WPCD to be of special ecological significance.

v. Produced water shall not be discharged within 1,300 feet (via water) of an active oyster lease, live natural oyster or other molluscan reef, designated oyster seed bed, or sea grass bed. No produced water shall be discharged in a manner that, at any time, facilitates the incorporation of significant quantities of hydrocarbons or radionuclides into sediment or biota.

This covers the section of LAC 33:IX.708 which pertains to the discharge of produced water to the surface waters of the State. Additional information concerning the water quality regulations or entire copies of LAC 33:IX.708 may be obtained by calling the WPCD Permit Section at 504-765-0634.

Mr. Douglas Hale earned a B.S. from the University of Southwestern Louisiana. He has been with the Louisiana Department of Environmental Quality, Office of Water Resources, for three years. He is the Environmental Quality Coordinator of the WPCD Oil and Gas Permits Section.

U.S. DEPARTMENT OF ENERGY'S PRODUCED WATERS RESEARCH PROGRAM

Dr. Brent W. Smith
U.S. Department of Energy

INTRODUCTION

Beginning with the fiscal year 1991 Budget Year, the U.S. Department of Energy (DOE) initiated a new Environmental Research and Development Program for Oil and Gas.

Objectives of the DOE Oil and Gas Environmental Research and Development (R&D) Program include:

- development of a data base of information that would result in technically sound and justifiable, scientifically based environmental regulations for oil and gas operations;

- maximization of the economic producibility of the domestic oil and gas resource while not degrading the environment; and

- development of cost-effective environmental compliance technologies for oil and gas operations.

CURRENT DOE ENVIRONMENTAL R&D ACTIVITIES

Current DOE environmental R&D activities include:

- wetlands mitigation studies by the DOE Argonne National Laboratory and the Louisiana Geological Survey,

- an Underground Injection Practices Council grant for State underground injection control (UIC) data management programs,

- an Interstate Oil and Gas Compact Commission (IOGCC) grant for Environmental Compliance for Exploration & Production Seminars,

- cosponsorship (with the American Petroleum Institute and the Gas Research Institute) of 40 waste management plan workshops,

- cosponsorship of the International Produced Water Symposium,

- an IOGCC grant for a cooperative study on temporarily abandoned or idle wells,

- a study by the DOE Idaho National Engineering Laboratory - characterization of naturally occurring radioactive materials (NORM) in oil and gas equipment and wastes,

- a Phase II NORM Risk Assessment (human and environmental risks associated with produced waters) by the DOE Brookhaven National Laboratory,

- a new competitive study - Environmental and Economic Assessment of Discharges from Gulf of Mexico Region Oil and Gas Operations (NORM in produced waters and produced sands),

- a study by the DOE Brookhaven National Laboratory - Toxic Air Emissions from Heavy Oil Production and Distillation,

- a programmatic environmental assessment for new oil research program by the DOE Oak Ridge National Laboratory,

- a Small Business Innovation Research Grant to Membrane Technology and Research, Inc. for an Oil Field Waste Minimization study, and

- 10 proposals selected for award in the following three topical areas under a Program Research and Development Announcement (PRDA) for Environmental R&D for Oil and Gas:

  - wetlands research related to drilling, production, and transportation,
  - management of wastes from drilling and production, and
  - lower cost environmental compliance technologies.

PRODUCED WATER STUDIES

As a result of the PRDA, four produced water studies were selected for award:

- R.T. Corporation: The Evaluation of Freeze-Thaw/Evaporation for the Treatment of Produced Waters,

- University of Michigan: Wetland Treatment of Oil and Gas Well Wastewaters,

- Pennsylvania State University: Development of a Cost-Effective Environmental Compliance Technology for Stripper Wells, and

- Bend Research, Inc.: Development of a Membrane-Based Process for the Treatment of Oily Wastewaters.

The Pennsylvania State University study is titled, "Development of a Cost-Effective Environmental Compliance Technology for Stripper Wells." The technical objective of the study is to enhance the viability of gas production from the Middle Devonian and Upper Silurian sandstone formation underlying the surface topography in the Appalachian Basin by perfecting a laboratory and pilot-tested brine treatment/discharge methodology.

The anticipated product is a computer software package that Federal and State agencies and Appalachian stripper gas well operators could use to provide specific design parameters for a treatment system tailored to their brine discharges.

The R.T. Corporation study is titled, "The Evaluation of Freeze-Thaw/Evaporation for the Treatment of Produced Waters." The objective of the study is to develop a water treatment process that uses the natural processes of water freezing and melting in the winter and evaporation in the summer to treat water produced in association with oil and gas. Freezing of contaminated water can be used to separate organics, heavy metals, and salts from the water, providing high-purity ice and concentrated brine. By combining freezing and melting in the winter and evaporation in the summer, the need to dispose of produced water by underground injection or other means can be eliminated.

The Bend Research, Inc. study is titled, "Development of a Membrane-Based Process for the Treatment of Oily Wastewaters." Its goal is to develop an economical oily-water treatment system based on reverse osmosis (RO). In previous DOE work, Bend Research developed and demonstrated feasibility of using a two-stage system based on synthetic membrane technology for treating oily wastewaters. The present study will combine previous work with the development of chemically resistant support fibers to obtain a system that will economically treat oily wastewaters. The project should lead to an affordable system that will allow small oil and gas operators to avoid the forced, premature abandonment of valuable oil and gas resources.

The University of Michigan study is titled, "Wetland Treatment of Oil and Gas Well Wastewaters." It advances the use of constructed wetlands for an inexpensive treatment of wastewaters generated by small scale oil and operators. In this study a wastewater stream is passed through shallow water containing an assemblage of emergent plants growing in organic soils. An underwater layer of plant litter covers the soils. The plant leaves and stems, together with the litter, provide for physical filtration of suspended solids. Data gathered from the implementation of above tasks will be analyzed to prepare engineering design guidelines for an efficient and cost-effective wetland treatment system for use by small scale oil and gas producers and operators.

The DOE will issue a Request for Proposals on approximately November 15, 1991, for a study entitled, "Environmental and Economic Assessment of Discharges from Gulf of Mexico Region Oil and Gas Operations."

This study will involve:

- environmental field sampling, testing, and analysis of NORM, heavy metals, and organics in produced water and produced sand in offshore Gulf of Mexico discharge sites,

- monitoring of the recovery of terminated wetland and open bay produced water discharge sites in coastal Louisiana and Texas, and

- preparation of an economic assessment of the impacts from offshore and coastal discharge requirements on present and future oil and gas operations in the Gulf of Mexico region.

This research should test the hypothesis that radionuclides contained in produced water discharges and produced sand have minimal impacts to the marine and coastal environments.

Specific objectives of this study include:

- delineation of the presence of oil and gas related NORM in coastal and offshore environments,

- providing adequate data to conduct ecological and human health radionuclide risk assessments for coastal and offshore areas, and

- delineating the presence of heavy metals and organics.

This information will be used to assist regulatory agencies in reviewing scientific data in order to develop technically sound and justifiable regulations.

The DOE recently issued a Small Business Innovation Research grant to Membrane Technology and Research, Inc. for a project entitled, "Oil Field Waste Minimization." This

Phase I effort is directed towards establishing the technical feasibility of using pervaporation to remove volatile organic compounds from oil field waste streams and to incorporate the system into the design of a process controlled unit that will reduce the volume of contaminated waste for disposal. The process controlled system is designed to incorporate pervaporation, filtration, and RO.

The DOE has recently funded DOE Brookhaven National Laboratory to conduct a "Phase II NORM Risk Assessment." The project is a continuation of a Phase I study, which was funded by the American Petroleum Institute. The purpose of this research is to perform a realistic assessment of the health risks associated with the ingestion of radium in fish and shellfish harvested near offshore produced water discharges.

Dr. Brent W. Smith is Project Manager for Environmental Research and University Programs at the DOE's Metairie site office. He has lead responsibility for managing DOE's implementation of its national programs for Oil and Gas Environmental Research and the Office of Fossil Energy's Historically Black Colleges and Universities Program. Dr. Smith has over 20 years of environmental research and assessment experience with Federal and State government, including approximately 3 years with DOE and over 11 years with Minerals Management Service and U.S. Geological Service. He holds a B.A. in anthropology from Louisiana State University (1970), an M.A. in social sciences from Northwestern State University of Louisiana (1974), and a Doctorate in public administration from Nova University (1986).

STATUS OF PROPOSED EFFLUENT LIMITATION GUIDELINES

Dr. Lee Gibson
U.S. Environmental Protection Agency

New regulations affecting produced water discharges from Gulf of Mexico offshore oil and gas industry operations are being considered in two separate rulemakings by the U.S. Environmental Protection Agency (EPA). In light of new EPA National goals focusing on the reduction of toxic discharges and the EPA's new policy on waste minimization, Region 6 is currently proposing the reissuance, in part, of the National Pollution Discharge Elimination System (NPDES) general permit to regulate discharges from Outer Continental Shelf (OCS) oil and gas exploration, development, and production in the western portion of the OCS of the Gulf of Mexico. The Region is proposing to add aquatic toxicity limits and bioaccumulation monitoring and to set limits on cadmium (3 mg/kg) and mercury (1 mg/l) in drilling fluid discharges.

Separate from this rulemaking, EPA in Washington D.C. is developing effluent limitations guidelines and new source performance standards for the offshore subcategory of the oil and gas extraction point source category. This rulemaking will establish regulations based on best available technology economically achievable (BAT), best conventional pollutant control technology (BCT), and new source performance standards (NSPS). These requirements are in addition to the current best practicable control technology (BPT) regulations. The NPDES permit will incorporate all effluent limitations.

On September 15, 1975, EPA promulgated effluent guidelines for interim final BPT requirements at 40 FR 42543, and proposed regulations for BAT and NSPS for the offshore subcategory. On April 13, 1979, the EPA promulgated final BPT effluent limitations, but deferred action on BAT and NSPS. On August 26, 1985, the EPA proposed BAT/BCT/NSPS effluent limitations for the offshore subcategory at 50 FR 34592. The proposed BCT requirement for produced water limited oil and grease discharges to 48 mg/l as a monthly average and 72 mg/l as a daily average maximum. The EPA reserved BAT guidelines for produced water in this proposal. On October 21, 1988, EPA published a notice at 53 FR 41356 requesting public comment on new technical, economic, and environmental assessment data relating to the development of BAT and NSPS regulations for the offshore subcategory. New effluent limitation guidelines have now been reproposed on November 26, 1990 (55 FR 49094) and March 13, 1991 (56 FR 10664) and will be finalized on June 19, 1992.

EPA'S EVALUATION OF PRODUCED WATER TREATMENT TECHNOLOGIES

The EPA has evaluated four treatment technologies for produced waters as part of their program to develop these effluent limitations guidelines for the offshore oil and gas extraction and production industry. These four technologies and their performance capabilities are discussed below and summarized in Table 5.1.

Table 5.1. Produced Water Treatment Technology Performance.

Treatment Technology	Long-Term Average Oil and Grease Effluent Concentration (mg/l)
Reinjection	0
Membrane Filtration	5.0
Granular Media Filtration	11.3
Improved BPT	22.6*

*preliminary analysis

Zero Discharge/Reinjection

Elimination of produced water discharges for the offshore oil and gas industry can be attained by reinjection. Reinjection of produced water is considered to be demonstrated and technically feasible in general, except at certain sites which, due to formation characteristics, would not enable reinjection to be used. Pretreatment of the produced waters prior to reinjection is generally necessary to prevent scaling, corrosion, precipitation, and fouling of the well downhole. Pretreatment usually consists of the same technologies used to meet BPT effluent limitations (separation and gas flotation) plus filtration. The EPA investigated two types of filtration for use prior to reinjection: granular media and crossflow membrane filtration. The effluent limit associated with the use of reinjection technology is, of course, no discharge of pollutants.

Membrane Filtration

In addition to pretreatment for reinjection, EPA investigated filtration as add-on technology to BPT technology prior to discharge. The primary purpose of filtration is to remove suspended matter, including insoluble oils, from produced water. The use of membrane separation by crossflow microfiltration to treat produced water is a relatively new application for this process. Crossflow microfiltration is a separation and concentration technology utilizing a solid microfilter support and a "dynamic membrane."

One type of microfiltration can briefly be described as follows. The ceramic filters consist of multichannel, cylindrical tubes in a ceramic block. The channels are superstratified with aluminum ceramic layers which form the filter. The fluid that passes through the membrane is depleted in contaminants, while the fluid becomes a concentrated waste. This concentrate is continuously recycled with a periodic blowdown. By regulating the velocity of tangential flow, the membrane is controllably fouled. By controlling the degree of fouling, the filtration capabilities of the membrane system are determined. Hence, the dynamic membrane nature of this system.

The EPA has analyzed data from full-scale treatability studies using the membrane filter. Data obtained from performance tests of the membrane technology are reported as low as 1.0 mg/l oil and grease. However, 1.0 mg/l is lower than the detection limit for oil and grease which is 5.0 mg/l (ASTM Gravimetric Method 4281). Thus, EPA considers 5.0 mg/l to be the long-term average oil and grease concentration. One question with respect to technology is its ability to sustain this high degree of performance for a long period of time.

Granular Media Filtration

The EPA also investigated the use of the more conventional granular media filtration technology as add-on to BPT technology. Granular media filtration involves the passage of water through a bed of filter media which capture solids during contact.

Effluent limits based on granular media filtration were developed from an extensive sample program at three oil and gas production operations. The long-term average of 11 mg/l is the mean oil and grease effluent concentration obtained from granular media filters.

Improved Performance of BPT Technology

The EPA promulgated effluent limitations based on BPT on April 1979. The purpose of BPT technology is to remove oil and grease. The EPA developed the oil and grease limitations on the performance capability of separation and gas flotation.

Through sampling programs on BPT effluents following the 1979 rulemaking, the EPA has discovered that BPT performance has improved and that better oil and grease removals can be attained than was previously determined. The EPA's most recent analysis shows that a long-term average of 22 mg/l oil and grease is being realized along with improved variability. This improved performance would produce lower effluent limitations than the current BPT requirements of 72 mg/l daily maximum and 48 mg/l monthly average.

Dr. Lee Gibson has worked at EPA for the last 3 years, currently serving as an environmental scientist in the Industrial Permits Section of the Water Division, Region 6. He has 30-plus years professional exploration and production experience in the oil industry, both foreign and domestic, as a geologist and stratigrapher in operations, research, and exploration management. Dr. Gibson received his B.A. in zoology and his M.A in geology from Washington University, St. Louis, Missouri. He has attended Texas A&M University, College Station, Texas (oceanography), the University of Chicago, Chicago, Illinois (ecology), and received his Ph.D. in geology from the University of Oklahoma, Norman, Oklahoma.

A REVIEW OF TECHNOLOGY FOR CLEANING PRODUCED WATER

Dr. Charles A. Petty
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INTRODUCTION

Hydrocarbon contamination of the oceans and estuaries is obviously undesirable. Existing and proposed regulations on the discharge of bilge water from oil tankers and formation water from offshore platforms are challenging the limits of available oil/water cleaning technology. The allowable daily average concentration of free oil in the discharge from platforms in the Bass Strait near Melbourne is 38 parts per million (ppm) by volume (Hayes *et al.* 1985). In the Gulf of Mexico, a monthly average of 48 ppm oil and grease is permitted (51 FR 24897). Inasmuch as the production water from the primary API gravity separator is typically 1,000 to 4,000 ppm of free oil, additional cleaning steps are needed to meet current discharge standards. Within 10 years, more than 10 million barrels water produced per day (BWPD) will be treated on offshore platforms worldwide (Howell 1989). As an oil field matures and produces even larger quantities of water, treatment of produced water may severely impact the economics of offshore oil production. Thus, there is a clear need for improved oily water cleanup technologies which can handle increasing amounts of production water over time while consistently meeting discharge specifications on water purity (Blytas 1988).

The purpose of this presentation will be to briefly comment on some of the more conventional technologies available to remove suspended oil and grease from produced water (Table 5.2). Recently, Humphrey and Seibert (1991) provided an overview of advanced emerging technologies to remove dissolved organics from waste streams. The emphasis here, however, will be on those unit operations which use various physical and/or chemical means to enhance the relative velocity between the dispersed phase (oil) and the continuous phase (water). The potential role of the hydrocyclone for cleaning oily waste streams will also be highlighted. Hydrocyclones have been used for liquid/liquid separation and for degassing liquids for more than 40 years (Bradley 1965) and may ultimately be the unit operation of choice for oil/water separation on offshore platforms and because of their compactness and simplicity of operation. Presently, hydrocyclones are being employed as a retrofit technology to provide additional clarification of production water. The use of lightweight, noncorrosive, high-strength, advanced polymer composite materials in hydrocyclone manufacturing may provide an additional incentive for this complementary unit operation on offshore platforms.

Table 5.2. Unit Operations for Treatment of Produced Waters.

API Gravity Separators	
Skimmer Tanks	
Skim Piles	
Plate Interceptors -	parallel corrugated
Filter/Coalescers -	upflow
	downflow
	crossflow
Free Flow Coalescers	
Gas Flotation -	dissolved
	hydraulic
	mechanical
Hydrocyclones/centrifuges	
Membranes -	organic
	inorganic
(Cross-flow Ultrafiltration)	

UNIT OPERATIONS

Some common methods for separating oil from water are listed in Table 5.2 (Perry and Chilton 1973, Humphrey and Seibert 1991). Table 5.3 identifies the underlying engineering principles which govern the design of separation equipment based on density differences and particle size. In a wastewater treatment facility, these unit operations are often organized to complement one another. For instance, the residence time of the API gravity separator may be specified to remove the large oil drops and, thereby, reduce the dispersed phase concentration from 100,000 ppm to 3,000 ppm. A compact, corrugated plate interceptor following an API separator can further reduce the dispersed phase concentration to 30 ppm. Although these two steps together have removed a significant portion of the oil from the influent stream, the dispersed phase oil content of the produced water is still too large for discharge. Thus, additional steps in the treatment process are designed to remove the finely dispersed oil droplets having diameters less than 50 microns.

Table 5.3. Physical Principles Governing Design of Separators.

(A) Upstream Process Flow Conditions Drop Breakup Drop Coalescence
(B) Stokes' Law
(C) Residence Time vs. Separation Time

Enhanced separation methods designed to remove small drops usually exploit one or more features which control the relative velocity between the oil drop and the continuous phase. Figure 5.1 shows that the drift velocity according to Stokes' Law can be increased by (1) increasing the particle size; (2) increasing the density difference; (3) increasing the acceleration; or (4) decreasing the viscosity of the continuous phase. Chemical treatment with high molecular weight polymers can be used to promote coalescence of oil drops by either neutralizing surface charges or by decreasing the interfacial tension. This approach is often combined with gas flotation, which increases the effective density difference between the dispersed particle (gas attached to an oil droplet) and the continuous phase. Carriere (1991) recently discussed the use of "free-flow-coalescence" in wastewater treatment to increase particle size without large quantities of surfactants.

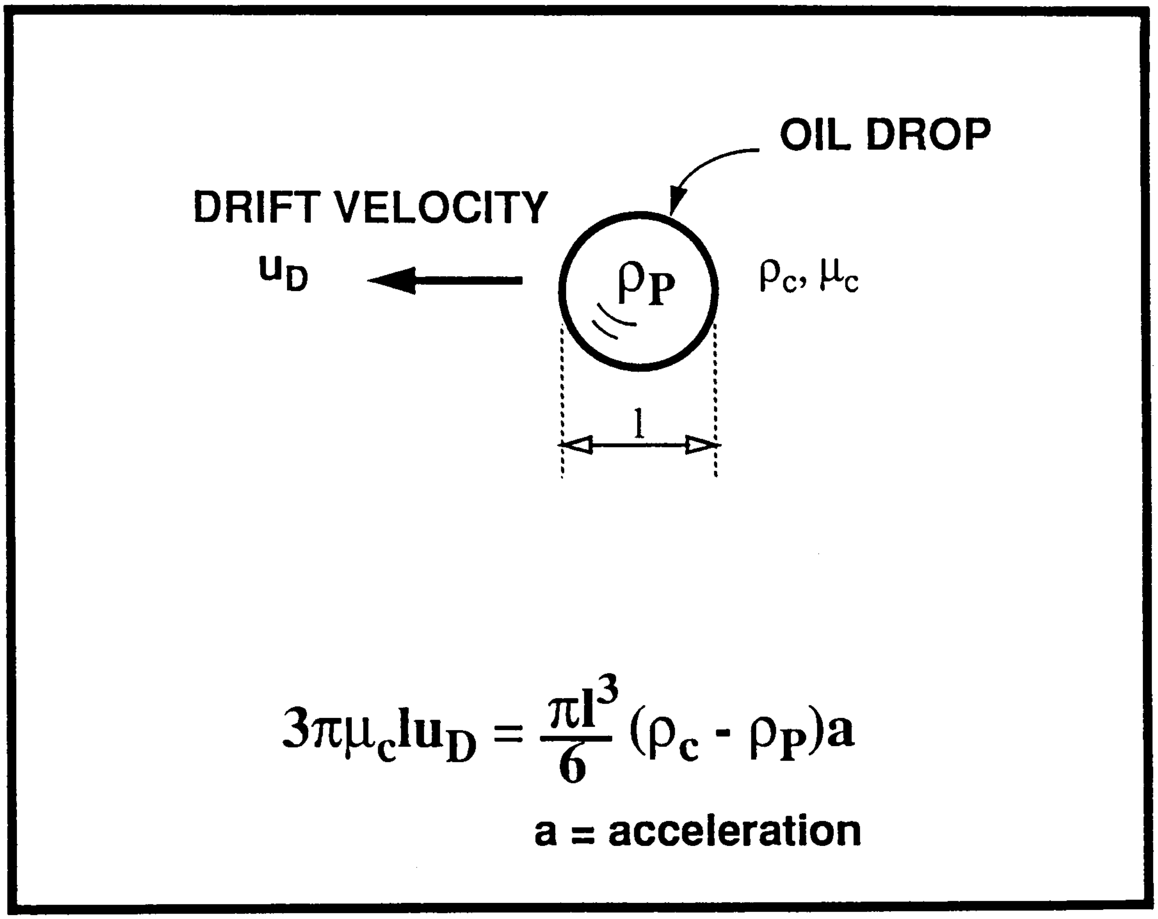

Figure 5.1. Force balance on an oil drop.

Gas flotation technology combined with chemical treatment has been used by the U.S. Environmental Protection Agency (EPA) to determine effluent standards for produced water. Gas flotation cells with sufficient residence time are expected to reduce the dispersed phase concentration of a "fine" suspension of oil from 300 ppm to 30 ppm. Gas flotation may be followed by so-called "polishing" steps which may involve filter/coalescers, submerged residence time vessels, membranes, hydrocyclones, or centrifuges (Table 5.2). In a hydrocyclone or a centrifuge, the net force acting on an oil droplet can be several thousand times the force due to gravity. Thus, even "small" drops can be removed from a dispersion provided sufficient residence time has been designed into the separator.

The underflow purity coefficient ϵ_u (Figure 5.2) associated with separation equipment for the removal of dispersed oil from water depends critically on the size distribution of the oil droplets in the feed streams, $f_F(\ell)$, and the underflow grade purity coefficient, $G_u(\ell)$. Equipment selection and operating conditions are based on a relative comparison between the mean drop size in the feed stream ($<\ell>_F$) and a characteristic "cut-size" for the unit operation, such as ℓ_{75} defined by $G_u(\ell_{75})$ = 0.75. The concentration of oil droplets of size $\ell > \ell_{75}$ entering the separator will be reduced by more than 75 percent in the underflow stream. Thus, high underflow purity coefficients for a given separator require ℓ_{75} to be much smaller than $<\ell>_F$. An API gravity separator has an underflow purity coefficient ϵ_u = 0.97 primarily because most of the oil phase is in the form of large drops. However, because the mean drop size in the process stream following an API separator has decreased significantly, the underflow purity coefficient for

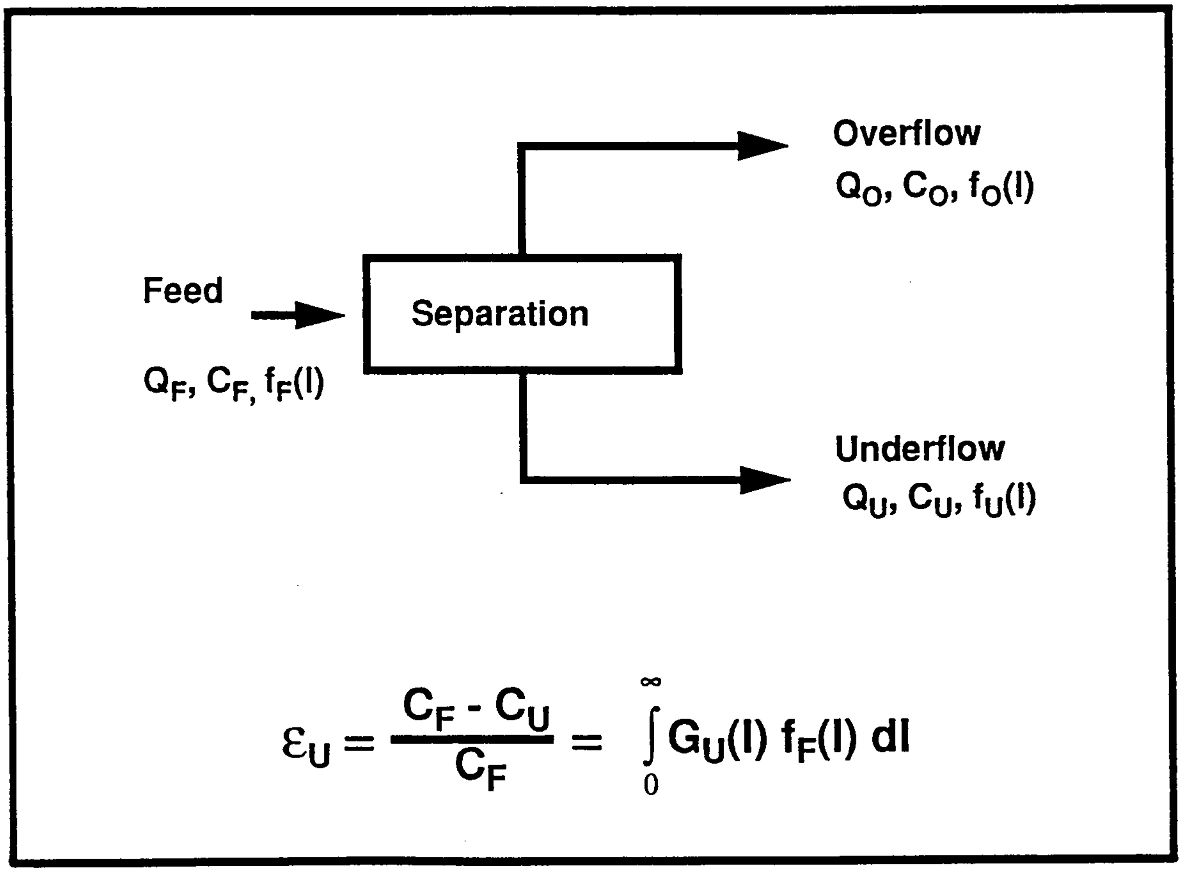

Figure 5.2. Performance measures associated with separation equipment.

plate interceptors and gas flotation cells is only about 0.90. The lower cut-size for a plate interceptor and for a gas flotation device partially compensates for the small drop sizes following an API separator.

HYDROCYCLONES

Regehr (1962) was apparently the first to study the use of hydrocyclones for de-oiling dilute dispersions of oil in water. Hydrocyclones were, however, used much earlier as liquid/liquid separators and as mass transfer contacting devices (Bradley 1965). Sliepcevich and Sheng (1969) developed hydrocyclones for liquid/liquid separation which promote coalescence of oil on selected internal surfaces made of hydrophobic materials. Colman and Thew (1983) developed a double-cone hydrocyclone for cleaning oily water streams, and, more recently, a class of "optimal" single-cone de-oiling hydrocyclones has been developed by Young *et al.* (1990). Bednarski and Listewnik (1987) developed a de-oiling hydrocyclone which features a rod positioned on the axis to assist in the flow reversal process, and to prevent the core fluid from contaminating the "clean" water underflow during upsets. Gay *et al.* (1987) developed an oil/water separator which is a hybrid between a hydrocyclone and a centrifuge. Recently, Plat and van den Broek (1990) have combined centrifugal separation techniques with gas flotation and oil coalescence.

Because immiscible fluids generally have low relative densities, very intense swirling flows are needed to separate a finely dispersed liquid phase by centrifugal action. A swirling flow is produced within a hydrocyclone by introducing the feed stream tangentially into a frustoconical device. The kinetic energy of the feed is large and the flow is turbulent. Fluid shear may break up large drops into smaller drops and, in some cases, may even cause a "stable" emulsion to form. This phenomenon, probably more than any other factor, has limited the widespread use of hydrocyclones as liquid-liquid separators.

Figure 5.3 shows the geometric scales of the double-cone hydrocyclone of Colman and Thew (CT-cyclone). This hydrocyclone has evolved to its present configuration through a 20-year development program at Southampton University (United Kingdom). The Southampton group has clearly demonstrated that this design has practical commercial value. Figure 5.4 shows that the ℓ_{75} cut-size for the CT-cyclone decreases from approximately 30 microns to 15 microns as the feed velocity increases from 3 to 10 m/s. This level of performance makes the hydrocyclone separator an attractive alternative to gas flotation provided (1) the mean droplet size of the feed, $<\ell>_F$, is larger than 30 microns; and (2) the interfacial tension between the oil and water phase is larger than 30 dynes/cm (see Figure 5.4).

Figure 5.4 also shows the behavior of the maximum drop size in fully developed pipe flow as the bulk average velocity increases and as the interfacial tension decreases from 40 to 20 dynes/cm. Unfortunately, for relatively low interfacial tension dispersions, it may be difficult to achieve high underflow purity coefficients with a hydrocyclone because ℓ_{75} and $<\ell>_F$ are comparable.

SUMMARY

As a compact, lightweight separator, the hydrocyclone complements other unit operations designed to clean produced water on offshore platforms. Current technology can attain underflow purity coefficients as high as 0.90 in a single stage, if the mean drop size in the feed stream is larger than 35-40 microns. Chemicals used to enhance the coalescence of oil droplets under quiescent (low shear) conditions may degrade the performance of hydrocyclones by lowering the interfacial tension. Gas flotation can also achieve underflow purity coefficients of 0.90, but require relatively large residence times compared to hydrocyclones.

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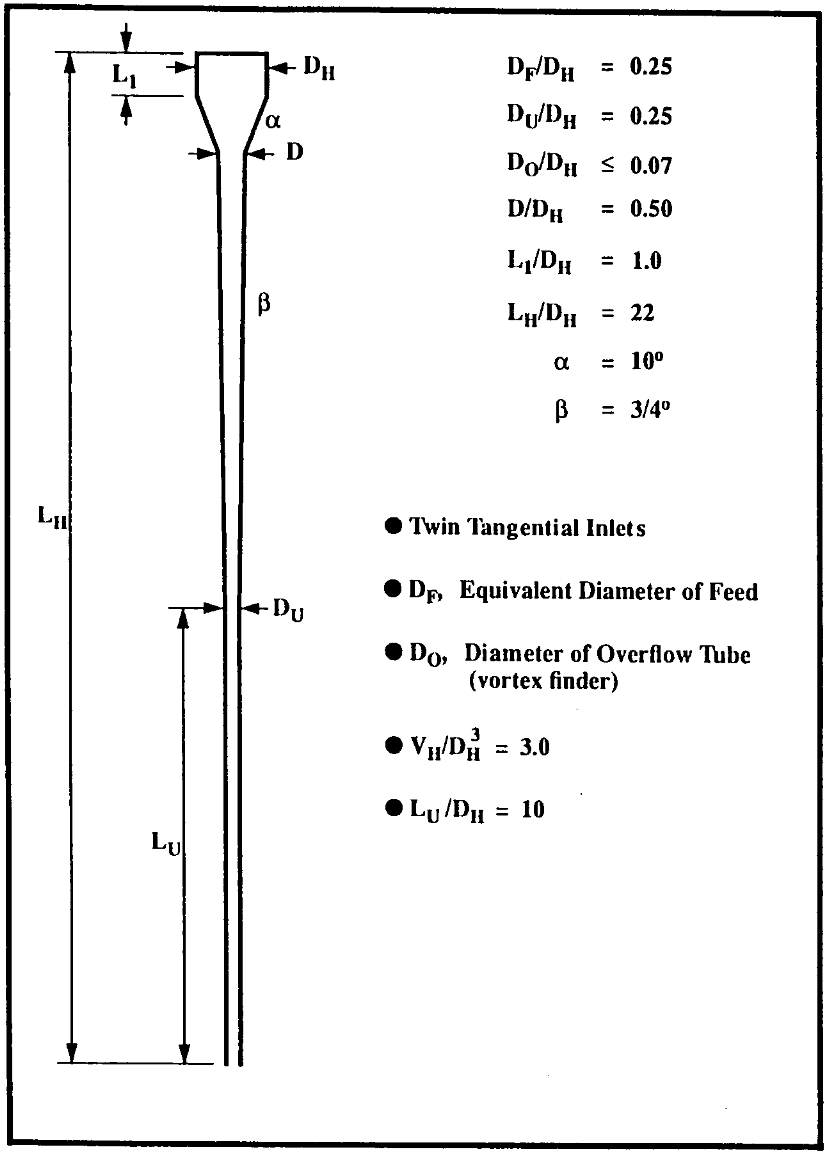

Figure 5.3. Double-cone de-oiling hydrocyclone (Coleman and Thew 1983).

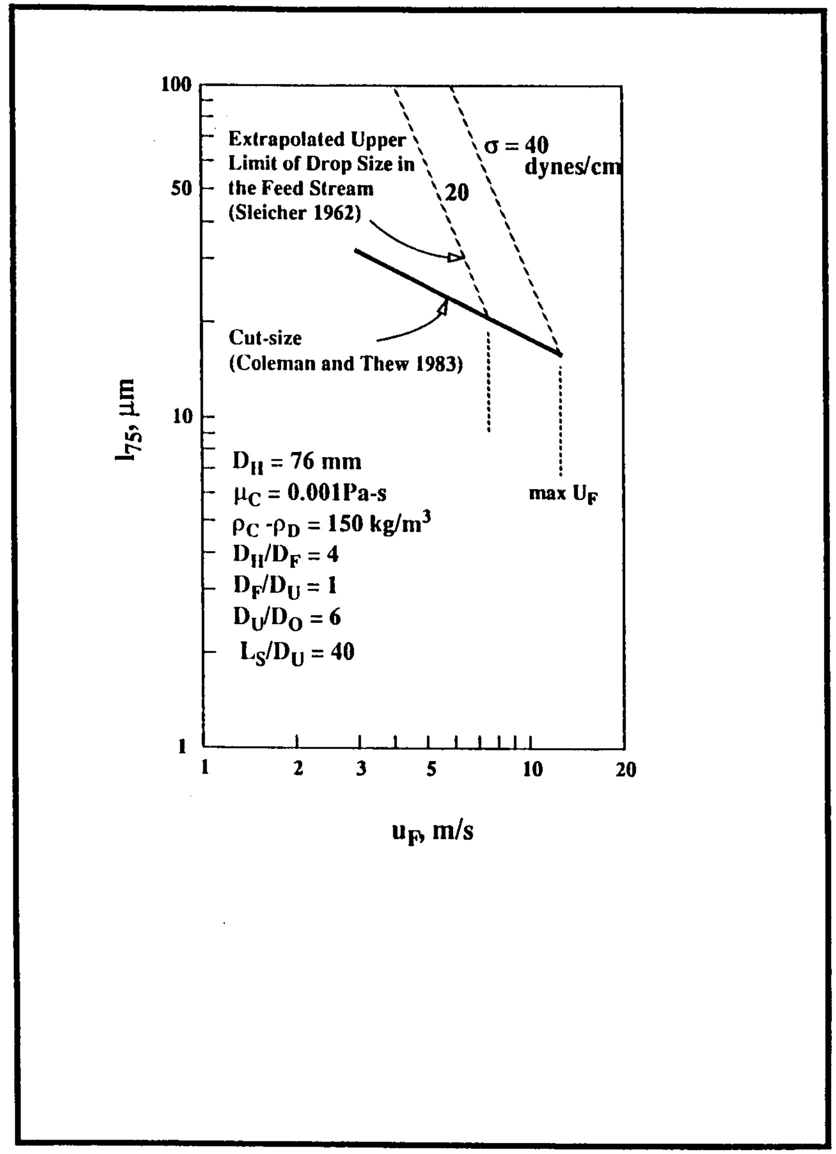

Figure 5.4. The effect of feed velocity on the cut-size of a de-oiling hydrocyclone.

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Dr. Charles A. Petty has worked at Michigan State University in the Department of Chemical Engineering for the past 14 years. His areas of research interest include turbulent transport phenomena, separations, and polymer composite processing. He recently formed an Industrial/University Consortium at Michigan State University to develop hydrocyclone technology for cleaning produced water. Dr. Petty received his B.S. and Ph.D. in chemical engineering from the University of Florida.

CURRENT STATUS OF MEMBRANE TREATMENT FOR PRODUCED WATER DISCHARGES

Mr. Ken E. Arnold
Paragon Engineering Services, Inc.

INTRODUCTION

This report discusses the capabilities and limitations of cross flow membrane systems available to treat produced water. The units studied are those for which the most data are available from pilot tests and research laboratories. It is believed that the different types of membranes covered by these units cover the range of likely candidates available for produced water treatment at this time.

The membrane systems evaluated are:

- Alcoa/Petrolox which uses a 0.2 to 0.8 micron ceramic membrane requiring development of a floc to precoat the membrane to prevent rapid plugging,
- Zenon, which uses a 0.03 micron polysulphone membrane,
- 3S Teknik/X-Flow which utilizes a 0.2 micron polyether sulphone membrane, and
- SDI which utilizes a non-porous regenerated cellulose crystalline membrane.

The use of filtration to remove oil and grease from produced water is not new. In the early 1950's "precipitators," sometimes called DOR units for "dispersed oil removal" units, were used both onshore and offshore. These units were pressure vessels filled with hay, excelsior or other "coalescing" media which trap the oil droplets. They produced an effluent with very low oil and grease concentrations when they were first placed in service. However, in a very short period of time the coalescing media would become saturated with oil, plugged with solids, or bypassed by the majority of the produced water stream. It was then necessary to remove the vessel from service, open it, and replace the coalescing media. The used oil-wet coalescing media then had to be handled in an acceptable manner as it could not be regenerated. Because of the required frequency of replacement and the volume of waste generated, these systems soon went out of favor onshore, and were never in widespread use offshore.

The next generation of filters were sand and multi-media filters (granulated filters) which were first used to clean produced water in the late 1960's and early 1970's. These units can be backwashed without having to be depressured and the media can be reused for long periods of time. Onshore the backwash water can be routed to large settling tanks where most of the oil can be separated and the bulk of the liquid trucked to disposal well sites. These filters have found application in final polishing of produced water (downstream of flotation units and hydrocyclones) prior to softening for boiler feed in thermal recovery operations.

Granular media filters have not found much application offshore because of the problem of handling the backwash water. That is, while granular media filters could reduce the oil and grease content of flotation unit or hydrocyclone effluents, the volume of backwash material generated would exceed the volume of oil and grease removed from the produced water stream by a large order of magnitude.

Crossflow membrane filters may present a possible solution to this problem by decreasing to near zero the amount of "backwash" fluid which is generated. In a crossflow membrane filter, the flow of the dirty water is parallel to the surface of the filter media (the membrane) and not through it. Thus, the flow of the feed tends to sweep the surface of the membrane and keep it clean as shown in Figure 5.5A. The permeate (the produced water which must be discharged) flows through the membrane.

The concentrate must take with it all the oil and solids which are separated from the produced water as well as sweep the surface of the membrane. Thus, the concentrate flow rate must be several times larger than the permeate flow rate. In Figure 5.5B if the feed stream is the "dirty" produced water, and the permeate stream represents "clean" produced water ready to be discharged, the feed pump must be sized for significantly more flow rate than the design produced water flow rate.

Oil and solids will "concentrate" or build up in the recycle loop. The ratio of the feed flow rate to the concentrate bleed flow rate determines the concentration of oil and solids in the membrane feed stream. For example, if there is 100 parts per million (ppm) oil and grease in the feed stream to the unit, the produced water rate is 10,000 barrels water produced per day (BWPD) and the concentrate bleed is 100 BWPD (feed to bleed ratio is 100:1), the feed to the membranes will contain 10,000 ppm oil and grease. In this case the membrane must be able to produce acceptable oil and grease content in the permeate for long periods of time with a 10,000 ppm feed without clogging. In addition, the 100 BWPD concentrate bleed must be capable of being recycled through the oil-water separation process without affecting either the oil treating or water treating system. If the concentrate bleed is increased to 1,000 BWPD, the concentration of oil and grease in the membrane feed will be decreased to 1,000 ppm.

The key to the "utility" of this technology in an offshore produced water system is whether the maximum ratio of concentrate bleed to feed flow rate would result in a sufficiently low membrane feed concentration so that the membrane provides an acceptable permeate without interrupting operations by requiring frequent membrane cleaning or replacement. The maximum bleed-to-feed ratio should be set without upsetting the existing oil/water separation process.

AREAS OF INTEREST

Table 5.4 shows the characteristics of the different units as determined from pilot tests and research laboratory results. The most data available are on the Alcoa unit and that is the only unit for which operating data are available. The results are summarized below:

- Requirements Prior to Filtration
  - Alcoa - Chemical pretreatment to create hydrophilic floc - No prefiltering for solids is required
  - Zenon - 20 micron filter for removal of solids - Emulsifiers for removal of free oil

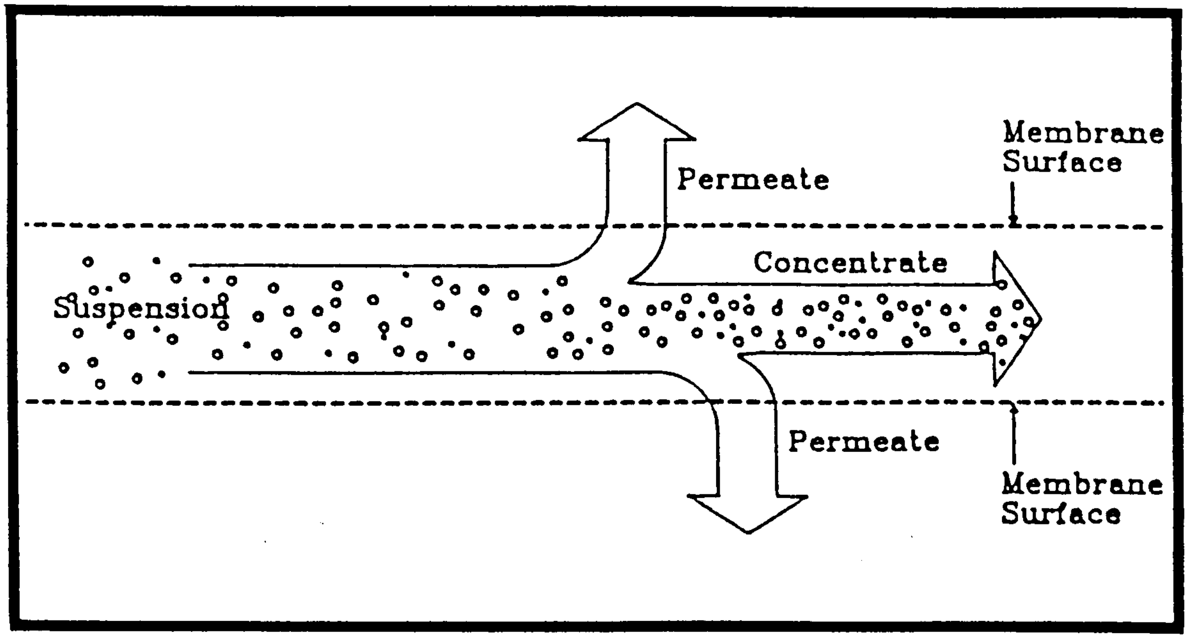

Figure 5.5A. Schematic of principle of operation of cross-flow filtration.

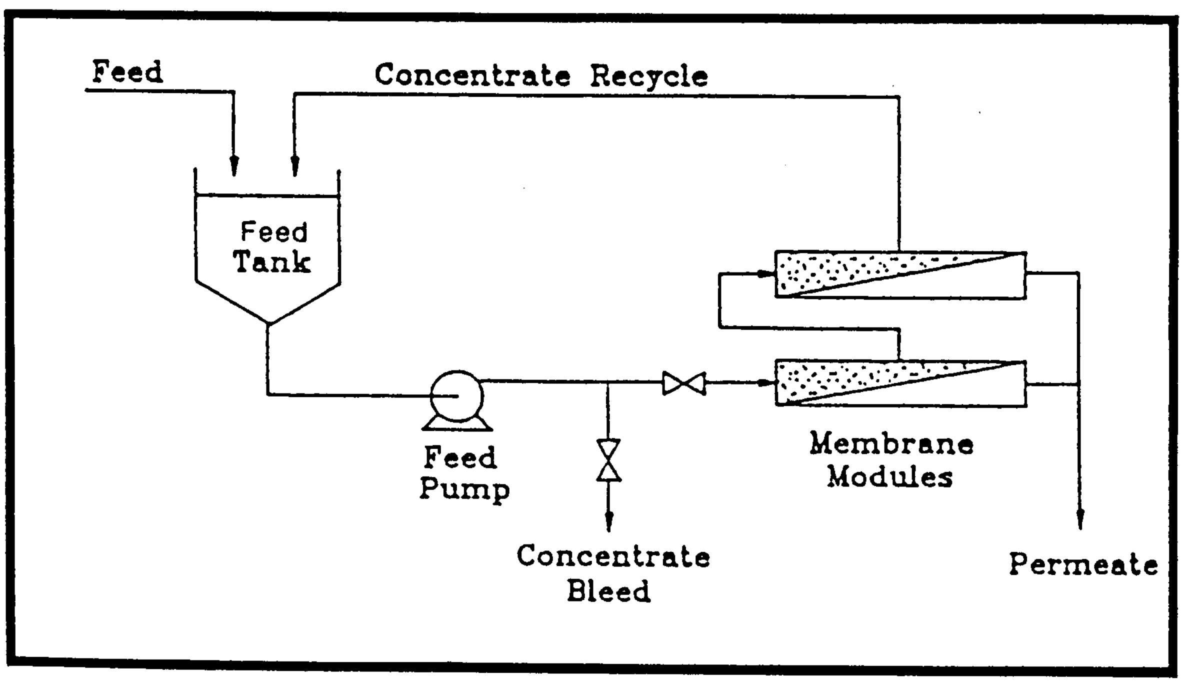

Figure 5.5B. Typical filtration system.

Table 5.4. Summary of Pilot Results for Different Membrane Filtration Systems.

	Alcoa	Zenon	X-Flow	SDI
I. Oil & Grease				
A. Removal				
1. Dispersed Oil to 15 mg/l	Y	Y	Y	Y
2. Dissolved Oil	N	P	NA	P
B. Confirmed by:				
1. Manufacturer's Data	Y	Y	Y	Y
2. Pilot Test	Y	Y	N	N
3. Operating Experience	Y	N	N	N
II. Suspended Solids				
A. Removal to 10 mg/l	Y	Y	Y	Y
B. Required Prefilter	N	20μ	80-150μ	5μ
III. Chemical Usage				
A. Pretreatment Required	Y	N[1]	N	N
B. Sensitive to Changes in Produced Water Chemistry	Y	NA	NA	NA
IV. Treating Recovered Oil	NA	NA	NA	NA
V. Disposal of Recovered Solids	NA	NA	NA	NA
VI. Flux Degradation				
A. Reversible	Y	Y	Y	Y
B. Irreversible	N	Y	N	N

Y = Yes
N = No
P = Partial
NA = Not Available
[1]Some emulsifying chemical may be needed to eliminate free oil.

- X-Flow - 80 - 150 micron filter for removal of solids
- SDI - 5 micron filter for removal of solids

• Oil and Grease
  - Almost total removal of dispersed oil by all
  - Ultrafiltration removes some dissolved oil
  - Microfiltration may or may not remove dissolved oil

• Treating of Recovered Oil
  - No data available
  - Alcoa has oil wet solids in floc
  - Ultrafiltration system using emulsifiers may have difficulties breaking the emulsion

• Chemical Pretreatment
  - Ultrafiltration units may require emulsifiers to eliminate free oil

   - Alcoa requires pre-treatment to create floc

- Suspended Solids Removal
   - Complete removal of suspended solids by all (0 - 1 ppm)
   - Prefiltration will make these units impractical

- Disposal of Recovered Solids
   - No data available
   - Solids off bottom of feed tank are assumed to be water wet but there is no data available at the present time to confirm this assumption

- Flux Degradation
   - Zenon shows irreversible flux degradation. Working on correcting this
   - Alcoa indicates long runs (three weeks) between wash cycles and no irreversible degradation
   - X-Flow claims 12 weeks of operation without need for cleaning with chemicals
   - Remaining units offer no data

- Conclusions
   - Will remove dispersed oil and grease
   - Irreversible flux degradation with time is a potential problem for all but Alcoa
   - Pretreatment chemicals for Alcoa present unanswered oil treating and solids treating questions. A 50 ppm stream results in 5,000 ppm of hard to separate water, oil, and oil wet solids (5% of 10% waste stream).
   - Prefiltering requirements for ultrafiltration units will make their use impractical

CAPITAL AND OPERATING COSTS

The only unit for which there is sufficient operating experience to estimate costs is the Alcoa unit. It is possible that further pilot testing with another unit could result in less cost due to fewer problems with chemical treatment and handling the oil wet solids, but it is premature to reach such a conclusion from the data available today.

Table 5.5 shows an example capital cost estimate based on 1500 BWPD per 36P 19-40 Petrolox module. One spare module is included. Capital costs are summarized in Figure 5.6.

Table 5.6 shows the assumptions used in calculating operating and maintenance costs. Figure 5.7 shows the cost as a function of flow rate.

CONCLUSION

- Crossflow membrane filtration has the potential to provide higher levels of oil and grease removal from produced water than that currently obtainable from flotation units or hydrocyclones.

- There is no field proven unit on the market for produced water treatment. No data is available for any unit which addresses the handling of concentrate bleed (the reject stream which carries oil and solids separated from produced water).

- The Alcoa unit requires no prefiltering of the feed to prevent plugging. X-Flow requires prefiltering with an 80 to 150 micron filter while the rest of the manufacturers require prefiltering with a 5 to 20 micron filter for the removal of suspended solids. Prefiltering of 5 to 20 microns renders these units impractical for offshore produced water cleanup.

- The unit with the most pilot and field data available is marketed by Alcoa. Flux degradation appears to be reversible and can be handled with an automatic wash cycle. This unit relies on the use of pretreatment chemicals to form a floc. These chemicals and their dosages are affected by changes in the pH of the produced water, as well as by changes in concentration of corrosion inhibitor, emulsion breakers, and water treating chemicals.

The only other unit for which data are available and which may not require the installation of upstream filters is manufactured by XFlow. No data are available to show that long term irreversible flux degradation is not a problem with this unit, but the concentrate bleed should be easier to process than with the Alcoa unit.

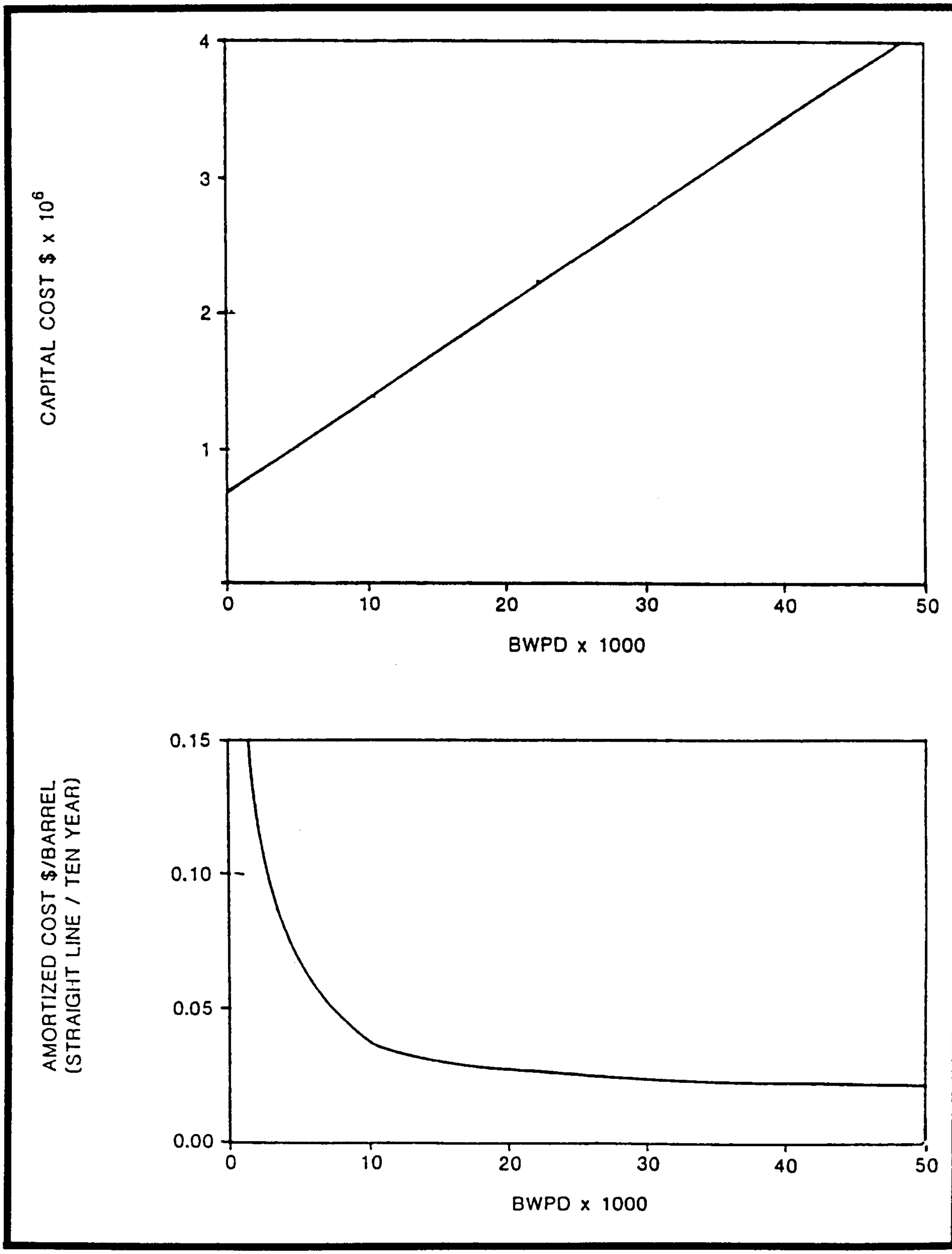

Figure 5.6. Capital cost and amortized cost per barrel for membrane filtration system.

Table 5.5. Installed Capital Equipment Cost. (Case B: 10,500 BWPD - 8 modules).

	M$	M$
1. Filtration Skid (160 ft^2)		335
2. Pretreatment Skid (160 ft.^{2})		465
3. Float Treatment Skid (108 ft.^{2})		
Separator (3 ft. x 10 ft.^{2})	6	
Controls	20	
Relief Valve	10	
Pumps (2 x 12 HP)	13	
Heat Exchanger (1.9 MMBtu/hr)	81	
Piping and Skid (50% of equipment)	65	
		195
4. Equipment Installation and Interconnect, onshore (20% of 1+2+3)		199
5. Instrument and Electrical Interconnect		20
6. Deck ($120/ft.^{2})		52
7. Engineering and Inspection (10% of 1-5)		121
		—
Total		$1,387
$/BWPD		132
Total Platform Space (ft.^{2})		428
ft.^{2}/BWPD		0.041

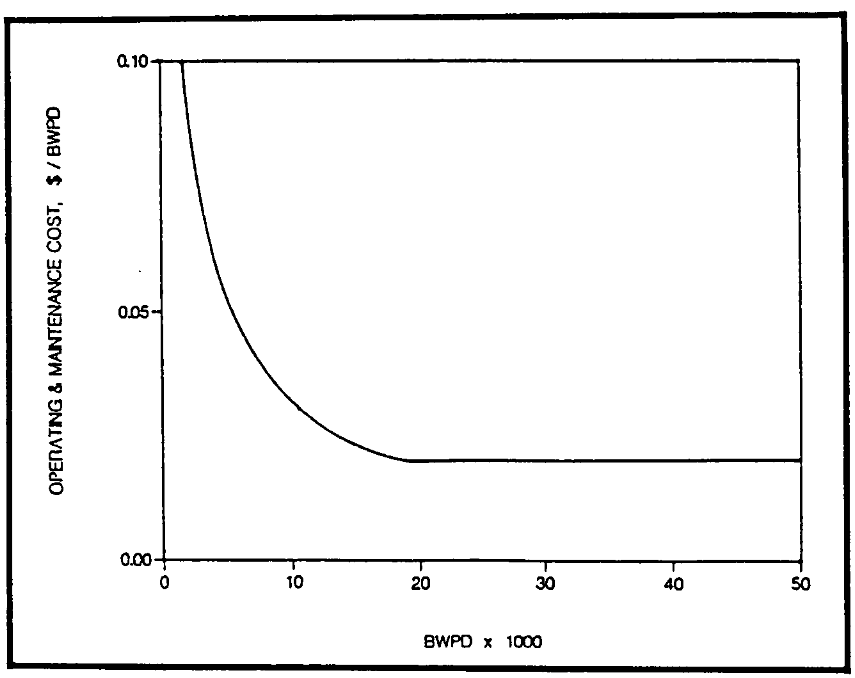

Figure 5.7. Operating and maintenance cost.

Table 5.6. Operating Cost Basis.

1. Operating Labor

   Operating labor is estimated at \$30/hr. in 1990 and escalated at 4% per year. One manhour per day is assumed.

2. Routine Maintenance & Parts

   2% of Capital Cost of Equipment per year escalated at 4% per year.

3. Special Maintenance & Parts

   Assume that the elements in each module must be replaced once during the life. Element cost is 50% of filtration skid cost. Use 5% of filtration skid cost per year. Cost is escalated at 4% per year.

4. Power

   Concentrate pump based on five times the produced water flow rate and 50 psi pressure increase. Float treatment pump based on 10% of produced water flow rate and 200 psi pressure increase. Chemical injection pumps are neglected. Incremental power costs are assumed to be \$0.04/KW-hr and are escalated at 4% per year.

5. Chemical Cost

   Marathon reports using 55 gallons of acid and 55 gallons of caustic every 3 or 4 cleaning cycles for four modules. Assuming three weeks between cleanings, 11.35 gallons of chemicals are required per month per module. 1990 chemical costs delivered offshore are \$300 per 55 gal. drum (\$5.45/gallon).

   Cost $FeCl_3$ is calculated using 50 ppm of total solution and a delivered cost of \$200 per 55 gal. drum (\$3.64/gallon) for a 30% solution in 1990.

The installed cost for an Alcoa unit constructed as part of a new facility ranges from \$528/BWPD for a design throughput of 1500 BWPD to \$83/BWPD for a design throughput of 46,500 BWPD. Cost for a 10,000 BWPD unit is \$1.4 MM. For comparison, a typical (10,000 BWPD) gas flotation produced water treating system, to which the Alcoa system would be added, costs approximately \$0.4 MM. Thus, reducing oil and grease concentration from that already being obtained will increase produced water treating capital cost by a factor of four over current gas flotation technology.

Operating costs for an Alcoa unit average between \$0.02 and \$0.03 per barrel of water. Below 10,000 BWPD costs rise sharply to \$0.10 barrel of water at 1,500 BWPD. The operating cost for conventional water treating is estimated to be \$0.01 per barrel. Thus, adding the Alcoa unit increases overall operating costs by a factor of approximately 3 to a total cost of \$0.03 to \$0.04 per barrel.

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MARATHON'S OPERATING EXPERIENCE WITH THE USE OF CERAMIC MEMBRANES FOR THE FILTERING OF PRODUCED WATER

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Marathon Oil Company
Gulf Coast Region

INTRODUCTION

Ceramic membranes have been used commercially since 1984 in over 250 installations worldwide in such applications as beverage, dairy, chemical waste treatment, and potable (bottled water and municipal potable water) etc. In the fall of 1989, Marathon Oil Company installed a cross-flow micro-filtration system (ceramic filter) to filter produced water on an offshore platform for re-injection into the reservoir for pressure maintenance. Our experience has been with Alcoa Separations Technology Division of Warrendale, Pennsylvania, marketed under the registered tradename of Petrolox TM.

Two units have been used. The presentation today will summarize their performance.

REVIEW OF THE COMPONENTS

The basic components of a ceramic filter are shown on Figure 5.8. A side-stream of overboard quality produced water is treated with chemicals to correct the pH and generate the required solid material for the dynamic layer. The dynamic layer is a coating of solid material that is formed on the surface of the substrate and acts as the primary filter. The feed enters the separation tank and commingles with the rejected concentrate from the filter. In the tank entrained gas is released, oil and excess solids are separated for disposal/treatment.

A centrifugal pump generates enough pressure to force the fluid through the membrane bank. Permeate is drawn off as product from the side of the filter modules, and the concentrate returned to the tank for separation. Two cleaning systems exist. The back-pulse uses permeate to remove the contaminated dynamic layer every few minutes by momentarily reversing the flow through the filter. A chemical cleaning system is used to clean the filter substrate every week and requires the filter train to be shut down. This is necessary as the dynamic layer is not 100 percent efficient. As there are many process variables to monitor and valves to be sequenced, a computer is used to control the process to minimize operator intervention.

PERFORMANCE OF UNIT #1

The first unit was installed in the fall of 1989. It did not meet expectations and went through significant amount of modifications. These can be summarized as follows.

- Back pulse system was giving insufficient pressure to shock the ceramic filter and efficiently remove the contaminated dynamic layer. The problem was resolved by:

    - installing high performance quick acting valves,
    - moving the valves close to the ceramic filter housing,
    - raising the operational pressure of the back pulse system,
    - adjusting the scour valves to increase the flow rate (and decreasing the filter pressure), and
    - changing the valve timing sequence during the back pulse to give a longer duration pulse.

- The modules could not be cleaned after being contaminated. This involved both mechanical and chemical solutions viz:

    - place the filters vertically (were horizontal),

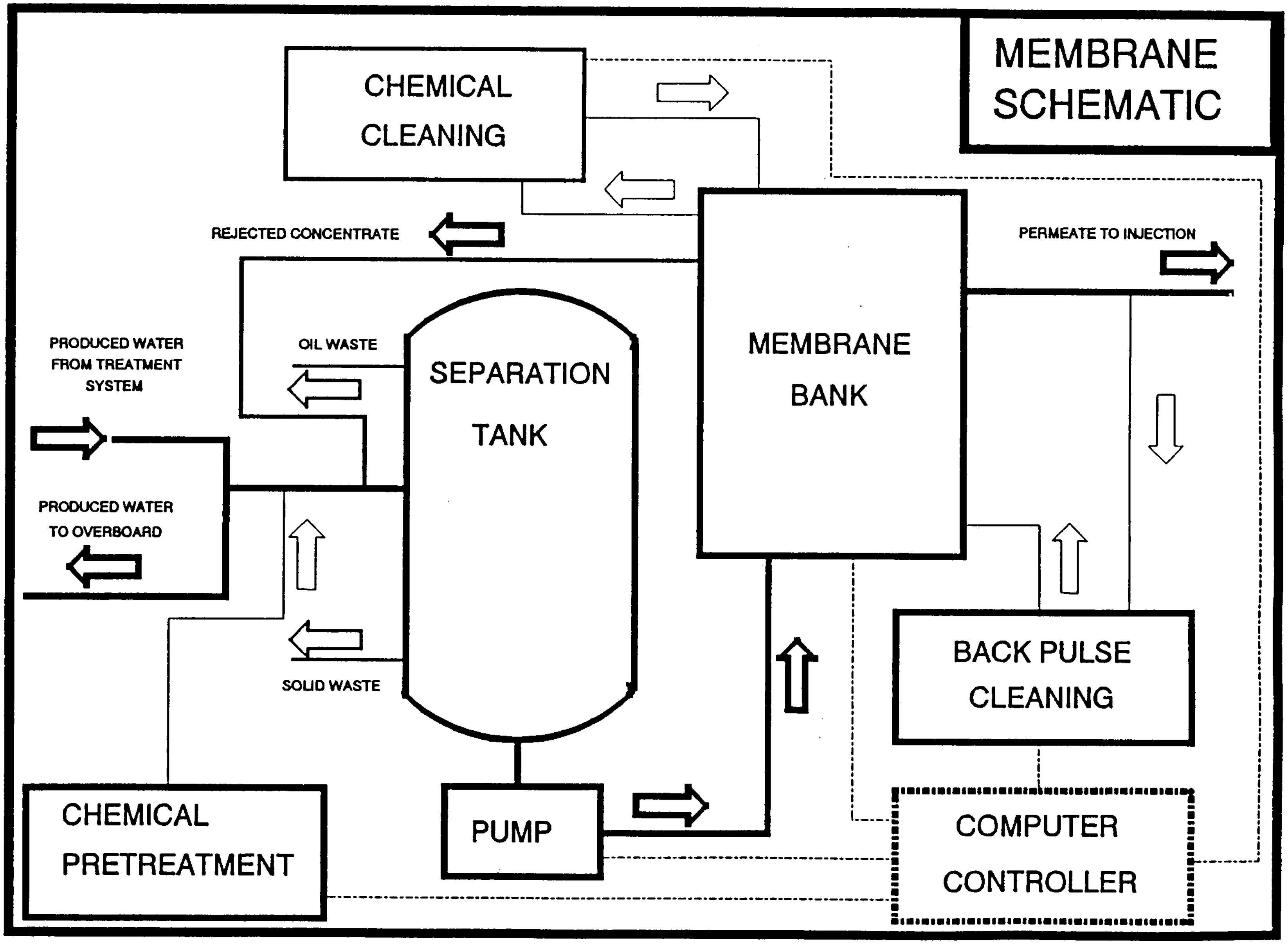

Figure 5.8. Basic components of a ceramic filter.

- increase the membrane size (from 0.5 to 0.8 microns),
- increase the concentration of the cleaning chemicals,
- use fresh chemicals only, and
- heat the caustic to 60° celsius.

- Modules were becoming contaminated with barium sulphate. The barium sulphate could be removed by special chemicals which would also dissolve the NORM scales present. The source of barium was in the produced water and the sulphate was from seawater entering the system when the sumps were pumped. This problem has been minimized.

- The filter was only lasting a few hours before requiring cleaning. The cleaning period was extended by:

  - improving the pretreatment,
  - installing two additional modules (total modules now four),
  - reducing the volume of solids and oil being recycled in the system, and
  - stop the unit from becoming oil wet by changing the upstream production chemicals.

PERFORMANCE OF UNIT #2

The performance of unit #1 was not satisfactory, and a second unit was installed in spring of 1991. This model incorporated all the additional features that were found necessary and is larger and much more complex than the original system.

The second unit was tested out after installation and was found to meet specifications. Due to problems with the injection well, the system has only been running at a quarter of its capacity and was operating satisfactory until recent months. Troubles have started to occur again. The pretreatment pump has not been delivering reliable volumes of chemical and this has resulted in poor dynamic layer performance and increased the contamination of the substrate. The caustic heater system broke and efficient cleaning of the substrate could not be achieved with cold caustic. The computer system has started to get out of sequence which prevents proper cleaning. Attempts to clean manually have not been successful. The cause of the problem is still under investigation.

Until last week the oil content in the permeate has always been below detectable levels with an IR unit, but 7 ppm has just been measured. It is suspected that a leak or failure in one of the elements has taken place and this is currently under review.

The surge tank downstream of the unit was recently opened and a large quantity of sludge was found and washed out. Samples are currently being analyzed.

Handling of the oil wet wastestream still poses a challenge. The oils are taken from the top of the tank and are returned to the separation train for treatment. With a high water and solids content in the oil, a pad forms at the oil/water interface in the separators making efficient separation difficult. Acids have to be injected into the interface to treat the problem, but this alters the feed water pH and the filter unit has to be shut down while this is being done. The solids being discharged from the bottom of the tank are not oil wet and can go directly overboard.

The unit remains a complex and sensitive piece of equipment to operate and maintain. It requires highly trained operators to run and fault find the unit. It has to run under constant flow and chemically stable upstream conditions. The recent breakdowns have raised the question of long-term reliability.

SUMMARY

The new ceramic filter has resolved many of the original problems found with unit #1; however, after six months of use, reliability problems are starting to occur with the equipment.

Based on Marathon's operating experience with Alcoa's Petrolox TM ceramic membrane filtration unit on the B platform of Eugene Island Block 349, the technology is not considered available for filtering of a total produced water stream for the following technical reasons:

- The unit cannot respond to dynamic flow.

- The process is chemically sensitive.

- The system has no long-term proven reliability.
- Handling of the ancillary waste streams generated by the unit have not been fully resolved.
- Insufficient data is available on different types of waters and the changing water chemistry during the life of a platform.

The true cost of such a system is also unclear.

A correctly cleaned ceramic filter does, under the proper chemical conditions and steady flow rate, produce a high quantity permeate product.

FURTHER REFERENCES

For further reading on operational experience, reference should be made to:

> Industry's Field Experience With Membrane Filtration Technology prepared by Jenny C. Yang, Ph.D., Marathon Oil Company, Houston, Texas, and James P. Meyer, Ph.D., ARCO Oil and Gas Company, Plano, Texas, dated June 1991.

For technical information on the ceramic membranes, reference should be made to:

> Alcoa Separations Technology, Inc.
> Subsidiary of Aluminum Company of America
> 181 Thorn Hill Road
> Warrendale, Pennsylvania

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OFFSHORE OPERATORS COMMITTEE STUDY OF FLOTATION SYSTEMS

Dr. Michael T. Stephenson
Texaco Inc.

The Offshore Operators Committee (OOC) is an organization of 58 companies who conduct essentially all of the offshore oil and gas exploration and production activities in the Gulf of Mexico. As part of an effort to assist the member companies in responding to regulatory pressures, the OOC undertook a study of offshore platforms using gas flotation technology for the treatment of produced water. There were several purposes for this study. In addition to obtaining a better understanding of gas flotation, there was also a desire to increase the U.S. Environmental Protection Agency (EPA) database for oil and grease analysis. The EPA database (EPA Method 413.1) for produced water from gas flotation consisted of approximately eight platforms. The OOC also wanted to assist the EPA in creating a database for the silica gel method (Standard Method 5520 F) for produced water. The reason for the creation of this new database was because the OOC had developed data to show that the materials affected by the silica gel are naturally occurring, have been measured as non-toxic against mysid shrimp, and cannot be removed by current technology, including gas flotation.

The study was based upon the study of platforms that met certain criteria which had been established by the EPA. It was necessary that the platforms use gas flotation for the treatment of produced water, that the platforms use properly applied chemical treatment to enhance the separation process, and that they be in compliance with current guidelines. Additionally, OOC also required that the platforms be in the Outer Continental Shelf (OCS). Of the 56 platforms nominated by the operators, 44 were chosen and 42 were actually able to participate. The platforms were geographically distributed from the Main Pass to the High Island area in the Gulf of Mexico with one platform off California. The platforms were operated by 12 different operators.

The sampling plan was designed to collect samples from each platform on each of three different sampling episodes. The sampling episodes were to be at least a week apart. Triplicate samples were taken for both EPA Method 413.1 and Standard Method 5520 F during each episode. There was a total of 18 individual analyses performed for each platform. All of the samples were analyzed by only one laboratory in order to reduce inter-laboratory variability. There was also a follow-on effort to collect samples that were not refrigerated in order to determine whether the requirement to refrigerate produced water samples is necessary.

As a result of conducting this study, the EPA database for Method 413.1 was increased by 64 platforms. There were 42 platforms from this study, 10 platforms from a previous study, and 12 platforms from the refrigeration study. Also, the EPA now has a 52 platform database for Standard Method 5520 F. There were the 42 platforms from this study and 10 platforms from the previous study. Additionally, EPA was provided with data about the necessity for refrigeration to preserve produced water. The OOC statistician used trimmed data from the databases to properly calculate discharge limits for each method.

OOC Calculated Discharge Limitations

Oil & Grease Method	99% Monthly Average (mg/l)	99% Daily Average (mg/l)
EPA Method 413.1	72	96
Std Method 5520 F	35	68

The statistician also evaluated the refrigeration data and found no significant effect of refrigeration over non-refrigeration using three different statistical tests to find a difference.

Finally, equipment loading impacts were evaluated. Unfortunately, the data did not show any apparent correlations between the loading of the flotation device and oil & grease (Figure 5.9), suspended oil (Figure 5.10), or non-hydrocarbon organic materials (Figure 5.11). The data appear to show that the key to efficient treatment of produced water to remove oil is:

- Minimizing the shearing of oil droplets into the water during the production process,
- Clean, efficient operation of the gas flotation equipment, and
- Efficient use of appropriate flocculation and coagulation chemicals in the gas flotation equipment.

As a result of this study, OOC petitioned EPA to change the analysis method for oil and grease in produced water from EPA Method 413.1 to Standard Method 5520 F. The OOC also requested EPA to delete the refrigeration for the preservation of produced water samples for oil and grease analysis.

Therefore, the OOC feels that the EPA should change the analytical method for oil and grease in produced water and delete the requirement for refrigeration of produced water samples for oil and grease analysis. Additionally, operators should be aware of droplet shear in their production systems and ensure that water treating chemicals are being used properly.

Dr. Michael Stephenson received a Ph.D in physical organic chemistry from Texas Tech University in Lubbock, Texas, in 1981. Since that time, he has worked for Texaco in the treatment of oil for sales, produced water for discharge or injection, scale prevention and removal, bacteria control, and paraffin and asphaltene control. Most recently, Dr. Stephenson has focused his attention on the environmental aspects of exploration and producing operations.

CHANGES IN EXXON'S GRAND ISLE PRODUCED WATER DISPOSAL SYSTEM

Mr. Lawrence D. Ziems
Exxon Company, USA

Exxon is preparing to start up upgraded produced water treating and injection facilities at Exxon Pipeline Company's Grand Isle, Louisiana Terminal.

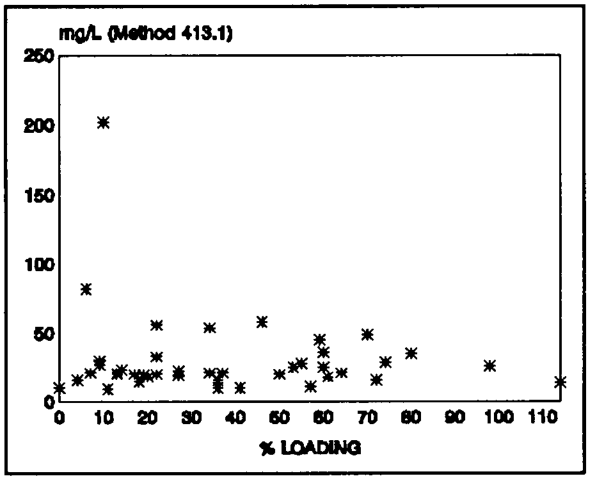

Figure 5.9. Oil and grease.

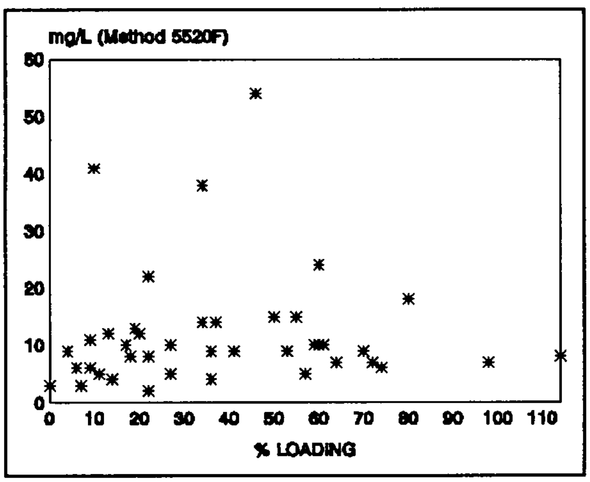

Figure 5.10. Suspended oil.

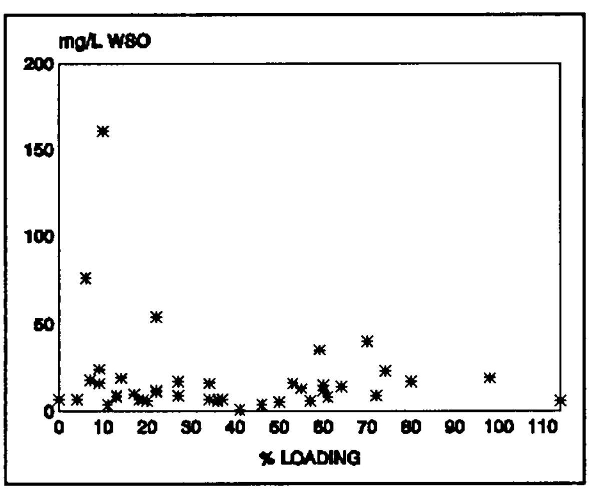

Figure 5.11. Water solubles.

These facilities, including one injection well, represent Phase I of a two-phase project which will result in the elimination of the surface discharge of produced water at this terminal. This paper describes the existing treating facilities and summarizes the factors and rationale which led to the installation of the upgraded water treating and injection facilities.

Exxon began producing in the Gulf of Mexico offshore Grand Isle in the late 1940's. This production (oil and water) flowed to a treating terminal on Grand Isle where the oil and water were separated, and the water was discharged into the surface waters of Bayou Rigaud to the north. Exxon's development off Grand Isle has grown to include production from seven fields ranging from the South Timbalier area to Mississippi Canyon. Oil and water from these fields still flows to the Grand Isle Terminal along with some production from other operators. As each new field was added, a conscious decision was made to continue flowing oil and water to Grand Isle because the treatment facilities there could economically be expanded to handle the increased volumes. Production is currently in the range of 60 thousand barrels of oil and 30 thousand barrels of water per day.

The existing Grand Isle facility is primarily a gravity separation treating facility. The oil and water flow to settling tanks from which the separated water is pumped to a skim pit prior to being discharged to open waters. This system currently produces effluent water with total oil and grease content generally below 40 mg/liter.

In early 1990, while negotiating a discharge permit, Exxon made a commitment to the Louisiana Department of Environmental Quality to eventually eliminate the discharge of produced water into Bayou Rigaud. Exxon was subsequently granted a discharge permit for the Grand Isle Terminal which required the elimination of the discharge by early 1994.

Exxon generated and evaluated alternative water disposal scenarios ranging from total offshore discharge to disposal via subsurface injection at Grand Isle. The Grand Isle injection alternative was selected primarily because it provided the lowest risk of exceeding discharge limits and because it was not subject to uncertainties associated with effluent limitations imposed by unknown future regulations. Treating all of the water at one location also resulted in a more efficient design when compared to multiple, smaller, offshore water treating facilities.

The upgrades to the Grand Isle treating facility include the addition of induced gas flotation equipment, media filtration, clear water holding tankage, injection pumps, and injection wells. Water will enter the new facilities directly from the existing skim tank and the skim pit will be eliminated. Phase I of the project, which will start up in December 1991, consists of a flotation cell, media filter, and holding tank, each with capacity to handle 100 percent of water production, along with one 800 HP injection pump and one injection well. The injection well is completed in a sand formation via cased hole gravel pack approximately 6,800 feet below the surface.

Plans are to operate Phase I for several months, gathering performance data on the treating equipment and the disposal well. This information will be used to optimize design of Phase II which will include additional treating equipment, pumps, and injection wells. The completed system will have capacity to handle all of the water plus an appropriate level of backup capacity to ensure uninterrupted operation. Startup of Phase II and the elimination of the Grand Isle discharge point is scheduled for early 1994.

Mr. Lawrence D. Ziems, P.E., is currently assigned to Exxon Company, USA's Offshore Production Division as a staff engineer in the Operations Regulatory and Environmental group. He has been with Exxon 11 years and has worked with the design, installation, and operation of offshore oil and gas production facilities throughout his career. Mr. Ziems received his Bachelor's degree in civil engineering from Virginia Polytechnic Institute and State University in 1980.

OIL SPILLS RESPONSE

Session: OIL SPILLS RESPONSE

Co-Chairs: CAPT William J. Loefstedt
Ms. Darice Breeding

Date: November 6, 1991

Presentation	Author/Affiliation
Oil Spills Response: Session Introduction	CAPT William J. Loefstedt Eighth Coast Guard District Marine Safety Division and Ms. Darice Breeding Minerals Management Service Gulf of Mexico OCS Region
Bioremediation for Marine Oil Spills	Mr. William E. Westermeyer U.S. Congress Office of Technology Assessment
Adaptation of the Minerals Management Service's Oil Weathering Model for Use in the Gulf of Mexico	Dr. Bruce E. Kirstein Chemical and Process Engineering Associates
Oil Spill Contingency Planning for Trust Resources of the U.S. Fish and Wildlife Service	Dr. Brian Cain U.S. Fish and Wildlife Service
Contingency Planning for the Treatment of Oiled Birds	Ms. Lynne Frink Tri-State Bird Rescue & Research, Inc.
Update of Clean Gulf Associates' Spill Response Planning	Ms. Belinda V. Breaux ARCO Oil and Gas Company
Marine Spill Response Corporation: An Update	Mr. Robert Allred Marine Spill Response Corporation
Shoreline Cleanup Assessment Team Applications in the Gulf of Mexico	Ms. Karolien Debusschere, Dr. Shea Penland, Ms. Karen Ramsey Louisiana Geological Survey Dr. Ed Owens and Dr. Ivor van Heerden Woodward-Clyde Consultants
Recent Oil Spill Response Initiatives at LOOP, Inc.	Ms. CaSandra J. Cooper-Gates Environmental & Regulatory Affairs LOOP, Inc.

(Continued)

Session: OIL SPILLS RESPONSE (continued)

Presentation	Author/Affiliation
Oil Spill Response Research and Development: Update on Oil Pollution Act of 1990 and Federal Initiatives	CDR Pete Tebeau Research and Development Center U.S. Coast Guard
Minerals Management Service Oil Spill Research: An Update	Mr. Joseph V. Mullin II Minerals Management Service Technology Assessment and Research Branch

OIL SPILLS RESPONSE: SESSION INTRODUCTION

CAPT William J. Loefstedt
Eighth Coast Guard District
Marine Safety Division
and
Ms. Darice Breeding
Minerals Management Service
Gulf of Mexico OCS Region

Presentation Text Summary not submitted.

CAPT William J. Loefstedt is presently serving as the Chief, Marine Safety Division for the Eighth Coast Guard Division, New Orleans, Louisiana. This district extends from St. Marks, Florida, to Brownsville, Texas. He oversees the work of seven Coast Guard Marine Safety Offices in inspections of vessels, investigation of marine casualties, port safety and security matters, pollution prevention, preparedness, and response. CAPT Loefstedt serves as the cochair of the Region 6 Regional Response Team. He has previously served as Commanding Officer of Marine Safety Offices in Memphis, Mobile, and New Orleans. CAPT Loefstedt is a 1963 graduate of New York State Maritime College with a B.S. in marine transportation and in 1979 earned a Master's degree in public administration from the George Washington University.

Ms. Darice Breeding

BIOREMEDIATION FOR MARINE OIL SPILLS

Dr. William E. Westermeyer
U.S. Congress
Office of Technology Assessment

Tragic as it was, the 1989 *Exxon Valdez* oil spill had the positive effect of stimulating a search for more effective technologies to fight marine oil spills. The possibility of using the capabilities of oil-degrading microorganisms to accelerate the natural biodegradation of oil, a process known as bioremediation, has drawn particular attention. Although using bioremediation as an oil spill response technology has been discussed for years, it has been only recently that some of the practical problems associated with this idea have begun to be investigated. The *Exxon Valdez* spill gave researchers an opportunity to evaluate the feasibility of using bioremediation to accelerate the biodegradation of oil stranded on Alaska beaches.

There are three different bioremediation approaches. Fertilization is the bioremediation method of adding nutrients, such as nitrogen and phosphorus, to a contaminated environment to stimulate the growth of indigenous oil-degrading microorganisms. Seeding refers to the addition of oil-degrading microorganisms to a spill site. Such microorganisms may or may not be accompanied by nutrients. Current seeding efforts use naturally-occurring microorganisms. Seeding with genetically engineered microorganisms may also be possible, but this approach is not currently being considered for remediating oil spills.

Bioremediation could provide an additional response tool for some oil spills. Nevertheless, there are still many uncertainties about the use of bioremediation as a practical oil spill response technology and its ultimate importance relative to other oil spill response technologies remains uncertain. Fertilization is the approach that has been tested most rigorously. This approach is currently viewed by many researchers as the most promising one for those situations in which bioremediation might be considered, in part, because the rate of biodegradation is usually constrained by the lack of sufficient nutrients in most marine environments.

Most scientists are more skeptical about the likely success of seeding a spill with microorganisms, in large part because the requirements that must be met for successful seeding are much more demanding than those for fertilization. Many scientists also question the need to add microorganisms to a spill site, since few ecosystems are without an adequate supply of oil-degrading microbes. If the native organisms grow too slowly or if they cannot degrade a certain hydrocarbon, introduced organisms with the appropriate attributes could possibly be beneficial. Effective seeding has not been demonstrated in realistic marine spill conditions.

The wide availability of naturally-occurring microorganisms is also likely to deter seeding with genetically engineered microorganisms. Moreover, greater research and development needs, regulatory hurdles, and public perception problems will remain obstacles to the near-term use of genetically engineered microorganisms even if they could prove

bioremediation technologies will be safe in all circumstances.

More development and testing of both fertilization and seeding technologies are needed before on-scene coordinators or others responsible for oil spill cleanup would be comfortable advocating their use. Some of the important research needs include: improving methods for enhancing the growth and activity of petroleum-degrading bacteria;

ADAPTATION OF THE MINERALS MANAGEMENT SERVICE'S OIL WEATHERING MODEL FOR USE IN THE GULF OF MEXICO

Dr. Bruce E. Kirstein
Chemical and Process
Engineering Associates

The Minerals Management Service's open-ocean oil-weathering model has been extensively modified and adapted for use on a personal computer. The modifications include the use of variable wind speed as an independent variable, the conversion of crude-oil subatmospheric distillation temperatures to one atmosphere, and the conversion of Saybolt Seconds (bulk) viscosity to centipoise. All these modifications make the model easier to use and alleviate the user from some of the more cumbersome input-data preparation details.

The use of variable wind speeds in the oil-weathering prediction is based on the use of a wind-speed table. The model uses a specified wind speed for a specified time (or duration). The wind-speed tables used here are examples derived from hourly buoy data from the Gulf of Mexico. Wind data from the Navy's collection of twice-daily 1° gridded wind components for the Gulf of Mexico are also discussed. The sea-surface temperatures used, and hence the oil temperature, are from monthly compilations of these temperatures for the Gulf of Mexico.

Crude-oil characterizations pertinent to the Gulf of Mexico are obtained (by modem) from the U.S. Department of Energy's Crude Oil Data Bank in Bartlesville, Oklahoma. This database is extensive and contains over 9,000 analyses including Louisiana offshore fields. Refined petroleum products which are shipped through the Gulf of Mexico are also discussed here and estimates of their physical properties pertinent for oil-weathering predictions are given.

The software codes developed to implement variable wind speed for oil-weathering predictions are all written in Basic and will run on any personal computer. The only special case is the oil-weathering routine which should be run as a compiled and linked .EXE file.

Dr. Bruce E. Kirstein received a Ph.D. in 1972 in chemical engineering from the California Institute of Technology and a B.S. in 1966 in chemical engineering from the University of Illinois/Urbana. Dr. Kirstein is a chemical engineer with 18 years experience in the areas of chemical process design, prediction of physical properties, and the conduct of bench-scale and pilot-scale experiments for both industrial and environmental processes. He has extensive experience in the field of oil-weathering predictions and crude oil physical properties predictions. Dr. Kirstein wrote the first oil-weathering model which utilizes industrial crude oil inspections. He also has experience in the fields of radionuclide transport through porous adsorbing media, radionuclide transport in the human body, filtration phenomenon, off-gas treatment for environmental control, and physical properties prediction in support of process and environmental predictions.

OIL SPILL CONTINGENCY PLANNING FOR TRUST RESOURCES OF THE U.S. FISH AND WILDLIFE SERVICE

Dr. Brian Cain
U.S. Fish and Wildlife Service

Presentation Summary text not submitted.

Dr. Brian Cain has been employed as an Environmental Specialist with the U.S. Fish and Wildlife Service since 1982. His duties include serving as the Texas Coastal Spill Response Coordinator for Region 2 Oiled Wildlife Rehabilitation Coordinator for Texas, and Habitat Restoration Coordinator. Dr. Cain is also responsible for the contingency plan review and input for four Coast Guard Stations, and contaminant assessment for NPL sites, Federal Projects, and Discharges.

CONTINGENCY PLANNING FOR THE TREATMENT OF OILED BIRDS

Ms. Lynne Frink
Tri-State Bird
Rescue & Research, Inc.

INTRODUCTION

Tri-State Bird Rescue & Research, Inc. was founded in 1976 and is currently one of two licensed organizations in the United States experienced in providing training programs, contingency planning, and rehabilitation responses for contaminated wildlife following major oil spills.

The effects of oil spills on wildlife can be dramatic and devastating. And, it is just this drama and this devastation that present the biggest obstacles to understanding how oil affects wildlife.

The sight of an oiled bird or otter struggling to shore elicits a tremendous emotional response from human beings. And, in the face of this emotional response, the biological, technical, and medical needs of the affected animals are often over-shadowed by an over-whelming urge to help.

This has resulted in some disastrous efforts to care for oiled wildlife. Birds have been dipped in melted butter, rolled in hot wax, dunked in kitty litter and lard, and plucked, all with tragic consequences.

REHABILITATION OF OILED ANIMALS

Rehabilitation of oiled animals is a medically complex and strategically challenging undertaking. If oiled birds are going to undergo rehabilitation, then the effort must be a serious professional endeavor and not a makeshift response by good-hearted but inexperienced volunteers.

The success with which oiled birds can be treated depends on three factors: the type of oil encountered, the species of bird contaminated, and the qualifications of those undertaking the rehabilitation effort.

External Effects

The external effects of oil on birds are the most noticeable and most immediately debilitating. Oil destroys the waterproofing and insulating properties of the plumage. The bird becomes chilled, unable to stay afloat in water, and, often, unable to fly. It has difficulty foraging for food or escaping predators.

In the past, all efforts have concentrated on treating the external effects by removal of the oil.

Internal Effects

The internal effects of oil, while not as apparent, are equally life-threatening. The bird may ingest oil while attempting to clean its feathers through preening. Ingested oil can result in ulceration and hemorrhaging in the gastrointestinal tract. Toxic components of the oil can be inhaled or can be absorbed through the intestinal wall or the skin. Dysfunction and damage can occur to the pancreas, liver, and kidney or respiratory system (Leighton 1991; Dein 1986). These internal effects must be treated immediately by an experienced oil spill response team.

TREATMENT

With the supervision of an oil-spill experienced, professional staff, each bird receives a complete physical examination, a leg tag, and an individual medical record. Oil is removed from the mouth and nares. The eyes are flushed with a sterile ophthalmic solutions. Blood samples should be taken at this time to assess packed cell volume and total solids.

A number of birds are severely dehydrated as a result of intestinal hemorrhage. Destruction of the intestinal wall results in the animal being unable to utilize food and water. These birds receive bolus injections of intravenous fluids which rehydrate the animal and provide limited nourishment. Less seriously affected birds receive nutrients via a stomach tube. The gastrointestinal tract is flushed to remove oil.

The bird is kept quiet, warm, and away from external stressors such as people while it stabilizes and awaits the strenuous cleaning process.

Oil must be removed from the feathers without damaging the delicate feather structure. Enormous quantities of hot water are needed; over 150 gallons of 104°F. water are needed to wash and thoroughly rinse one Canadian goose. Specialized cleaning procedures incorporate three or more large tubs of hot water and a 2-10 percent detergent solution. Many cleaning agents have been promoted for use in cleaning oiled animals. Very few work. Extensive testing of agents, courtesy of the DuPont de Nemours Company located in Wilmington, Delaware, indicates that Dawn dishwashing detergent manufactured by Procter & Gamble is the most effective agent at removing oil and is also the easiest cleaning agent to rinse off of the feathers.

The feathers must be completely rinsed with hot water under pressure. Any detergent residue will prevent waterproofing. The bird is not completely rinsed until diamond-like beads of water roll freely from the feathers and the feathers begin to look "dry."

Full details of treatment protocols, special equipment needs, and organizational strategies are described in Tri-State's booklet, "Oiled Bird Rehabilitation: A Guide for Establishing and Operating a Treatment Facility for Oiled Birds."

The above treatment protocol discussed basic care for a single animal. To care for 50, 100 or 500 birds in need of immediate treatment poses severe logistical and equipment challenges. To care for 100 birds over a single day would require three 8-hour shifts with an absolute minimum of 25 people/shift to provide medical care, wash teams, rinse teams, and facilities management. Cleaning teams would need 8,000 gallons of hot water under pressure. Provision would have to be made for environmentally acceptable disposal of 5,000 gallons of oily, soapy wastewater.

There is not time in this presentation to discuss OSHA compliance, human safety concerns, liability insurance, damage assessment protocols, and the very important techniques for preventing animals from becoming contaminated (Welte 1990).

When interagency planning has been done in advance of a spill, it is possible to design procedures to minimize the impact of oil on wildlife. It is possible to streamline communication so that retrieval of oiled animals can be quickly and correctly carried out. And, it is possible to incorporate an experienced management team into the wildlife response. When the rehabilitation effort is managed by an experienced oil spill response team, oiled bird rehabilitation has been carried out, with particular success in Anatidae species, averaging over 90 percent release of ducks and geese.

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Welte, S. and L.S. Frink. 1990. Rescue and rehabilitation of oiled birds. Waterfowl Management Handbook, U.S. Fish and Wildlife, Washington, D.C. Service Publication 13.2.8.

Ms. Lynne Frink is the Director of Tri-State Bird Rescue & Research, Delaware. This wildlife rehabilitation/research facility has 15 years experience in training and response to major oil spills in North America.

Most recently, Ms. Frink was requested by the United Nations to lead a 6-person team to travel to Saudi Arabia and provide wildlife training and response following the oil spills in the Arabian Gulf. Her most recent publication in this field is a chapter on rehabilitation of oiled birds for the U.S. Department of Interior's *Waterfowl Management Handbook*.

UPDATE OF CLEAN GULF ASSOCIATES' SPILL RESPONSE PLANNING

Ms. Belinda V. Breaux
ARCO Oil and Gas Company

The primary objective of Clean Gulf Associates (CGA) is to assure that adequate response capabilities exist for member companies' oil spills in the Gulf of Mexico. The CGA therefore maintains an ongoing process of assessing and upgrading response capabilities according to the needs of members. Recent additions to the CGA stockpile include three identified boats equipped for ocean skimming and 18,000 feet of open ocean boom. In addition, modifications to existing equipment have been made which result in improved response times and operability of equipment. Also to be placed in inventory are a fourth identified boat, 10,000 feet of shoreline protection boom, and two shallow water skimmers.

BACKGROUND OF CGA

The CGA is a spill cooperative established in 1972 by 33 oil and gas exploration and production companies then operating in the Gulf of Mexico. Current membership includes 139 offshore oil and gas companies. The purpose of the organization is to establish a plan for containing and cleaning up oil spills of members involved in operations offshore. The organization has purchased and maintains a stockpile of offshore oil spill cleanup equipment for use by member companies and provides operations manuals and training on the use of the equipment for each member company. Funds needed to maintain CGA are divided between the member companies based on a formula which takes into consideration each member's oil production. The amount and type of equipment stockpiled is predicated on the potential needs of the membership. The equipment is intended to handle the likely drilling or production spills, with worst case being a blowout situation. Equipment stockpiles are maintained at strategic locations throughout the Gulf of Mexico coast.

Membership in CGA is limited to oil and gas operators in the Gulf of Mexico. Only companies engaged in the exploration and production of oil and gas within the given boundaries of the Gulf of Mexico are allowed to be members; therefore, pipeline companies, marine transportation companies or other users of the Gulf of Mexico are not members of CGA but may have access to CGA equipment through their oil and gas affiliate companies. Non-members may use CGA equipment upon approval by the Executive Committee. In fact the largest spill response in which CGA equipment has ever been utilized was the *Mega Borg* spill in 1990. The CGA was in the process of adding to the equipment inventory prior to the *Mega Borg* incident, but experience gained in this event was used to modify existing equipment in order to optimize performance.

The CGA is guided through the efforts of a full-time Executive Director and a "voluntary" Executive Committee made up of executives from nine member companies. Assisting the Executive Committee are the Legal, Accounting, Operations, and Technical Subcommittees as well as Ad-Hoc committees that are formed as needed. Halliburton Services, Inc. serves as the contractor to purchase and maintain the equipment, to provide supervisory personnel, to provide training, and to perform certain administrative functions. There are 10 full-time Halliburton personnel dedicated to CGA serving as marine supervisors and mechanics in addition to one administrative person.

The initial equipment inventory in 1972 included one high volume open sea skimmer, one fast response over-the-side skimmer (FRU), one shallow water skimmer, 1,000 feet of boom, and miscellaneous smaller items. The current CGA stockpile includes the HOSS barge, 12 FRU's, 3 identified boat skimming systems, 6 boat spray systems, 6 helicopter underslung sprayer systems, 39,375 gallons of dispersant, 3 self-propelled shallow water skimmers, 18,000 feet Expandi-4300 Ocean boom, 5,000 feet of 36-inch nearshore boom, a communications system, a portable biological and chemical field sampling unit, a waterfowl rehabilitation station, bird scare guns, sorbent material, and miscellaneous auxiliary equipment. The current assets of CGA are on the order of $12 million, with a replacement cost of $21 million.

NEW EQUIPMENT

In order to keep in step with the needs of operators in the Gulf of Mexico and to continue to improve upon our response capabilities, CGA has over the last two years embarked on a major capital program. The additions to the CGA stockpile that have been completed include three skimming systems mounted on existing identified offshore service vessels (ID boats) and 18,000 feet of Expandi-4300 open ocean boom. A fourth ID boat, 10,000 feet of shoreline protection boom, and two shallow water skimmers will be placed in CGA inventory in the near future.

An ID boat is a utility vessel under charter to an oil company in the Gulf of Mexico on which skimming equipment is mounted by CGA for use by member companies as a first response to a spill in the area. The concept of mounting skimming equipment on dedicated vessels was considered, but the idea of mounting the equipment on a vessel that is operating offshore in critical oil producing regions actually results in an improvement in response times over the shore-based dedicated boat. The boats are strategically located in areas with a high concentration of oil production as follows:

ID Boat	Oil Co.	Boat	Location
#1	Shell	Cecelia C	South Timbalier 26
#2	Mobil	Autry G	West Cameron 71
#3	Texaco	John Michael G	South Marsh Island 240

A skimming system including a crane, power pack, outrigger and boom, GT-185 skimmer (design rating 200 gpm), and 2,100 gallon oil separator are skid-mounted on each vessel. There are also 500 feet of Expandi-4300 open ocean boom stored on the vessel to be used for containment in conjunction with the skimming operations.

In the event of a spill by a member company, the member would call the Halliburton dispatcher for release of the ID boat and upon approval by a member of the Executive Committee or the Executive Director, Shell (or Mobil or Texaco) would release the vessel to respond to the spill. The ID boat would be the first responder to the incident and remain until the CGA FRU reaches the location. Then the ID boat would be returned to service for the operator.

Another major investment by CGA is the purchase of 18,000 feet of Expandi-4300 open ocean boom. Between 1,500 to 3,000 feet of the boom are stockpiled at each of the CGA bases. The basis for choosing the Expandi boom was that it is compactly stored and is easily deployed and retrieved. The boom can be deployed off the back of a workboat to contain an area of floating oil for subsequent skimming. As mentioned previously, an additional 500 feet of Expandi boom will be located on each of the ID boats for rapid deployment at a spill site.

In addition to the open ocean boom, the purchase of 10,000 feet of shoreline protection boom has been approved by the Executive Committee. The boom is a tricompartment boom with two water containing sections on bottom and an air-filled section above. The purpose of the boom is to isolate an oiled section of beach from a clean or biologically sensitive area to protect the adjacent areas from being oiled.

Another planned addition to the CGA stockpile are two additional shallow water skimmers. The skimmers selected for purchase are EGMOPOL 1041 DAHSWA. These skimmers were selected based on their durability, storage capacity, shallow draft, unmanned operation potential, and ability to handle weathered oil.

AERIAL DISPERSANT APPLICATION CAPABILITY

Several possibilities for cooperative arrangements of dedicated aircraft to be available to CGA membership for dispersant application are being considered. One possibility is a shared arrangement with LOOP for the DC-3 and DC-4 aircraft they have under contract. The CGA is also considering a proposal from a private firm for a smaller aircraft.

EQUIPMENT MODIFICATIONS

Modifications and improvements are made within CGA when situations and experience warrant. Many of the following modifications were made at the recommendation of operators after use of the equipment at either a training exercise or during a spill response.

- Dispersant Boat Spray System - A recent assessment of the existing boat spray system by Mr. Gordon Lindblom is being reviewed by the Technical Subcommittee.

- HOSS Barge - Modifications planned include an emergency shelter area for crew, reduction of labor needs by changing the type of boom used, and improved communication and navigation systems.

- Communications Systems - An Ad Hoc Committee was formed in 1991 to assess the needs for communications systems for use by member companies in spill response. Experts from several oil companies participated on this committee and developed a proposal for the upgrade of the CGA communications equipment. We will be adding several cellular phones, a multiple voice radio system and a facsimile machine, an aviation base station, and LORAN equipment for the HOSS barge.

BIOLOGICALLY SENSITIVE AREA MAPS

The CGA has been investigating possible sources for updating and improving on the maps of biologically sensitive resources located along the Gulf of Mexico coast. A comparison of available and currently developing computerized systems which would also provide trajectory and dispersant decisionmaking capabilities was reviewed by CGA. The CGA is currently in the final negotiating stages of purchasing the MIRG - S.L. Ross oil spill trajectory model through MIRG. The computer-based model incorporates trajectory models for both dispersed and untreated oil and an oil fate model and includes an impact assessment system.

SUMMARY

In summary, CGA is continuing to assess its spill response capabilities based on member company needs and is making appropriate modifications and additions to the equipment stockpile. Significant new equipment purchases have been made in the past two years and are underway for the near future. These include the ID boats, open ocean boom, shoreline protection boom, and shallow water skimmers. Modifications to existing equipment are also made as indicated by the needs and experiences of member companies.

Ms. Belinda V. Breaux has been employed by ARCO Oil and Gas Company for the past six years and is presently the Supervisor of the Regulatory Compliance and Environmental Department in the Southern District. She is also serving as chairman of the Technical Subcommittee of CGA and has been a member of the committee since 1986. Ms. Breaux received a B.S. in chemical engineering from Lamar University in 1981.

MARINE SPILL RESPONSE CORPORATION: AN UPDATE

Mr. Robert Allred
Marine Spill Response Corporation

Presentation Summary text not submitted.

Mr. Robert Allred is the External Affairs Manager for the Gulf Region of the Marine Spill Response Corporation (MSRC) headquartered in Lake Charles, Louisiana. He has worked in public affairs/public relations for 10 years and has been with MSRC since April 1991. Prior to coming to MSRC, he did public relations for both Baylor University and Stephen F. Austin State University in Nacogdoches, Texas, and holds a B.S. degree in advertising.

SHORELINE CLEANUP ASSESSMENT TEAM APPLICATIONS IN THE GULF OF MEXICO

Ms. Karolien Debusschere,
Dr. Shea Penland,
Ms. Karen Ramsey
Louisiana Geological Survey,
Dr. Ed Owens
and
Dr. Ivor van Heerden
Woodward-Clyde Consultants

BACKGROUND

The recent oil spill experiences in Alaska, California, and the Gulf of Mexico demonstrated that the effectiveness of a rapid cleanup response effort was dependent on the evaluation of the shoreline oiling conditions using field teams to collect the data within a systematic framework. Without this database, the accurate forecasting of cleanup logistics cannot be made and the approval of environmentally accepted cleanup and treatment methods will not be authorized by the responsible state and federal agencies. The involvement of state and federal agencies as well as the appropriate land managers is very important in the shoreline cleanup assessment process and is the key to facilitating rapid consensus on the most appropriate cleanup or treatment method. By standardizing the shoreline assessment process with other agencies, the accuracy of reporting, terminology, and map bases increases, and, in turn, reduces the potential for conflicting reports and misinformation. Miscommunication and inaccurate oil spill interpretations only hamper and delay shoreline cleanup approval. The goal of the Gulf of Mexico Oil Spill Research and Response Program is to develop an oil spill assessment program, in cooperation with the responsible state and federal agencies, based on the Exxon model used in the *Valdez* oil spill in Prince William Sound and the Gulf of Alaska (Teal 1990; Owens 1991; Owens and Teal 1990; Knorr *et al.* 1991; Teal 1991). By preplanning a shoreline cleanup assessment program, we intend to establish a cooperative working relationship with the state and federal agencies in order to expedite rapid concurrence and approval for cleanup to proceed.

EXXON VALDEZ SCAT PROGRAM

In response to the *Valdez* oil spill in Prince William Sound and the Gulf of Alaska, Exxon established command centers in Valdez, Seward, Homer, and Kodiak to coordinate the flow of information in support of the cleanup effort. Representatives from state, federal, and other major land managers were organized into committees called Interagency Shoreline Cleanup Committees in Valdez and Kodiak, and Multi-Agency Committees in Seward and Homer. The Interagency Shoreline Cleanup Committees and Multi-Agency Committees worked with Exxon and the U.S. Coast Guard to set cleanup and treatment priorities in Prince William Sound and the Gulf of Alaska. Three critical pieces of information remained out of reach of the cleanup operations: (1) the type of shoreline oiled (cliff, beach, cobble, sand), (2) the type of ecological resources (coastal/marine communities, cleanup concerns), and (3) the type of oiling (morphology, distribution) in Prince William Sound and the Gulf of Alaska. With more than 8,000 km of coastline in the Prince William Sound and Gulf of Alaska, Exxon and the interagency committees were uncertain as to how much of Alaska's shoreline was impacted by oil and what the oil character was. In response to this information void, Woodward-Clyde Consultants organized teams of coastal geologists, coastal ecologists, and archaeologists for Exxon in order to map and collect site-specific information. These interdisciplinary teams eventually became known as Shoreline Cleanup Assessment Teams (SCAT). The SCAT teams working out of Valdez, Cordova, Seward, Homer, and Kodiak Island ultimately surveyed every meter of oiled shoreline in Prince William Sound and the Gulf of Alaska.

During 1989, the location and degree of oiling was independently assessed by the Alaska Department of Environmental Conservation and the U.S. Coast Guard (USCG) as well as Exxon. These independent assessments produced conflicting reports and interagency confusion that slowed down the cleanup operations. Eventually as the spill response activities progressed during the summer of 1989, it was the data from the systematic EXXON SCAT survey program that served as the primary input used by the Interagency Shoreline Cleanup

Committees and Multi-Agency Committees for making specific recommendations. In 1990, the state and federal agencies agreed to Exxon's initiative to conduct cooperative shoreline assessments. Exxon's goal was to foster interagency coordination and consensus. Exxon's interagency 1990 Spring Shoreline Assessment Team program was very successful in improving the working efficiency between the various agencies and groups in support of cleanup operations.

An early and important part of the SCAT process was the aerial videotape mapping program. The SCAT aerial videotape survey crews consisted of a pilot, a navigator, and a coastal geologist that videotaped contiguous sections of shoreline in a helicopter to conduct initial assessments of shoreline character and the degree of oiling. The coastal geologists served as the cameramen and provided geomorphology and oiling commentary. This preliminary information was used by SCAT to prioritize shorelines for survey. The SCAT evaluations were sent back from the field to Valdez or Kodiak, where they were quickly analyzed to develop cleanup recommendations and constraints that were in turn submitted to the Interagency Shoreline Cleanup Committees/Multi-Agency Committees for review, then forwarded to the Federal OnScene Coordinator (FOSC) for approval. Due to obvious time constraints, this information flow was compressed into as short a time as possible. Complicating the process was the fact that much of the baseline geological, biological, and cultural data had not been compiled by the respective land-managing agencies prior to the oil spill. As a result, the inventory data for accurate shoreline assessment was collected in the midst of the oil spill emergency in Prince William Sound and the Gulf of Alaska. Over 8,533 km of shoreline were videotaped and over 5,474 km of shoreline were subjected to SCAT evaluation in an oil spill encompassing parts of Prince William Sound and the Gulf of Alaska.

GULF OF MEXICO OIL SPILL RESEARCH AND RESPONSE PROGRAM

The goal of the Louisiana State University/ Woodward-Clyde Consultants Gulf of Mexico Oil Spill Research and Response Program is to build on the *Exxon Valdez* experience in Alaska in order to develop a preplanned shoreline assessment program in coastal Louisiana, Mississippi, Alabama, and Florida. The major objective of this program is to develop a SCAT program with the capability to conduct an interagency assessment of the geological and ecological impact of oil spills on coastal environments in order to establish rapid concurrence on the most effective and environmentally safe cleanup and treatment methods. Each team will consist of a coastal geologist and ecologist as well as representatives from the responsible federal, state, and private agencies to facilitate a productive and cooperative work effort aimed at mapping the distribution of spilled oil, identifying interagency coastal resource concerns and recommendations, and developing a cleanup strategy based on interagency cooperation and concurrence.

The Louisiana Geological Survey at Louisiana State University and Woodward-Clyde Consultants will support the SCAT response program by providing pre-spill interagency coordination, SCAT preparedness, spill drill participation, training, Geographic Information Systems (GIS) services, and routine aerial videotape surveys. In the event of a spill, Louisiana Geological Survey and Louisiana State University in cooperation with Woodward-Clyde Consultants will support industry by providing SCAT program coordination and team operations. The SCAT program is comprised of four major components: (1) the SCAT Command Center, (2) the SCAT Team Operations, (3) the SCAT Aerial Videotape Survey Team, and (4) the GIS database system.

The SCAT Command Center is housed within the Command Center infrastructure and interfaces with the industry representative. The Louisiana Geological Survey/Woodward-Clyde Consultants personnel will be responsible for team coordination, data compilation, and SCAT report production. The SCAT Command Center will have the facilities to support rapid data reduction from aerial videotape surveys and field reports from the SCAT Teams. The SCAT Command Center manager will be supported by a coastal geologist and a GIS specialist for in-house data reduction.

The mission of the SCAT program is to map the oil spill impact, coastal geology, and coastal ecology in order to make rapid cleanup recommendations. This interagency assessment of the geological and ecological impact of oil spills on coastal environments is designed to establish rapid concurrence on the most effective and environmentally safe cleanup methods. In the development of the SCAT program, Louisiana Geological Survey and Woodward-Clyde Consultants organized meetings with the federal and state agencies in order to establish a line of interagency coordination and communication in Louisiana. In some cases, agencies identified personnel by name or rank to participate in the various functions of the SCAT program. Currently, a SCAT program is being developed in Mississippi and planned in Alabama and Florida.

The SCAT field operations consist of one Management SCAT Team and four Area Teams. The Management SCAT team consists of a coastal geologist (leader) and ecologist with representatives from the appropriate federal, state, and parish agencies in addition to the local land managers, if applicable. Once SCAT is developed in Mississippi, Alabama, and Florida, the appropriate county agencies will be included. The Management SCAT Team is the first to respond to an oil spill and is responsible for providing information for planning and prioritizing the activities of the SCAT field team, environmental protection, and cleanup operations. Based on the initial reports from the Management SCAT Team, the SCAT Command Center will direct the oiling impact assessment in coordination with the Command Center. If the oil spill is large enough, the SCAT Command Center has the capability of mobilizing the SCAT aerial videotape survey team. Coastal Louisiana is divided in four SCAT areas that are bound by the official boundary of Louisiana, the Port Arthur, Morgan City, and New Orleans Marine Safety Office of the Eighth U.S. Coast Guard District (USCG). In the case of the Morgan City Marine Safety Office, it is further subdivided into two SCAT areas due to the large area covered. The Louisiana Geological Survey is currently developing SCAT regions for Mississippi, Alabama, and Florida; however, to date only Louisiana is established. The SCAT Area 1 is within the Port Arthur Marine Safety Office and extends from Texas/Louisiana border to Freshwater Bayou, Louisiana. The SCAT Area 2 is within the western half of the Morgan City Marine Safety Office and extends from Freshwater Bayou, Louisiana to Oyster Bayou, Louisiana. The SCAT Area 3 is within the eastern half of the Morgan City Marine Safety Office and extends from Oyster Bayou, Louisiana to Sandy Point, Louisiana. The SCAT Area 4 is within the New Orleans Marine Safety Office and extends from Sandy Point, Louisiana to the Louisiana/Mississippi border. The Area SCAT Teams are assigned to the four locations. The mission of the four area SCAT teams are to conduct a geological and ecological assessment of an oil spill for making cleanup recommendations.

The SCAT Aerial Videotape Survey System is responsible for conducting a rapid response to document the oil impacted coastal area for SCAT activities and cleanup planning. The SCAT Aerial Survey Videotape Team consists of a coastal geologist serving as the videotape cameraman and shoreline geology and oiling narrator. The navigator is responsible for navigation and 35 mm photography; the flight engineer is responsible for system operation and the flight log. The aerial videotape imagery is used to map the coastal geology and habitats as well as the degree and distribution of oiling. The base maps used for these aerial videotape surveys are the USGS 1:250,000, NOS 1:80,000, and USGS 1:24,000 series.

A GIS will provide more timely and accurate oil spill data by substantially assisting in data maintenance and analysis for contingency planning and spill response. Analysis with a GIS is facilitated by functions that provide interactive and association of features from other spatial information. Data collected by the SCAT Aerial Survey Videotape Team and Area Scat Teams are returned or transmitted to the location of the GIS where analysts will enter the field data. These data will be used for analysis, reports, and measurement of the extent and impact of the spill. The data will provide managers with the necessary information to assess the damage in geographic and environmental terms and to direct the efforts of crews, material, and equipment for the cleanup effort. In addition, updated maps will be plotted to reflect the field reports of the latest known conditions and to provide revised maps to SCAT teams and cleanup crews.

SUMMARY

The Louisiana State University/Woodward-Clyde Consultants Gulf of Mexico Oil Spill Research and

Response Program is designed to develop a pre-planned cooperative response framework in the event of an oil spill. A SCAT Program was developed in order to facilitate a productive and cooperative work effort to assess shoreline oiling impacts, identify environmental sensitive resource areas, and develop cleanup strategies based on interagency concurrence. The SCAT Management framework is supported by four individual components: the Command Center, SCAT Teams, SCAT Aerial Video Survey Teams, and a GIS Computer system. In the event of an oil spill, the four components act together in the SCAT Program to provide a comprehensive and realistic analysis of the impacted shoreline in order to expedite cleanup operations.

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RECENT OIL SPILL RESPONSE INITIATIVES AT LOOP, INC.

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THE LOOP FACILITY

The LOOP, Inc. (an acronym for "Louisiana Offshore Oil Port") operates the nation's single deepwater port facility, located approximately 18 miles off the coast of Louisiana in the Gulf of Mexico. Very large crude carriers and ultra-large crude carriers call at the LOOP marine terminal facility to offload their cargoes of crude oil. The oil is pumped ashore through a 48-inch diameter pipeline to an onshore storage terminal, approximately 28 miles inland, near Galliano, Louisiana. The Clovelly Dome Storage Terminal is comprised of eight salt dome caverns and has a capacity of nearly 40 million barrels. From the onshore storage facility, crude oil may be delivered through any of five connecting pipelines to refineries in Louisiana, Texas, and the Midwest. During 1990 and 1991, an average of approximately 900,000 barrels of crude oil were offloaded at the facility each day.

The LOOP, Inc. operating philosophy is one of prevention and preparedness. The number one priority of the company is safe and efficient operations. The LOOP continues to focus on equipment which is available and procedures which may be implemented (such as its new Emergency Response Vessel) in furtherance of its commitment to operate the safest oil transfer facility possible. However, LOOP recognizes that despite the most stringent procedures and mechanisms in place to prevent accidents, they can and do occur. Therefore, LOOP has developed a comprehensive Oil Spill Contingency Plan and acquired an extensive inventory of mechanical response equipment as well as dispersant spraying capability which would be necessary in the event of a major oil spill incident at the port. The LOOP continues to explore the availability of new and innovative oil spill response and remediation technology to respond to such incidents.

PORT SAFETY AND ACCIDENT PREVENTION

Inherent in the design of the LOOP deepwater port facility are several safety features. For example, the facility is constructed in a water depth of approximately 110-115 feet, significantly reducing the threat of groundings. Because of the size and capacity of the tankers which call at the facility, a vessel traffic separation scheme is implemented, minimizing the perils of port congestion. Because of its distance from land, in the event an offshore spill were to occur, there is a greater opportunity to react to the incident, preventing or minimizing any impact to environmentally sensitive areas.

There are no physical boundaries surrounding the port complex; therefore, navigation obstructions are not present. However, the port area is protected through the designation of a Safety Zone, or area in which any activity that may directly or indirectly increase the environmental and safety risks associated with operation of the deepwater port may be minimized or prohibited. This area consists of approximately 36 square miles and includes an approach section, anchorage area, and terminal section. The LOOP Safety Zone is established by U.S. Coast Guard regulation and appears on all navigational charts and maps. The LOOP Safety Zone is monitored on a 24-hour basis with uninterrupted radar watch and communications capabilities.

Vessel movement within the port area is directed by personnel employed by or under contract to LOOP in an effort to assure clear, concise guidance in the area. Communication with tankers is established by a vessel traffic controller as tankers enter the Safety Fairway. Two mooring masters (one in the bridge and one on the bow) and two deckwatch personnel must board tankers prior to entry into the Safety Zone and as it approaches the berth. These personnel remain aboard the tankers throughout the discharge of cargo, constantly monitoring conditions for maximum safety and environmental protection.

Following cargo discharge, these mooring masters and deckwatch remain with the tanker throughout the disconnect procedures and until it exits the LOOP Safety Fairway.

Finally, the entire LOOP facility and all components are maintained to achieve the highest operational standard. Through an aggressive preventive maintenance and inspection program, all parts of the facility are subject to stringent test and check out and changeout requirements to avoid hazards in operations as well as potential environmental impact which could result through their failure.

In a further effort to achieve the maximum level of operating safety, LOOP has always maintained a strong drug and alcohol policy, which has recently been restructured to meet current regulatory requirements. As part of this policy, the use, possession, distribution or sale of any unauthorized drugs or alcohol on any company premises is prohibited. The policy includes unannounced searches of LOOP employees as well as employees of contractors, and all personal property on company premises. Periodic searches and random testing are also provided in the policy. Any violation of the policy (which includes the refusal to consent to testing or a search) will subject such personnel to disciplinary action, including termination.

Emergency Response Vessel

As part of the company's philosophy of prevention as the key to preparedness, LOOP continually assesses its operations to isolate procedures and situations which may be modified to achieve a maximum level of safe operations. In assessing the risks associated with the deepwater port operation, tanker movements and cargo transfer operations represent a significant portion of the risk of oil spills. The deepwater port and its components are fixed structures, while the tanker and its cargo are in motion while in the port area.

To reduce, to the greatest extent practicable, the risk associated with tanker movement, LOOP has commissioned the construction of a purpose built emergency response vessel, the LOOP RESPONDER. The emergency response vessel will have as its number one priority disabled tanker assistance and will have the built-in capability to provide-tanker escort service. The vessel will also have on board considerable firefighting capability and oil spill response equipment. The LOOP RESPONDER is designed to be 155 feet in length; it has a beam of 48 feet and draws a draft of 15 feet. Its 7,000 horsepower engine and Voith Schneider propulsion system make it quite suitable for "finessing" tankers which lose power or steering while in port. This vessel will remain in the port area at all times.

While the LOOP RESPONDER is under construction, an interim emergency response vessel is on station at the port. Though somewhat smaller (and having a different type propulsion unit), this vessel is capable of performing many of the functions of the purpose built emergency response vessel and has on occasion been called upon to do so while at the LOOP facility.

OIL SPILL RESPONSE PREPAREDNESS

The LOOP, Inc. Oil Spill Contingency Plan

The LOOP's operating experience indicates that it has been most effective in its efforts to minimize the release of oil into the marine environment. It is therefore LOOP's intent to maintain a state-of-the-art response capability in both equipment and personnel. During 1989, LOOP undertook the task of revising and strengthening its Oil Spill Contingency Plan to reflect the level of preparedness of its response team. The revised contingency plan sets forth in very clear, concise terms the chain of command and channels of communication between response team members. Detailed job descriptions and checklists were made part of the plan to allow the substitution of team members in the event necessary. In addition, the plan provides an immediate access to the notification directory (including team members, government agencies, and contractors), location and quantity of all available oil spill response equipment and supplies, cleanup plans, wildlife rehabilitation plans, sensitive areas resource requirements, and environmental monitoring details. The LOOP Oil Spill Contingency Plan functions as a working document for all members of the response team and, as such, is tested frequently through drills and training exercises which involve LOOP and contractor personnel as well as government agency representatives.

Mechanical Response Equipment

Because of LOOP's areas of operation, it is necessary to maintain a response capability for both the onshore and offshore environments. Through the strategic placement of response equipment at each LOOP facility, the company can provide the immediate dispatch of equipment to the required location. The LOOP currently has in inventory 24 skimmers, of which 9 are designed for open water use. Offshore skimmers consist of 5 Waloseps, 2 Vikoma Sea Skimmer 50's, 1 Lamor, and 1 GT-260. This represents a total offshore skimming capacity of nearly 8,000 barrels per day, assuming an 8-hour workday.

In addition, LOOP stocks over 43,000 feet of various types of containment boom. A significant component of this inventory area is 9,000 feet of Expandi Model 4300 boom for open water containment. The remaining inventory, which includes 20,000 feet of Expandi Model 3000 and various other types of boom, is dedicated to shoreline and inland waters protection.

As part of LOOP's containment and skimming system, it has also designed and fabricated 16 Department of Transportation-approved recovered oil storage tanks. These tanks are also capable of use in storing chemical dispersant. The tanks are loaded and transported via flatbed trailer attached to a fifth-wheel truck. The fifth-wheel truck, owned by LOOP, is equipped with a hydraulic knuckleboom crane, facilitating the offloading of these tanks or other response equipment as needed at remote deployment locations.

The company also owns and operates eight work vessels dedicated to boom deployment and skimming operations in inland waters. All vessels which are used in routine port operations are also outfitted to assist in oil spill containment and skimming efforts.

Through periodic training and drills, LOOP personnel as well as its contractors are briefed and exercised in the maintenance and use of all spill response equipment. As part of this process, the LOOP response team endeavors to determine and utilize the most efficient methods possible in handling and maintaining a state-of-the-art inventory.

All LOOP oil spill response equipment is maintained in storage areas in close proximity to potential sources of discharge. Onshore skimmers, containment boom, and other small tools and equipment are stored at the Galliano, Louisiana facility, the majority in oil spill response trailers in the Clovelly Dome Storage Terminal area. This location provides immediate, unhampered access to equipment by operating personnel who would be called upon to contain a discharge until designated response team members arrive at the scene.

Equipment and supplies which are available for offshore use (or at the LOOP Fourchon, Louisiana facilities) are housed in an environmental warehouse in Fourchon, Louisiana, also adjacent to the operating area. Immediate deployment by helicopter or vessel from this facility is planned in the event of an incident.

At the marine terminal facility (offshore), LOOP stores approximately 4,000 feet of Expandi Model 4300 Boom with 1,500 feet maintained in 2 roto-packed bundles of 750 feet each and the remainder being maintained on 2 hydraulic reels; 1 GT-260 skimmer and 1 Walosep W4 skimmer are also kept at the port.

Dispersant Capability

Prior to commencing operations, LOOP realized that a combination of response tools would be required to combat the potential effects of released oil and made a commitment to research all available technology, including mechanical response equipment as well as dispersants and surface collecting agents. As a result of the relatively small operational spills which have occurred at the facility, LOOP has confirmed that mechanical response alone will prove vastly ineffective in the event of a major oil spill.

During the time period of 1986-1988, LOOP, through various consultants, conducted extensive toxicity tests on a range of species indigenous to its area of operation to determine the comparative effects of crude oil versus dispersant and dispersant/crude oil mixtures on such species.

Based on these test results, LOOP moved forward to develop a procedure which would provide regulators with the necessary information to render a quick response in the event an application to use dispersant was required during an oil spill incident. Acknowledging that an effective dispersant response is an immediate one, the Environmental Protection Agency Region VI Regional Response Team delegated to the Federal On-Scene Coordinator for the region pre-spill authorization for the use of dispersants within a designated geographic area, based upon a very detailed plan formulated by LOOP. It is the intent of the manual to set forth all information which would be required by the On-Scene Coordinator in determining the appropriateness of dispersants in the particular incident, including the dispersability of the crude oil which has been spilled; the likelihood of impact on an environmentally sensitive area; the type, quantity and location of dispersant available for use; calibration reports; and toxicity studies.

The LOOP has secured and maintains an extensive dispersant application capability by both vessel and aircraft. The primary mode of dispersant application at LOOP is by fixed wing aircraft, the DC-3 and DC-4 aircraft under exclusive contract from Airborne Support. Inc. stationed at Houma, Louisiana. The contract requires that these aircraft be constantly maintained in an airworthy condition and that a back-up aircraft be available under the same terms during scheduled maintenance as well as unanticipated downtime. Upon notice from LOOP, the contractor will have the first aircraft available for dispatch within four hours and, if requested, the second shall be available within eight hours of the initial request.

The spray systems aboard these aircraft have been fully calibrated and are included in the routine preventive maintenance program of LOOP. The DC-4 aircraft is capable of spraying approximately 10,000 gallons of dispersant per day (given five sorties per day) and the DC-3 has an application capacity of 5,000 gallons per day under the same assumption.

In addition to the fixed wing aircraft, LOOP has dispersant spray systems which have been outfitted for a helicopter and three vessels. The capacity of the helicopter system is 1,320 gallons per day and the combined capacity of the vessel systems is approximately 17,000 gallons per day. This represents a grand total application capacity of approximately 33,400 gallons of dispersant per day.

RECENT DEVELOPMENTS

During 1991, LOOP has undertaken the task of further refining its response capability to achieve the fastest and most efficient response effort practicable. In furtherance of this effort, four specific projects have been initiated which will significantly improve the ability of the oil spill response team to move quickly having all equipment and supplies required at their immediate disposal. This effort also includes LOOP contractors and customers as well as other members of industry who may experience oil spill incidents requiring assistance beyond the capabilities of their respective operations.

Modular Offshore Skimming System

The LOOP is developing a modular oil spill skimming system, which is a skid-mounted response unit consisting of the following equipment: a knuckleboom crane, an aluminum outrigger, 75 feet of containment boom, a hydraulic power unit, and a 2,000 gallon oil storage tank. It is anticipated that in the event of an oil spill requiring mobilization from several locations, these units will be placed aboard a wide range of vessels with generic specifications, or vessel-of-opportunity, as all components required for deployment of the response equipment and recovered oil storage are contained within the unit. The prototype is scheduled for testing in late November 1991. Three additional units are planned for fabrication upon successful testing of the prototype.

Vessel Tracking Systems

The LOOP has entered an agreement with Otto Candies, Inc., a local vessel owner/operator, to conduct a continuous vessel tracking system. This tracking operation focuses on ordinary supply vessels which would serve as vessels-of-opportunity during an oil spill incident. These vessels will serve in any number of capacities from the containment and skimming function to support for the LOOP environmental monitoring team. The tracking system provides LOOP with up-to-date information on the location and availability of such vessels as well as detailed information on the physical description and capabilities of the craft. The feature of this system which enhances the efficiency goal is that Otto Candies, Inc., will actually contract with LOOP (under an established agreement) for the desired vessel, eliminating the need to negotiate several agreements with individual vessel operators during a spill incident. Through oil spill drills and training exercises, the company has tested the tracking system and found it to be a most useful tool in launching and sustaining an efficient and continuous response effort.

Aircraft Dispersant Spraying
System Participation

The LOOP continues to discuss with other members of the industry, including oil spill response cooperatives, the importance of pooling resources to maintain a responsible level of preparedness for emergency response incidents. A significant portion of this preparedness lies in the area of dispersant aircraft.

As has been demonstrated in actual oil spill incidents as well as in testing, the key to an effective dispersant response operation is the ability to act without undue delay. To this end, LOOP saw the need to secure dedicated aircraft for this purpose and continues to maintain the capability through an exclusive services agreement. However, the potential need for such services is not exclusive to LOOP. Therefore, LOOP has approached industry regarding the need to share the costs of maintaining this mutually-needed contract.

While the specific terms of such a participation agreement must be negotiated with the contractor, LOOP envisions that the contract would include a DC-3 and DC-4 aircraft (and a backup aircraft during periods of maintenance) for a fixed retainer fee and additional agreed-upon charges for actual flight time, training exercises, and crew certification.

The immediate availability of dedicated aircraft during a response effort is critical. Recognizing that other aircraft may or may not be available at the time of a spill represents a risk that is unacceptable to LOOP. Therefore, LOOP continues in its efforts to sustain this dedicated capability, while conferring with other potentially affected parties on the need to share the associated costs.

Emergency Response Agreements

On occasion, LOOP is called upon to lend assistance to other operators in the vicinity of the port facility that have experienced an oil spill incident. While it is LOOP's intent to provide whatever assistance it possibly can in such situations, such requests must be balanced against the regulatory requirements that LOOP maintain a certain response capability at its port. Therefore, any equipment or personnel provided is loaned on the premise that the responsible party will concurrently arrange for contract labor and equipment to replace that which has been provided by LOOP. To reduce delays associated with negotiating contractual terms during such critical periods, LOOP has developed an Emergency Response Agreement form which it will make available to shippers and tanker owners/operators calling at the deepwater port or operations in the vicinity of the facility. This agreement would be executed prior to the time of need and would be considered part of the operators' contingency plans while operating in the area.

SUMMARY

In conclusion, LOOP continues to evaluate its operations to assure that available preventive measures are implemented to achieve a safe and efficient operation. Additionally, the company routinely reviews its level of preparation to respond to oil spill incidents which have the potential to occur at any oil transfer facility. In this regard, the quantity and type of skimmers, boom, and associated equipment available is continually reviewed to confirm that the company employs the best available technology in its response efforts. For this reason, new and innovative equipment or applications are always the focus of research at LOOP.

Ms. CaSandra J. Cooper-Gates has been employed by LOOP, Inc. for 11 years spending approximately 10 years in its Law Department and recently moving to the position of Manager, Environmental and Regulatory Affairs. She received a B.S. in

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OIL SPILL RESPONSE RESEARCH AND DEVELOPMENT: UPDATE ON OIL POLLUTION ACT OF 1990 AND FEDERAL INITIATIVES

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On March 24, 1989 the *Exxon Valdez* ran aground on Bligh Reef in Prince William Sound producing the largest oil spill in U.S. history. This spill, along with several other smaller but significant major spills since then have refocused national attention on the prevention of oil spills from tankers and the response to oil spills when they occur. To date, numerous government and industry reports have been completed which analyze the technological deficiencies related to these spills and the subsequent response, and make specific recommendations for further Research and Development (R&D) efforts.

Immediately following the *Exxon Valdez* spill, the various federal agencies recognized the need for a coordinated interagency and industry effort in this area. Although the anticipated level of funding for R&D in this area will be significant, it will not be unlimited and there are a number of projects and initiatives to pursue. Priorities must be determined and any duplication of effort must be avoided. To this end, an interagency workshop was convened on 26-27 September 1989 at the U.S. Coast Guard (USCG) R&D Center to address overall goals and objectives, agency responsibilities, agency technical needs, information exchange, interaction with industry, and establishment of a mechanism and forum to promote and insure coordination at the federal level. This committee and mechanism were formalized by passage of the Oil Pollution Act of 1990 (OPA 90).

Title VII of OPA 90 establishes an Interagency Coordinating Committee on Oil Pollution Research charged with coordinating a comprehensive program of research, technology development, and technology demonstration among federal agencies in cooperation with industry, universities, research institutions, state governments, and other countries. In addition to establishing the Interagency Committee, the act addresses specific federal activities including development of a Federal Oil Pollution R&D Plan outlining a comprehensive five year effort to upgrade technology for oil spill prevention and response, a program to study the effects of specific oil spills to be monitored by the Department of Commerce and the Environmental Protection Agency (EPA), demonstration projects in specific port areas to be conducted by the USCG in coordination with other agencies, and a regional grants program addressing regional aspects of oil pollution such as prevention, removal, mitigation, and the effects of discharged oil on regional environments. Title VII further authorized funding of \$27.25 million and specified the following allocation among the specific programs: Comprehensive Five Year Program at \$19 million annually, Regional Grants Program at \$6 million annually, and Demonstration Projects at \$2.25 million annually.

At present, there are 19 member agencies and four ex-officio member agencies participating on the Committee and involved in preparing the Interagency Oil Spill R&D Plan. The Committee is chaired by the Department of Transportation and is organized into four smaller subcommittees addressing major areas of the 5-year comprehensive program, and three subcommittees or working groups addressing special programs within Title VII. The four major research area subcommittees include Prevention, Spill Planning and Management, Spill Response, and Effects and Restoration. The three special program subcommittees include the Regional Grants, the Demonstration Projects, and the State and Private Sector Coordination.

At this time, the Committee has completed the initial draft of the Comprehensive 5-Year Oil Pollution R&D Plan. The plan outlines comprehensive research efforts in the areas associated with the four subcommittees. The prevention section outlines research efforts in vessel design, operation, and inspection; waterways management including vessel traffic systems; facility design, operation, and inspection; and pipeline design, operation, and inspection. The spill planning and management section outlines research efforts in risk assessment and contingency planning, spill response training and readiness, spill operations management, communications, and health and safety. The spill response section outlines research efforts in vessel salvage and source containment, spill surveillance, containment and recovery, on-water treatment and burning, shoreline mitigation and cleanup, and disposal. The fate, transport, and effects section outlines research projects in spill transport and oil properties, environmental fate and effects, natural resource damage assessment, ecologically sensitive areas, and scientific monitoring and evaluation. The restoration section outlines research efforts on methods for determining recovery of oil contaminated ecosystems and development of environmental restoration methods for oil spill sensitive areas. The plan is currently being reviewed within the Executive Branch prior to submission to the Congress.

Concurrent with development of the Interagency R&D Program mandated by OPA 90, federal agencies have aggressively pursued specific research efforts individually and together as joint projects. Most of these projects have been directly related to oil spill response and address the key technological needs identified at the initial interagency workshop and further addressed in detail in the Interagency Plan. In fact, several of these R&D initiatives were begun during the *Exxon Valdez* cleanup effort itself. The following summary highlights some of the more significant research efforts underway, but is by no means all inclusive. In addition, only the major participants are mentioned; but in many cases other agencies not mentioned, as well as participants from private industry, are providing support as well.

In the area of spill planning and management, a major joint effort is being undertaken by the USCG and National Oceanic and Atmospheric Administration to develop an integrated, prototype Decision Support System for oil spill response. This Decision Support System will provide On-Scene Coordinators and Scientific Support Coordinators with detailed maps of specific areas showing attributes relevant to managing spill response operations, and databases with accurate and accessible technical information for spill response. Databases completed or being developed at this time include a spill histories database highlighting the circumstances surrounding significant spills, countermeasures used, and environmental effects; a technical experts database; an oil properties and behavior database; a chemical countermeasures database summarizing the current effectiveness, toxicity, and availability data on products on the NCP product schedule; a sorbent products database; a cleanup equipment capabilities database; and a database summarizing the environmental effects of various countermeasures.

In the surveillance area, several efforts are underway. The USCG is conducting two studies to define oil spill surveillance systems of the future. One study focuses on the short-term upgrade of its oil spill surveillance capability; the other study, being conducted under contract by the Environmental Research Institute of Michigan, focuses on a longer term upgrade within the USCG multi-mission remote sensing surveillance system. In addition, an aggressive oil spill sensor development effort focusing on the laser fluorosensor and laser thickness sensor is underway as a joint project with Minerals Management Service (MMS), Environment Canada, ESSO Resources Ltd. Canada, and the American Petroleum Institute.

In the area of cleanup equipment test and evaluation, the MMS, with support from the USCG, Navy, and Environment Canada, is in the process of reopening the Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) facility in Leonardo, New Jersey. Test protocols for oil containment booms and skimmers have been completed by the OHMSETT Interagency Technical Committee, and efforts are underway for standardization of the protocols under ASTM. An aggressive OHMSETT test and evaluation program is expected over the next few years to define the capabilities of current systems, and identify and develop innovative systems for oil spill recovery.

To improve mechanical recovery, the USCG, with support from the Navy, is undertaking several projects to streamline the current oil spill recovery process by developing technologies to separate oil from water and provide temporary storage for recovered oil and debris, and test and improve vessel-of-opportunity skimming systems. In addition, MMS and Environment Canada are planning joint projects to develop high current containment and cleanup equipment; and the EPA is addressing cleanup systems and equipment for inland spills.

In the area of chemical countermeasures technology for oil spills, protocols are being developed both by the EPA and Environment Canada to better define the effectiveness and toxicity of dispersants, surfactants, gelling agents, and solidifying agents. Studies to further explore the mechanisms governing the effectiveness, toxicity, and ultimate fate and effects of these chemical agents in the marine environment are being undertaken by the EPA, MMS, and Environment Canada. In addition, MMS and Environment Canada have a major research effort underway to develop the next generation of dispersants to significantly improve effectiveness while minimizing toxicity.

One of the most important research efforts underway is the Interagency *In Situ* Burning Experiment. This effort is being coordinated and co-funded by MMS, National Institute of Standards and Technology, USCG, and Environment Canada, with support from the American Petroleum Institute and industry. The project is designed to fully explore and document the effectiveness and environmental impact of *in situ* burning as a promising countermeasure for dealing with a large spill on open water. Laboratory tests and meso-scale tests have been completed. An offshore full-scale cold water burn is planned for Newfoundland next summer; and a full-scale warm water burn is planned for offshore Louisiana pending approval of the EPA.

In the area of bioremediation, the EPA is undertaking a major R&D program to assess and improve this technology. This includes continuing post *Exxon Valdez* bioremediation research at the EPA's Gulf Breeze, Athens, and Cincinnati labs; and development of a bioremediation use and monitoring protocol for application of bioremediation agents on subsequent spills. To support more extensive test and evaluation of bioremediation products, the EPA and National Environmental Technology Application Corporation are developing a three-tiered protocol including initial vendor tests, more extensive laboratory effectiveness and toxicity tests, and microcosm tests. The establishment of an EPA bioremediation testing center is also being considered.

As these efforts progress, an ongoing effort will be made to provide periodic updates to regional federal agency offices, state agencies, and private institutions through the Interagency Subcommittee for State and Private Sector Coordination, and through the National Response Team R&D Subcommittee in coordination with the Regional Response Teams.

CDR Pete Tebeau is Chief of the Environmental Safety Branch, USCG R&D Center. He has spent the last 12 years in USCG R&D, predominantly working in oil and hazardous chemical spill response technology. He received B.S. degrees in general engineering from the Coast Guard Academy and in environmental engineering from Florida International University; and his M.S. in physical oceanography from the University of Miami.

MINERALS MANAGEMENT SERVICE OIL SPILL RESEARCH: AN UPDATE

Mr. Joseph V. Mullin II
Minerals Management Service
Technology Assessment Research Branch

BACKGROUND

The Technology Assessment and Research Program is managed by the research branch of the Minerals Management Service's (MMS) Offshore Operations. Since the inception of the research program almost a decade ago, approximately 170 projects have been undertaken in the areas of operational safety, offshore structures and pipelines, engine exhaust pollution reduction, and oil spill containment and cleanup. These studies have yielded over 1,000 technical reports and papers, all of which, with the exception of proprietary studies, are available to the public.

The MMS oil spill research program funds and develops the technology used for oil spill contingency planning for the Outer Continental Shelf (OCS). In 1979 the MMS joined the U.S. Coast Guard (USCG), the Environmental Protection Agency (EPA), the U.S. Navy, and Environment Canada in sponsoring an interagency and international oil spill response program that evaluated oil spill response equipment and procedures at the EPA facility in Leonardo, New Jersey. This facility is known as OHMSETT, the Oil and Hazardous Materials Simulated Environmental Test Tank.

In 1981, the program was expanded and other research efforts were begun. In 1986, MMS and Environment Canada signed a Memorandum of Agreement to conduct research on oil spill prevention and response technologies. This joint agreement further expanded the MMS program. This expansion coincided with the elimination of oil spill response studies by other agencies. With the advent of the *Exxon Valdez* spill, the program was again expanded to include funding from the American Petroleum Institute and the USCG. This combined research program is directed at attaining significant improvements and milestones within 3 to 5 years.

SIGNIFICANT ACCOMPLISHMENTS

The MMS research has pioneered the development of using specially tuned shipboard navigational radar to locate and track oil spills (Tennyson 1988). The Department of the Interior, on the behalf of the MMS, has received a patent for this process. However, before the radar technique can become a reliable operational tool, additional research is required to correlate oil slick characteristics (e.g., slick thickness and sea conditions) with radar presentation.

In 1983, MMS initiated an *in situ* burning program. This program evaluated the burning of spilled oil in different environments, and also examined the limiting factors associated with crude oil combustion (oil slick thickness, oil type, weathering, sea-state, wind, temperature, degree of emulsification, and degree of ice coverage). All of the tested oils burned with 80-95+ percent removal ratios, as long as emulsification had not occurred. The effects of ice coverage up to 95 percent, wind speeds to 50 knots, and water temperatures from -1° to 17°C were minimal to the outcome. Weathered, but not emulsified oils, burned with a higher percentage removal rate than did fresh oil. Heavily emulsified oils could not be effectively burned.

To consider the air quality issue related to *in situ* burning, the MMS contracted with the Building and Fire Research Laboratory of the National Institute of Standards and Technology, to investigate phenomena associated with crude oil combustion and related air quality impacts. These include heat radiation, burning rates, smoke emission and composition, and smoke dispersion in the atmosphere (Evans 1988). Continuing analyses of airborne pollutants indicates that dioxins, furans, and polyaromatic hydrocarbons (PAHs) are not generated as a result of combustion. The PAH compounds in the oil are partially destroyed or converted to higher molecular weight compounds which are less acutely toxic (Evans *et al.* 1989).

In 1987, the MMS and Environment Canada developed and tested downwind containment techniques for the recovery of spilled oil. In addition, we have evaluated mechanical recovery devices and procedures, and subsequently developed innovative techniques for the recovery of spilled oil.

We have evaluated the efficiencies of various chemical dispersant and other treating agents on a variety of crude oils. Over 14,000 tests have been conducted.

We have evaluated and tested two promising chemical nondispersants. These chemicals inhibit the formation of emulsions, breakdown emulsions when formed, retard slick spreading, and change the physical properties of the spilled oil to enhance recovery or treatment.

We have reviewed the state-of-the-art in airborne remote sensing and are improving its capabilities. The MMS and Environment Canada are developing a new generation of sensors which will detect oil on and in water, and also remotely measure oil slick thickness. We are also investigating the behavior of a variety of oils. All California Outer Continental Shelf oils are being evaluated.

CURRENT RESEARCH

OHMSETT

The refurbishment of OHMSETT has been completed. This facility, closed by the EPA in 1988, is expected to be re-opened for testing in November 1991. This is the only oil spill response test facility in the United States where full size response equipment can be evaluated in oil and in waves, while advancing through the water. Tank testing is used as a full-scale and environmentally-safe evaluation method before field verification is attempted.

Specific types of testing to be conducted include:

- evaluation of innovative skimming devices;
- evaluation of oil nondispersing chemical additives;
- evaluation of subsurface oil detection and collection concepts; and
- evaluation of innovative containment and collection techniques for broken ice conditions.

Standard Test Procedures

The MMS, with support from the USCG and Environment Canada, is developing Standard Test Procedures (protocols) for the testing of containment booms and skimmers. These are necessary to generate a comparative performance database. This project will ensure that only appropriate equipment is approved for use in oil spill contingency plans. A draft test protocol has been developed and will be finalized when testing is resumed at OHMSETT.

In Situ Burning

In situ burning represents one of the most promising technical improvements for removing large quantities of spilled oil from the oceanic environment, providing the environmental effects of the resulting combustion products are acceptable. The MMS and Environment Canada are continuing to evaluate *in situ* burning as an oil spill countermeasure option and to develop this technique to the stage where it can be widely accepted. Concerns over atmospheric emissions, however, remain the biggest barrier to the widespread use of burning. Extensive studies on what these emissions consist of have been conducted recently. Laboratory scale experiments of burning oil on water have been conducted by National Institute of Standards and Technology in their laboratories. Court defensible data were developed on the air quality effects by burning a wide range of crude oils under carefully controlled conditions.

The next phase involved carefully measuring the characteristics of the parent oil and the airborne components and residue associated with the burn. In May-June 1991, mesoscale test burns of up to 50 x 50 feet were conducted on land in Mobile, Alabama, under the direction of the National Institute of Standards and Technology, with direct participation of Environment Canada and the USCG. These mesoscale tests were to prepare for the large scale test burns by testing sampling procedures, comparing laboratory findings, and measuring the test parameters on a large scale and in an unconfined space. Preliminary results of the air sampling show the following:

- Many of the air samples taken had insufficient soot/PAHs to register a reading. Ground sampling stations not under the plume showed insufficient soot/PAHs to register a reading.
- No PAHs were detected in any of the water samples. Sensitivity was not a problem here. This appears to indicate that burning does not produce increased water-borne PAHs.
- Samples collected by an instrumented blimp tethered in the smoke plume showed low PAH concentrations. These readings, prior to detailed analysis, appear to be much lower than during the laboratory experiments.
- In the main smoke plume, 300-700 feet directly downwind of the burn, the concentrations of aldehydes and ketones were similar or slightly higher to background levels in normal urban environments.

The final phase of the project will be large scale test burns in the open ocean. We are planning two full-scale, at-sea experiments. Sites preferred for large scale tests are offshore Newfoundland and offshore Louisiana. The emphasis will be on the verification of the efficiency of *in situ* burning and the quantification of pollutants resulting from the burn. A permit application, for the Louisiana experiment, to allow the release of oil into the environment for experimental purposes was submitted to the EPA on June 30, 1991.

Airborne Oil Slick
Thickness Sensor

When responding to an oil spill, it is necessary to know where the largest gains can be made in retrieving the oil. The development of a reliable oil slick thickness sensor for remote sensing is critical to improving oil spill response capabilities. Current remote sensing techniques cannot discriminate between oil slicks thick enough to recover and those which are not.

A technique which employs low level laser-induced energy beams to initiate a train of acoustic waves in the oil slick is being examined for remotely gauging oil slick thickness. This technique has been evaluated in the laboratory under a wide range of conditions, and a prototype has been built. Preliminary tests for oil slick measurement have been very encouraging. Field testing has begun.

High Speed Water
Jet Barrier Boom

A prototype oil containment barrier that uses high pressure waterjets to induce a wind over an oil slick to oppose its movement by current or natural wind has been built and tested. Its effectiveness and deflection mode has been demonstrated in a 1.6 knot current (approximately three times conventional boom capability). Development of this system will significantly increase protection capabilities of nearshore and tidally-flooded areas where relatively high currents occur. Tests have shown that this new barrier is also effective in reducing smoke emissions when oil contained within a boom is burned.

Beachline Cleanup Study

This project consists of a field study to assess the environmental effectiveness and impact of promising cleanup options on coarse or mixed sediment beaches, characteristic to the Pacific coastline. This study will evaluate the effectiveness of the different cleanup techniques and the environmental damage resulting from each of the techniques. Results from this study will allow spill response personnel to choose shoreline cleanup strategies which minimize ecological damage. Final site selection for this study is underway.

Chemical Treating Agents

The chemical treating agents program has a number of components:

- Development of realistic laboratory effectiveness test protocols for dispersants - Over 14,000 evaluations of laboratory effectiveness with various oils and degrees of weathering have been conducted on available and experimental dispersants.

- The study of dispersant action mechanisms - This component has been very successful with significant findings related to the compositional changes of oil after dispersant treatment. This study is examining the fate of dispersants, and of dispersed oil and undispersed oil in water.

- Tests of new oil spill chemical treating agents which are nondispersants - This category has high potential for improving existing response techniques, when used in combination with containment booms or burning. Two chemicals which have been tested inhibit the formation of emulsions, breakdown existing emulsions, or change the adhesiveness of spilled oil to enhance mechanical recovery.

- Investigation of new chemical dispersant formulas - Benefits of existing chemical dispersants are highly questionable. However, it is possible that compounds can be formulated which will have substantially more affinity for dissolving oil than for mixing with water. Improved dispersants are being developed and evaluated in the laboratory.

Laser Fluorosensor for the Detection of Oil in Ice or Open Water

Existing remote sensing packages routinely report false slicks. Features such as freshwater inflows, seaweed, tidal riplines, or debris can be mistaken for oil slicks. The Environment Canada began a research program, which MMS joined in 1987, to develop a system which could discriminate between spurious targets and those containing oil. The laser fluorosensor offers a potential method for the remote sensing of oil spills. Laboratory tests have shown that the sensor can distinguish between biogenic and petrogenic oil, and also has been successful in detecting oil in broken ice.

Development of this sensor along with the thickness sensor represents a new generation of remote sensing over side-looking airborne radar, ultra-violet, infra-red, and false color imagery. Laser fluorosensors in combination with the thickness sensor may significantly enhance existing remote sensing capabilities. An experimental prototype is scheduled for field testing during the winter of 1991-1992.

Physical Behavior of Spilled Oil

The physical and chemical characteristics of spilled oil sometimes change significantly before and during spill response (Bobra 1989a, b). An increased understanding of the behavior and fate of spilled oil is necessary for designing an optimum spill response. Three behavioral aspects in particular are being investigated; density changes, the submergence or over-washing of oils, and the formation of water-in-oil-emulsions.

Atypical oils such as those found off Southern California and Alaska behave very differently from commonly-produced crude oils. Unlike most crudes, these oils rapidly form emulsions or surface skins or sink after relatively short periods of time. Understanding the behavior of these types of oils is crucial in developing improved response strategies. One project goal is to provide improved algorithms for behavior modeling.

Development of a Portable Oil Analysis Kit for Responders

Oil spill cleanup coordinators must decide which response strategies will be most efficient on a given spill. Unfortunately little specific information exists early in a spill to aid in the decision process. A portable field analysis kit providing on-scene personnel with necessary physical and chemical characteristics of the spilled oil would assist in the decision to deploy appropriate spill response equipment.

Oil characteristics to be measured are: density, viscosity, water content, degree of emulsification, and flash point. Testing of the kit is presently underway and, when complete, this kit will become a standard response item.

World Catalog of Oil Spill Response Products

The MMS, USCG, and Environment Canada have provided funding to develop and update the 1991 (third edition) World Catalog of Oil Spill Response Products. This catalog contains complete listings of oil spill containment booms, skimmers, sorbents, and beach cleaning equipment. This catalog is currently available commercially.

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Mr. Joseph V. Mullin II is an oceanographer with the Technology Assessment and Research Branch of the MMS. He is responsible for analyzing OCS oil spill response operations, advising on appropriate spill response techniques and equipment, and for procuring and managing oil spill response contractual research.

Mr. Mullin holds an A.S. and B.S. in oceanographic technology from Florida Institute of Technology. For 16 years, prior to joining MMS, he was employed by the National Oceanic and Atmospheric Administration as a technical expert in physical oceanography and hydrography.

MINERALS MANAGEMENT SERVICE ENVIRONMENTAL STUDIES PROGRESS REPORTS, II

Session:	MINERALS MANAGEMENT SERVICE ENVIRONMENTAL STUDIES PROGRESS REPORTS, II
Co-Chairs:	Dr. Robert M. Rogers Dr. James J. Kendall
Date:	November 6, 1991

Presentation	Author/Affiliation
Minerals Management Service Environmental Studies Progress Reports, II: Session Introduction	Dr. Robert M. Rogers and Dr. James J. Kendall Minerals Management Service Gulf of Mexico OCS Region
Mississippi-Alabama Shelf Pinnacle Trend Habitat Mapping Study: A Status Report	Mr. Richard A. Shaul Continental Shelf Associates, Inc.
Overview of Oil and Oil Dispersants Toxicity Program	Mr. Brian J. Balcom Continental Shelf Associates, Inc., Mr. Kenneth W. Fucik, and Ms. Susan J. Butler T.H.E. Laboratories, Inc.
Long-Term Monitoring on the Flower Garden Banks: Preliminary Results	Dr. Stephen R. Gittings Geochemical and Environmental Research Group Department of Oceanography Texas A&M University, Mr. Kenneth J.P. Deslarzes, and Mr. Derek K. Hagman Department of Oceanography Texas A&M University
Incorporation of Trace Elements in the Coral *Montastraea annularis* at the West Flower Garden Bank, Northwest Gulf of Mexico	Mr. Kenneth J.P. Deslarzes, Dr. Paul N. Boothe Department of Oceanography Texas A&M University, and Dr. Stephen R. Gittings Geochemical and Environmental Research Group Department of Oceanography Texas A&M University
The Effects of Oil Spills on the Corals of the Gulf of Eilat, Red Sea	Dr. Yossi Loya Faculty of Life Sciences Tel Aviv University

(Continued)

Session: MINERALS MANAGEMENT SERVICE ENVIRONMENTAL STUDIES PROGRESS REPORTS, II (continued)

Presentation	Author/Affiliation
Mississippi-Alabama Continental Shelf Ecosystem Study: Summary and Synthesis	Dr. Rezneat M. Darnell Department of Oceanography and Dr. James M. Brooks Geochemical and Environmental Research Group Department of Oceanography Texas A&M University

MINERALS MANAGEMENT SERVICE ENVIRONMENTAL STUDIES PROGRESS REPORTS, II: SESSION INTRODUCTION

Dr. Robert M. Rogers
and
Dr. James J. Kendall
Minerals Management Service
Gulf of Mexico OCS Region

This Marine Ecosystems Studies session was organized to report on the progress of a number of Minerals Management Service (MMS) marine ecological studies, as well as one presentation on the effects of oil spills on coral reefs. The marine ecological studies series is a large component of the MMS Environmental Studies Program.

As oil and gas exploration and development proceeds in the Gulf of Mexico, environmental issues of concern are identified by state and federal agencies and the environmentally concerned public. After prioritizing these technical issues, environmental studies are designed to address these information needs.

These marine studies have provided valuable information on potentially sensitive resources and have been useful in formulating stipulations and mitigating measures for protecting these resources. Recently, these studies have centered about such environmentally sensitive areas as the Mississippi/Alabama Outer Continental Shelf (OCS) and Flower Garden Banks on the Texas-Louisiana OCS. Also presented here is a preliminary progress on an investigation on the impacts of dispersed oils on biological resources.

Dr. Robert M. Rogers is an oceanographer with the Environmental Studies Section, MMS, Gulf of Mexico Regional Office. He received his B.S. and M.S. degrees in zoology from Louisiana State University and Ph.D. in marine biology from Texas A&M University. His research interests have included the ecology of coastal meiobenthic organisms and trophic interrelationships. He has been involved in the MMS/Bureau of Land Management Environmental Studies Program since 1977.

Dr. James J. Kendall is a biologist with the Environmental Studies Section, MMS, Gulf of Mexico Regional Office. His research interests include the effects of contaminants on the physiology of corals, the behavior of reef animals, and procedures for aquatic toxicity testing. Dr. Kendall has conducted research and monitoring programs in the Gulf of Mexico, Galveston Bay, the Florida Keys, and the Gulf of Eilat, Red Sea. Dr. Kendall received his B.S. in biology from Old Dominion University and his Ph.D. in oceanography from Texas A&M University.

MISSISSIPPI-ALABAMA SHELF PINNACLE TREND HABITAT MAPPING STUDY: A STATUS REPORT

Mr. Richard A. Shaul
Continental Shelf Associates, Inc.

INTRODUCTION

The Mississippi-Alabama Shelf Pinnacle Trend Habitat Mapping Study was awarded to Continental Shelf Associates, Inc. (CSA) by the Minerals Management Service (MMS) during August 1990. The area of study is adjacent to an area previously investigated during the MMS-funded Mississippi-Alabama Marine Ecosystems Study and shown in Figure 7.1. The objectives of the study are to geologically characterize pinnacles and significant hard bottoms throughout the study area and then to conduct a biological reconnaissance of the significant features.

METHODS

The first sampling effort, a geophysical characterization survey designed to locate and identify significant topographic and geologic features throughout the study area, was conducted during 12 September - 10 October 1990. A second sampling effort, to identify and characterize the biological communities associated with significant features identified during the geophysical

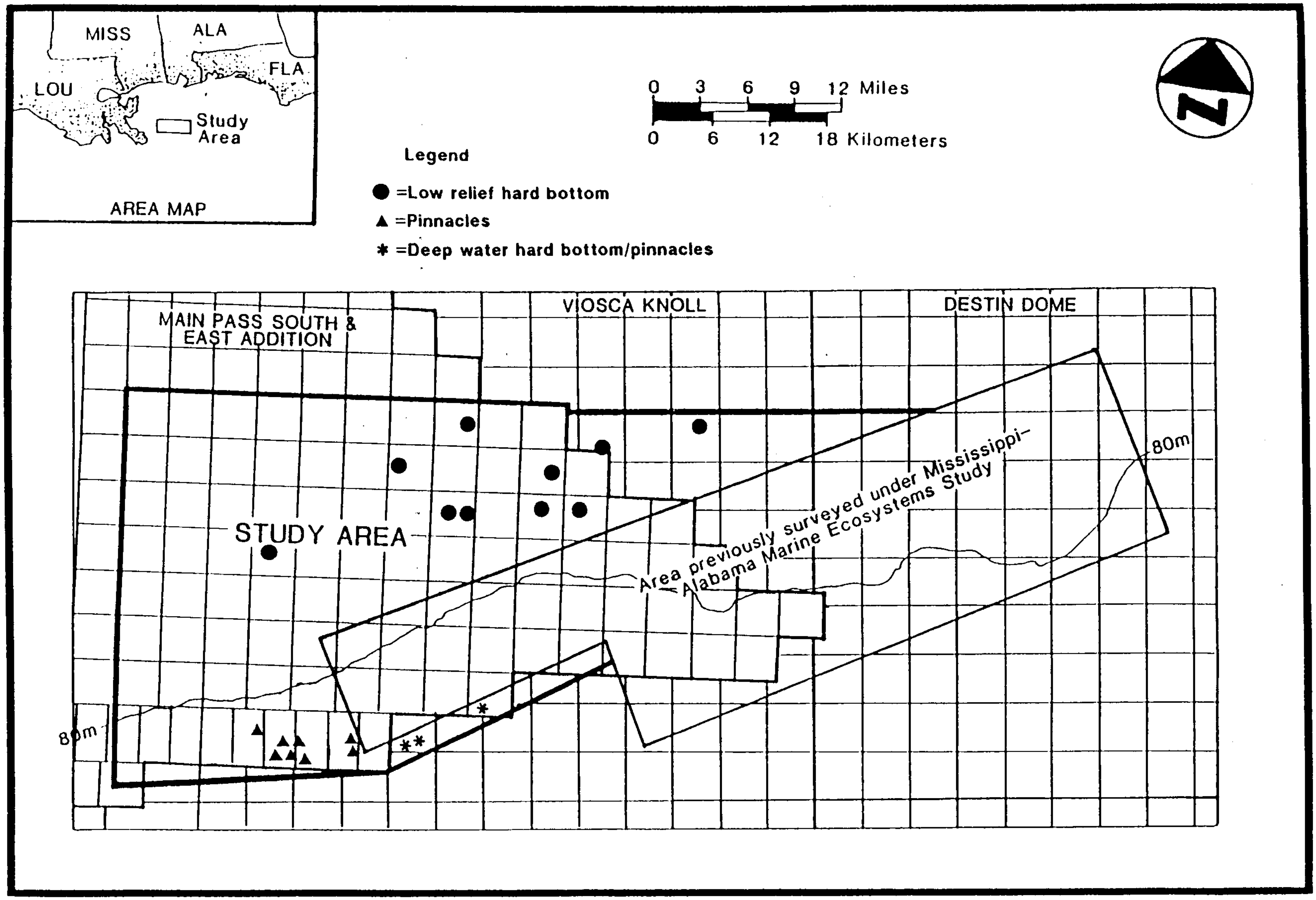

Figure 7.1. Location of topographic features identified for biological characterization.

characterization survey, began on 13 October 1991 and is still underway at this time.

Survey 2 - Biological Reconnaissance

After review of the geophysical data collected during Survey 1, significant topographic features were identified for further biological characterization. Features were relocated with the side-scan sonar and navigational system used during Survey 1. A Phantom HD remotely operated vehicle (ROV) is being used to conduct the biological reconnaissance. Video and still photographic data are being collected by the camera systems on the ROV. Voucher specimens of selected biota are being collected using the manipulator arm on the ROV. Additional voucher specimens are being collected by rock dredge and hook and line sampling. All specimens will be identified to the lowest possible taxonomic level to identify biota that appear in photographs and videotapes.

RESULTS AND DISCUSSION

Analysis of data collected during the recently completed geophysical characterization (Survey 1) of the study area identified numerous targets for further biological characterization. At this time, only features in the main pinnacle trend located in the south-central portion of the study area have been investigated. Only a preliminary review of these recently collected data is available at this time. These features range in size from 10 to 70 feet, occur in water depths ranging from 250 to 350 feet, and are present in a northwest-southeast trend. At least two dozen pinnacles occur within the area. Typical biota on the features included varying densities of comatulid crinoids, ahermatypic corals (*Rhizopsammia, Oculina*, and *Madrepora*), octocorals, and antipatharians. Fishes observed/collected associated with the features include vermilion snapper (*Rhomboplites aurorubens*), red snapper (*Lutjanus campechanus*), amberjack (*Seriola dumerili*), and tattler (*Serranus phoebe*), and numerous anthiads. Additional data concerning the biological communities associated with these features will be obtained by further detailed review of the data.

SUMMARY

An area on the Mississippi-Alabama shelf was surveyed for significant hardbottom/topographic features using geophysical equipment. Interpretation of the geophysical data identified numerous features of interest for investigation during the Survey 2. Biological communities present on these features are being investigated during an ongoing biological reconnaissance effort (Survey 2). A report will be prepared to synthesize the geological and biological data collected during the study. Maps of significant topographic/geologic features and bathymetry also will be produced.

Mr. Richard Shaul has been with CSA for 10 years. As a senior staff scientist for CSA, he has considerable experience investigating the environmental effects of oil and gas activities in the marine and estuarine environment. Mr. Shaul received his B.S. and M.S. degrees in biological sciences from the Florida Institute of Technology.

OVERVIEW OF OIL AND OIL DISPERSANTS TOXICITY PROGRAM

Mr. Brian J. Balcom
Continental Shelf Associates, Inc.,
Mr. Kenneth W. Fucik,
and
Ms. Susan J. Butler
T.H.E. Laboratories, Inc.

Continental Shelf Associates, Inc. (CSA), with the support of two subcontractors (T.H.E. Laboratories, Inc.; VISTA Laboratories, Inc.) and a two-member Scientific Review Board, has recently initiated a 24-month study entitled "Oil and Oil Dispersants Toxicity Program: Dispersed Oil Toxicity Tests with Biological Species Indigenous to the Gulf of Mexico." This study effort is being funded by the U.S. Department of the Interior, Minerals Management Service (MMS), Gulf of Mexico Outer Continental Shelf (OCS) Region under MMS Contract No. 14-35-0001-30617. The MMS Contracting Officer's Technical Representative is Dr. James Kendall. Figure 7.2 reveals the program

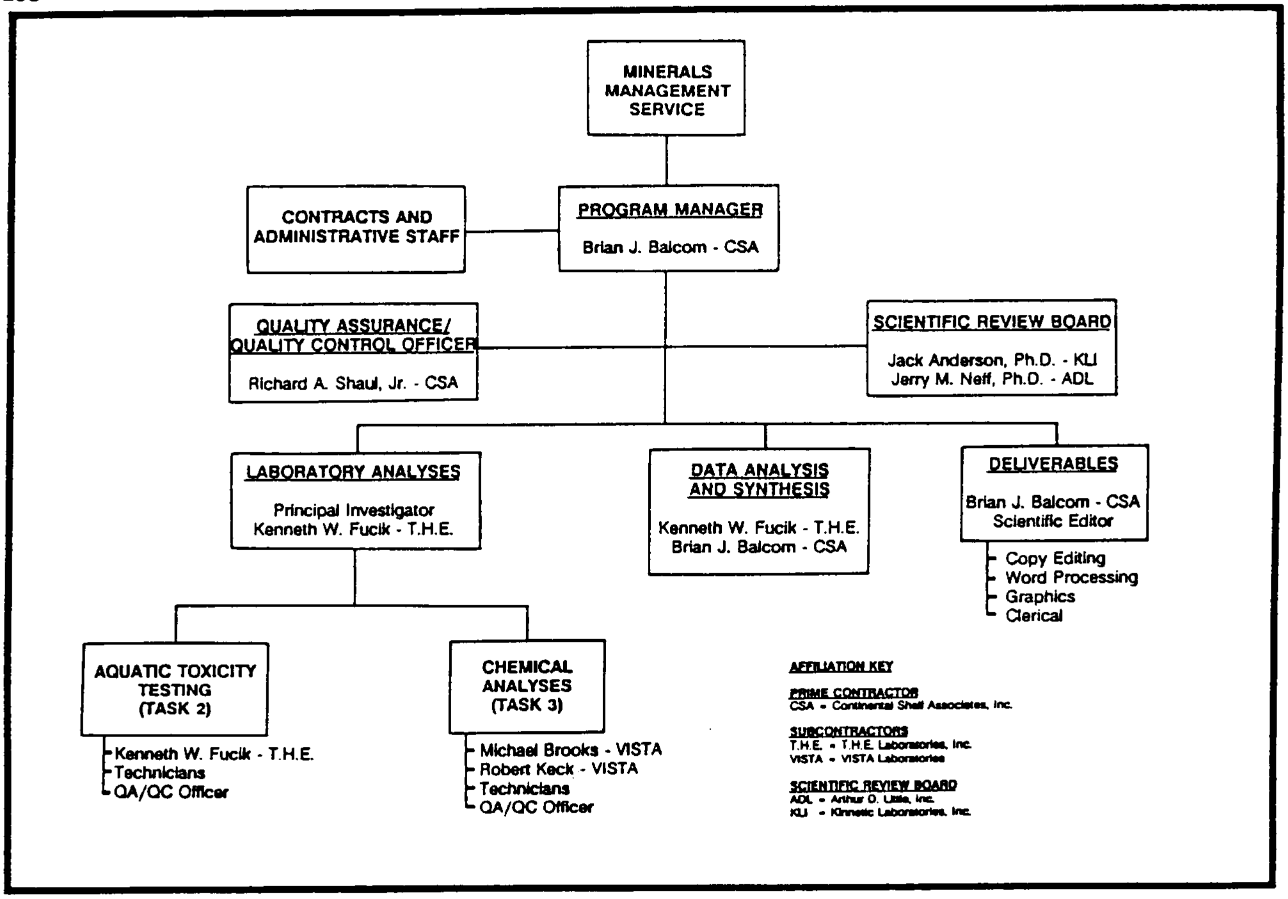

Figure 7.2. Program management diagram.

management structure and the various tasks to be completed under this contract.

The CSA, as prime contractor, will be responsible for overall program management, quality assurance/quality control, data management, and the preparation of deliverables, the latter of which will include a final report, final technical summary, and one or more peer-reviewed journal publications.

Task 1, which has remained unlabelled in Figure 7.2, entails the establishment and involvement of a Scientific Review Board (SRB) to provide expert input during the course of the program. The SRB consists of two individuals who are highly respected in their field: Dr. Jack W. Anderson of Kinnetic Laboratories, Inc., Carlsbad, California, and Dr. Jerry M. Neff of Arthur D. Little, Cambridge, Massachusetts. Drs. Anderson and Neff will provide expert evaluation and critical review of the acute toxicity testing methodologies to be employed. They will also provide review and recommendations regarding interpretation and presentation of test results and submittal of the program results for peer-reviewed journal publication.

Task 2, the acute toxicity testing or biomonitoring phase of the program, will be undertaken by T.H.E. Laboratories, Inc., under the direction of Mr. Kenneth W. Fucik, Principal Investigator. Mr. Fucik has extensive experience in oil fate and effects studies. His research experience includes investigations on the effects of petroleum hydrocarbons on fish eggs and larvae, molluscs, corals, crabs, shrimp, and other benthic macroinvertebrates. He has published papers on guidelines for the use of dispersants and is currently involved in a study to evaluate the Marine Industry Group model for oil spill dispersants usage.

Task 3, comprising the chemical analyses portion of the program, will be completed by VISTA Laboratories, Inc. through its affiliation with T.H.E. Laboratories. VISTA will utilize several different analytical techniques during the course of the program, including gas chromatography (GC) with flame-ionization detection (GC-FID), gas chromatography/mass spectrometry (GC/MS), and infrared spectroscopy (IR). Both T.H.E. and VISTA are located in Broomfield, Colorado.

A combination of static, static renewal, and flow-through biomonitoring exposure methodologies are to be utilized on egg and larval stages of five commercially important invertebrate and fish species (Table 7.1). Species to be evaluated include brown shrimp (*Penaeus aztecus*), white shrimp (*Penaeus setiferus*), blue crab (*Callinectes sapidus*), eastern oyster (*Crassostrea virginica*), and redfish (or red drum, *Sciaenops ocellatus*). Species to be evaluated under three contract options include gulf menhaden (*Brevoortia patronus*), inland silverside (*Menidia beryllina*), and spot (*Leiostomus xanthurus*).

Upon contract award in late September 1991, a 90-day trial testing period was initiated to evaluate various test methodologies prior to implementation of full-scale biomonitoring.

Table 7.1. Species and Life Stages Selected to Undergo Aquatic Toxicity Testing.

Species	Lifestage
Invertebrates:	
Brown shrimp (*Penaeus aztecus*)	eggs larvae post-larvae
White shrimp (*Penaeus setiferus*)	eggs larvae post-larvae
Blue crab (*Callinectes sapidus*)	zoeae megalops (alternate)
Eastern oyster (*Crassostrea virginica*)	eggs larvae
Fish:	
Redfish (red drum) (*Sciaenops ocellatus*)	eggs larvae
Option 1:	
Gulf menhaden (*Brevoortia patronus*)	eggs larvae
Option 2:	
Inland silverside (*Menidia beryllina*)	eggs larvae
Option 3:	
Spot (*Leiostomus xanthurus*)	eggs larvae

Figure 7.3 represents a generic flow-through toxicity testing method for the rearing and exposure of shrimp and crab larvae. At present, a modification of this experimental design (Figure 7.4) has been constructed and evaluated. Results of mixing tests are presented in Figure 7.5. It is evident from a comparison of tank versus in-beaker conductivity measurements made over a 2-day period that sufficient mixing occurs using this experimental design.

Full-scale biomonitoring is expected to begin in early 1992 and continue for approximately 13 months. The availability of eggs and larvae of each test species is an important concern to the success of the program, particularly in light of the number of species and various life stages to be tested. Table 7.2 summarizes the availability of the early life stages of the eight test species. This table also indicates the anticipated time frames for completion of acute toxicity testing.

Test organisms will be exposed to two different oils and dispersed oil mixtures, as well as to the dispersant alone. The two oils to be tested will be "pipeline system" oils, selected specifically to be representative of oil produced within the Central and Western Gulf of Mexico Planning Areas, respectively. The first test oil has been collected from production on the Texas OCS, while the second test oil has been taken from production facilities located offshore of Louisiana. The dispersant to be tested will be Corexit 9527. At present, range finding tests on the dispersant have been initiated. Preliminary acute toxicity testing with the first test species (inland silverside, *Menidia beryllina*) is scheduled to begin in early November 1991.

Multiple chemical analyses (i.e., GC, GC/MS, IR) will be conducted on both oil and dispersed oil mixtures at various phases of biomonitoring to characterize the degradation of oil and dispersed oil mixtures and to identify the components which may be most toxic to eggs and larvae (Table 7.3). Chemical components to be determined include total petroleum hydrocarbons, purgeable aromatic hydrocarbons, and polynuclear aromatic hydrocarbons. Chemical analyses will be conducted concurrently with acute toxicity testing.

Several months after the initiation of acute toxicity testing and chemical analyses, the initial phases of data analysis and report preparation will begin. These aspects of the program are projected to last 10 to 12 months. A draft and final report are slated for submission to the MMS in May and September 1993, respectively.

It is evident that there are critical information needs regarding the use and ecological effects of dispersants, particularly with regards to decisionmaking and the use of dispersants in the waters of the Gulf of Mexico. For this reason, the MMS has chosen to fund this study to develop additional data on the effects of dispersed oil on early life stages of eight important commercial and recreational species from the Gulf of Mexico region. It is anticipated that the data derived from this study will be used for the preparation of environmental impact statements for offshore oil and gas leasing and development and for review of oil spill contingency plans. These data will also be useful in assessing the potential damage associated with the use of these materials.

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Mr. Brian J. Balcom, Senior Scientist, has been with CSA since 1981 and presently serves as Regional Manager of CSA's Ventura, California office. Mr. Balcom also serves as CSA's Scientific Editor. His areas of research interest include marine soft- and hard-bottom benthic communities and the fate and effects of oil on marine ecosystems. Mr. Balcom received his B.S. and M.S. degrees in biological sciences and biology, respectively, from the University of Southern California.

Mr. Kenneth W. Fucik is the president of T.H.E. Laboratories, Inc., Broomfield, Colorado. His areas of research interest include acute toxicity testing and the ecological and physiological effects of contaminants in aquatic environments, natural resource damage assessment techniques, and the

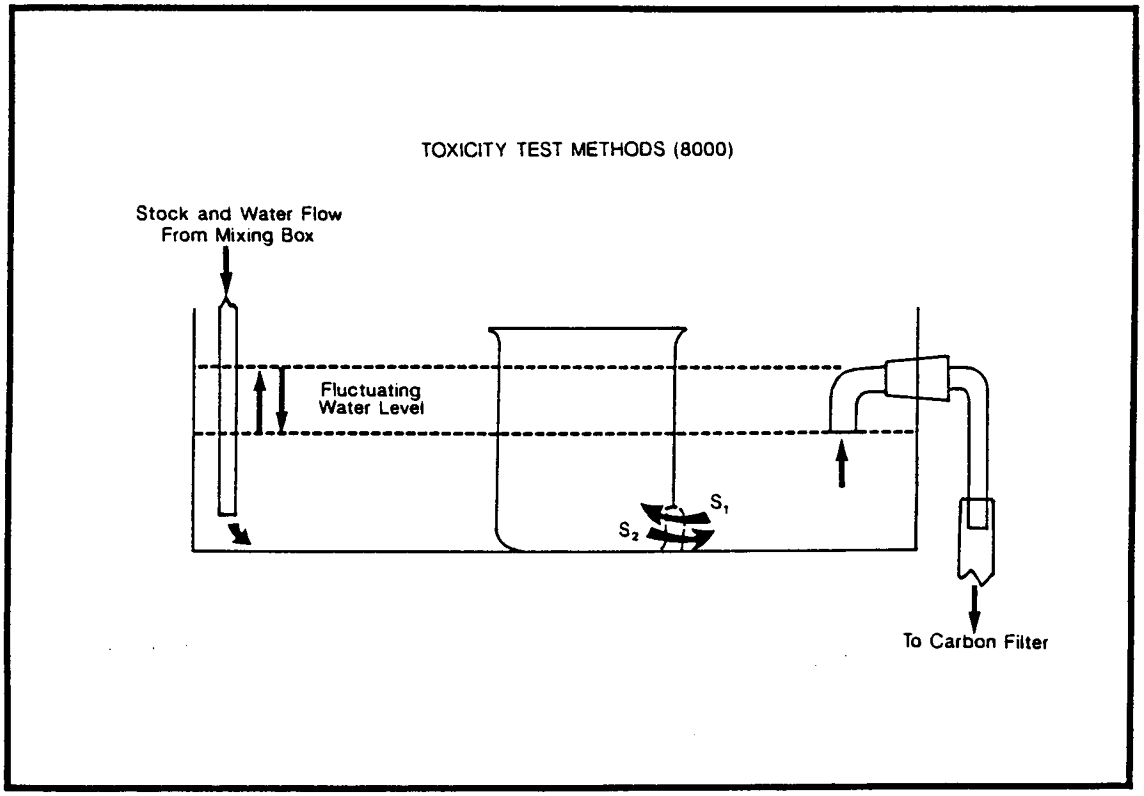

Figure 7.3. Rearing and exposure beaker and automatic siphon for shrimp and crab larvae (adapted from APHA/AWWA/WPCF 1989).

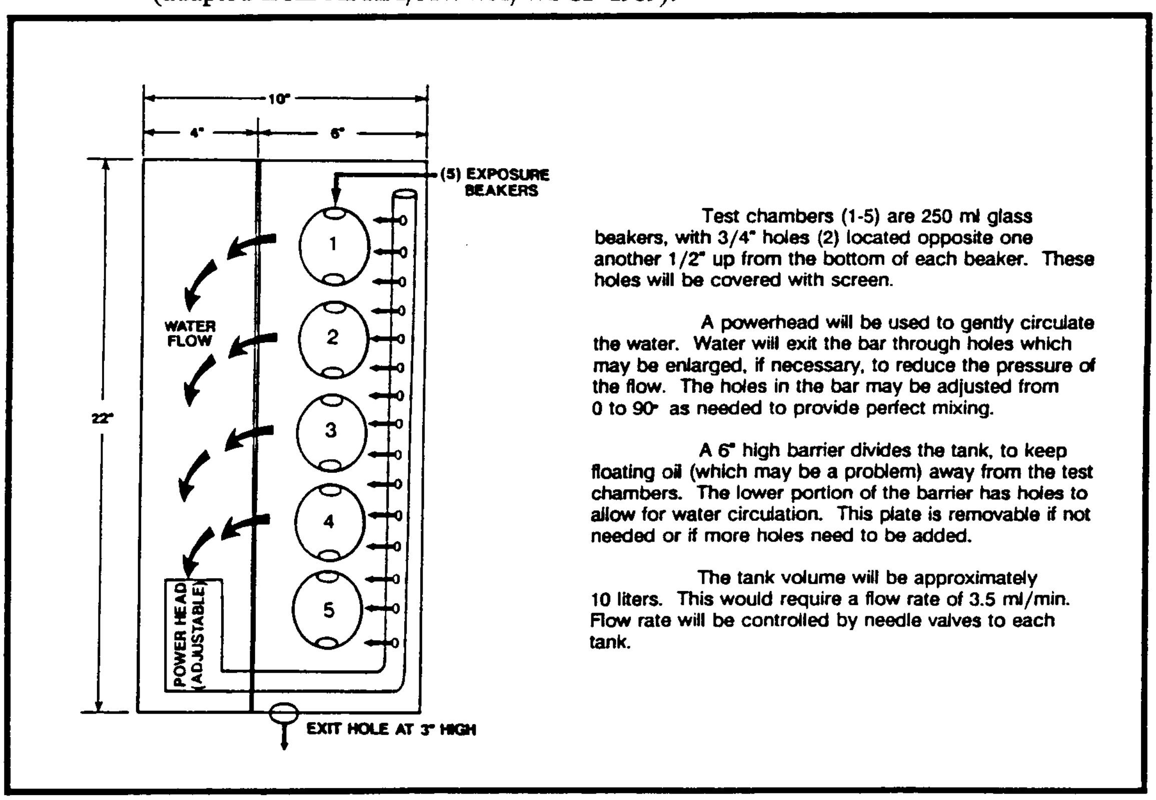

Figure 7.4. Modified test chamber.

Table 7.2. Availability of Test Organisms and Summary of Acute Toxicity Testing.

Month	Species
November	Inland silverside (Option 2)
December	Brown shrimp
January	Redfish
February	Gulf menhaden (Option 1)
March	Spot (Option 3)
April	Blue crab
May	White shrimp
June	Eastern oyster

Summary: Each test has five (5) concentrations with five (5) replicates each and appropriate controls
- Static, static renewal, and flow-through tests
- Oil, oil plus dispersant, and dispersant

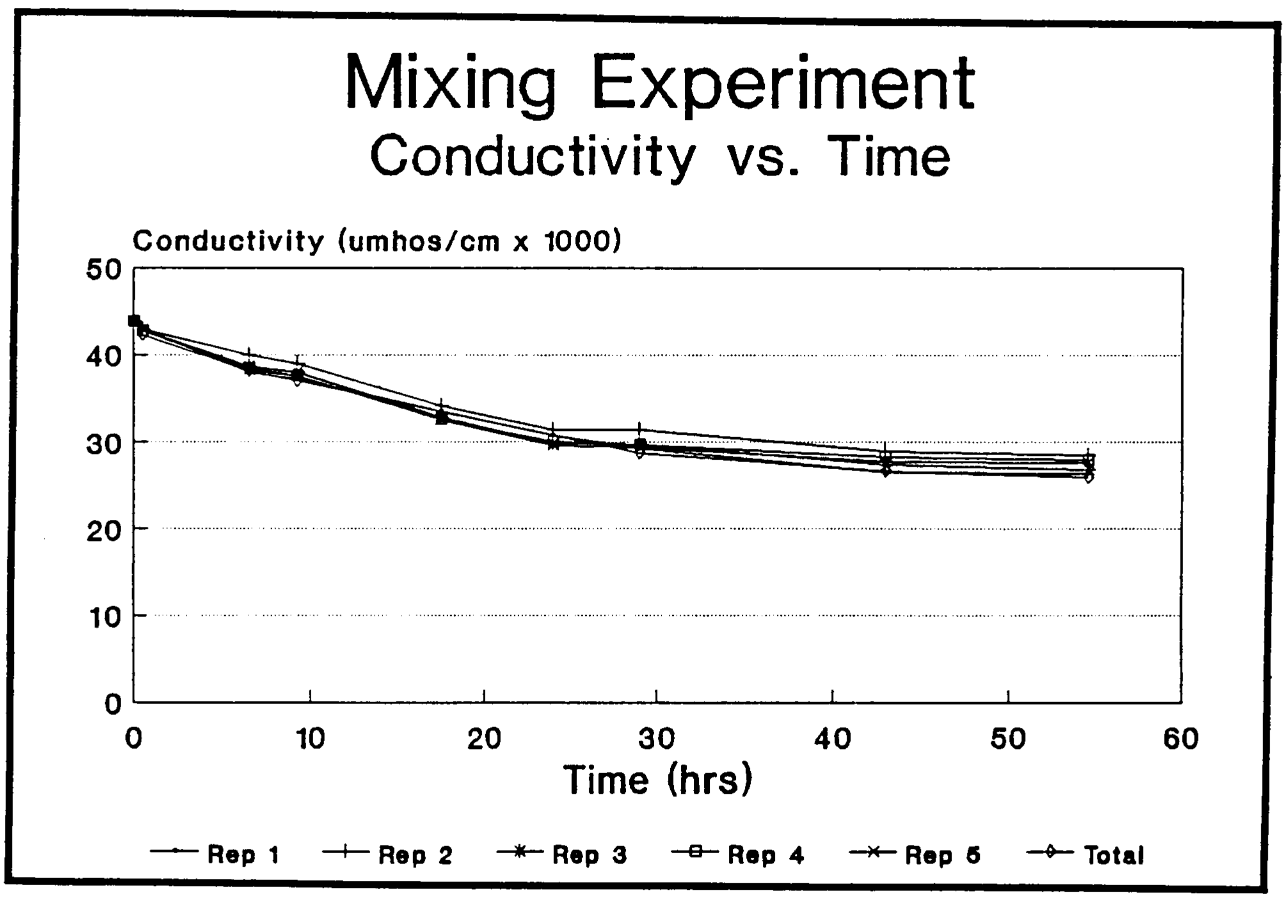

Figure 7.5. Results of mixing tests using a modified test chamber. (Test results with five replicates reflect a comparison of tank versus in-beaker conductivity.)

Table 7.3. Total Numbers of Analyses Proposed for Each Type of Test During the Course of the Project. (Numbers are based upon three tests each with a dispersed and non-dispersed oil scenario for two oils).

Test Type	Time (hrs)	TPH	Purgeable Aromatics	PAH	IR
Static	1	9	15	9	Y*
	2				Y
	4				Y
	6		15	9	
	8				Y
	12				Y
	24	9	15	9	Y
	48			9	Y
	72				Y
	96	9		9	Y
Static Renewal	1	9	15	9	Y
	2				Y
	4				Y
	6	9		9	
	8				Y
	24	9	15	9	Y
	36				Y
	48	9	15	9	Y
	72	9			Y
	96	9		9	Y
Flow-Through	1	9	15	9	Y
	2				Y
	4				Y
	6	9	15	9	
	8				Y
	24	9	15	9	Y
	36				Y
	48	9		9	Y
	72	9		9	Y
	96	9	—	9	Y
Totals		135	135	144+	
Other Tests:					
Oil 1	1 day			2	
	30 days			2	
Oil 2	1 day			2	
	30 days			2	

* = IR will be included on all, or at least a majority, of the toxicity tests
+ = PAH total represents 36 GC/MS (apportioned between initial and last samples in each of the three analytical methods) and 108 GC analyses

fate and effects of oil in the marine environment. He has been an invited lecturer and given training on topics involving oil spill response, dispersants usage, and aquatic toxicity testing. Mr. Fucik received his B.S. degree from Texas Tech University and his M.S. degree from Texas A&M University.

Ms. Susan J. Butler is a Senior Research Associate with T.H.E. Laboratories, Inc., Broomfield, Colorado. Her areas of research interest include the culturing and testing of marine and freshwater organisms for bioaccumulation and acute toxicity testing. Her extensive culturing and bioassay experience encompasses more than two dozen aquatic invertebrate and vertebrate species. Ms. Butler received her B.S. degree in marine biology from Long Island University.

LONG-TERM MONITORING ON THE FLOWER GARDEN BANKS: PRELIMINARY RESULTS

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INTRODUCTION

The East and West Flower Garden Banks (EFG and WFG) are two of many topographic highs in the northwest Gulf of Mexico resulting from diapirism of Jurassic-age salt (Rezak *et al.* 1985). They are 19 km apart, and their summits contain coral reefs between 15 and 36 m depth. The reefs are dominated by massive, head forming corals. The shallowest areas are dominated by *Montastraea annularis* (~26% cover), *Diploria strigosa* (~8.5%), *Porites astreoides* (~3.5%), *M. cavernosa* (~3%), *Colpophyllia natans* (~2.5%), and the hydrozoan *Millepora alcicornis* (~2%) (data from this study). Total coral cover on the reefs averages about 47.5 percent. These six species comprise over 95 percent of this cover. An additional 12 reef-building species total approximately 2 percent cover. Neither acroporids nor shallow-water gorgonian corals are known to occur on the Flower Garden Banks.

The Flower Garden Banks are unique in many respects, not the least of which is the fact that these isolated environments harbor coral reefs very near the northern physiological limits for tropical hermatypic corals in the Gulf of Mexico. Less than 50 km northward, winter temperatures are too low for reef development (Rezak *et al.* 1990). The northerly location of the Flower Garden Banks has resulted in reduced community diversity (Bright *et al.* 1984). Only 18 of the 65 Western Atlantic hermatypic coral species occur. Nevertheless, abundance and growth rates compare favorably with those in more tropical locales at similar depths (Rezak *et al.* 1985).

A program designed for long-term monitoring of these reefs, sponsored by Minerals Management Service (MMS), is being conducted by the Geochemical and Environmental Research Group at Texas A&M University. Environmental concerns at the Flower Gardens include the long-term effect of hydrocarbon production activities (platforms are located within 2 km of the EFG), discrete and cumulative effects of mechanical impacts caused by ship anchors and ground tackle, and long-term natural change caused by events of unknown origin (e.g., coral bleaching and species-specific mass mortalities). Due to the sensitivity of corals, coral reefs are thought to be effective monitors of environmental change. Change under natural conditions is typically slow. Under deteriorating conditions influenced by human activities, change can be gradual or rapid. Under extreme conditions, acute tissue loss is apparent (e.g., Banner 1974). The goal of the monitoring program is to address concerns related to both gradual and punctuated degradation of these unusual offshore ecosystems.

METHODS

Site establishment, field techniques, and laboratory methods have been discussed by Gittings *et al.* (1990) and Gittings and Boland (1991). Briefly, semi-annual cruises were conducted between 1988 and 1991. Monitoring stations were installed in winter of 1988 and spring of 1989. Fifteen days were spent on site installing site boundary markers (four corner eyebolts and floats at each 100 m x 100 m study area), posts for large scale repetitive photography (40 on each bank), spikes for repetitive measurement of accretionary (upward) growth of corals (30 on each bank), and nails for repetitive close-up photography to measure encrusting coral growth (120 on each bank), mapping and tagging stations, and collecting the first samples.

Subsequent cruises were conducted in late winter/early spring and late summer/early fall. Each required approximately four days on site (two days on each bank) using 5-6 dive teams. During each cruise, boundary lines were deployed to mark study area boundaries and quadrants within each area. Twenty 10-m stratified random transects were photographed at each study site by taking adjacent photographs using a camera framer. Encrusting growth stations (13.3 x 19.7 cm) for monitoring lateral growth of *M. annularis* and *D. strigosa* were photographed using a diopter framer attached to an underwater camera. The spikes used to monitor accretionary growth of *M. annularis* were also measured during every cruise. Since it was difficult to ensure secure growth spikes, growth measurements were also made by sclerochronology (annual band measurements) of four cores taken from *M. annularis* heads during May 1990. Repetitive quadrats (8 m^2 each) were photographed using a 2-m tall, T-shaped camera frame. Single frames were shot at each station. Repetitive transects of 100 m length (two on each bank) were videotaped during each sampling effort to show the general conditions of the coral community at each study site and to document changes over time. Additional measurements made during cruises included light penetration, temperature, salinity, and dissolved oxygen (all taken at a depth of 1 m and near the bottom).

In the laboratory, coral, algae, and sponge cover on random transects was measured using a calibrated planimeter (each transect represented a single sample of any given parameter). Also calculated were the number of colonies of each species, the amount of bare coral substrate (most is actually covered by calcareous or other algae), relative dominance of each coral species (% cover relative to total cover), the frequency of occurrence of each species, Shannon-Weaver species diversity (H'), and evenness (the apportionment of individuals, or species cover, among species). Diversity and evenness were calculated using both cover and colony counts. Data were analyzed using a Kruskal-Wallis test (a distribution-free analysis of variance procedure based on ranked data) and Tukey's multiple range test.

For encrusting growth stations, planimetric measurements included areas of tissue advance and retreat, and border length where tissue advanced, retreated, or remained stable between cruises. Growth and retreat were analyzed separately, and data were combined for analysis of net tissue changes over time. The proportions of growing, retreating, and stable margins were plotted on ternary diagrams (three-coordinate plots) to depict temporal patterns of marginal change. This technique was first used to study coral growth on corals impacted by a ship grounding (Gittings *et al.* 1988). The method was useful in determining the deleterious effects of the displacement of coral heads into sandy habitats by the ship.

Templates of repetitively photographed 8 m^2 quadrats (traces of colonies made from projected images) taken during the second cruise (the method was modified after the first cruise) were used to compare later samples in order to identify large scale temporal changes. Individual colony changes and conditions (growth, mortality, disease, bleaching, etc.) were recorded and the fates of colonies affected were determined. Coral counts were made directly. Measurements were made either by planimetry or using a random point-intercept method (100 randomly located points on overlays used to estimate the percent of area covered, or affected by bleaching, disease, or other factors). For the latter, three measurements were made on each image.

RESULTS

Results given below are preliminary and may change somewhat following more rigorous statistical examination. Also, encrusting growth data and repetitive 8 m^2 quadrat have not yet been completed, primarily those from Cruise 6. Video transect data have yet to be analyzed. Sclerochronology data and ancillary data will be presented in the final report to MMS (due in March 1992).

Random Transects

Preliminary data analyses have been conducted on total coral cover, without considering species separately. Total coral cover did not vary significantly ($p > 0.05$) from mean values on either bank and did not differ significantly between banks during any cruise (47.34% on the EFG and 47.99% on the WFG). No significant upward or downward trends occurred. Kraemer (1982) reported cover of 50.42 percent ($45.1 < \mu < 55.7$) and 55.15 percent ($23.8 < \mu < 86.5$) for the EFG and WFG, respectively, but used a different method of analysis (line-intercept method rather than planimetry). Nevertheless, confidence intervals overlap cover estimates acquired in this study. Furthermore, cover for individual species reported by Kraemer were close to those found in this study (all within 2%). Photographs taken in the late 1970's and early 1980's by Kraemer and other investigators will be reanalyzed using current methods for comparison.

Pooled (both banks) coral species diversity indices based on colony counts (standard Shannon-Weaver Diversity Index) showed no differences between cruises, though on Cruises 2, 4, and 6 the WFG had significantly higher H' than the EFG ($p < 0.05$). In fact, the WFG had higher overall H' than the EFG (all samples combined). The opposite was true for diversity based on coral cover (EFG > WFG overall, and on Cruise 5). For this diversity estimate, p_i in the formula $H' = -\Sigma\ p_i \ln p_i$ is relative dominance (defined above). Evenness showed exactly the same patterns as cover, whether based on counts or cover. Though differences between cruises occurred for all diversity and evenness indices, no trends occurred. Confidence intervals for diversity and evenness reported by Kraemer (1982) overlap those found in this study.

Encrusting Growth

Preliminary analysis of data suggests that net growth rates of *M. annularis* and *D. strigosa* at the Flower Gardens were positive for nearly all periods since 1989 (Figure 7.6; Cruise 6 has not yet been analyzed). Net growth takes into account areas of advance and areas of retreat. For *D. strigosa,* net growth averaged 0.08 cm/6 months through Cruise 5 (fall/winter 1990). For *M. annularis,* the rate was 0.12 cm/6 months. By itself, a positive net growth rate is significant. Gittings (1988) found net lateral growth rates of essentially zero on apparently healthy adult corals analyzed in the Florida Keys.

Advance rates and retreat rates were also analyzed separately (Figure 7.7). Though retreat rates often exceed advance rates (corals usually die faster than they grow), the Flower Garden corals exhibited nearly similar rates over much of the study period. This suggests a stable condition where retreat is dictated by natural factors, such as competition for space, rather than man-induced stress (e.g., Gittings *et al.* 1988).

The amount of tissue added vs. the amount lost between cruises is also informative. Figure 7.8 shows that, until Cruise 5, the ratio of tissue lost (retreat) to tissue gained (advance) was less than 1.0. Thus, between the winter of 1988 (Cruise 1) and late summer of 1990 (Cruise 4), significantly more tissue was gained than lost on growth stations for both species. Substantial tissue loss occurred between Cruises 4 and 5, as indicated by high Cruise 5 retreat to advance ratios for all *D. strigosa,* and for *M. annularis* on the WFG.

Ternary plots depict the "condition" of coral margins at growth stations by comparing the relative amounts of advancing, retreating, and stable margins. Both banks and both species exhibited high standards compared to locations studied in the Florida Keys (Figure 7.9; Gittings *et al.* 1988). With the exception of Cruise 5, all data indicated high proportions of marginal growth. Data from Cruise 6 are clearly required to elucidate the abrupt change in coral growth shown in Cruise 5 data.

Accretionary Growth

Data from 26 of 30 stations on the WFG and 23 of 30 stations at the EFG were used to calculate accretionary growth (Table 7.4). Data were not used from sample periods when stations had loose growth spikes.

Accretionary growth rates were also measured for separate intervals between cruises. Rates averaged 3.5 mm for six month periods (7.0 mm/year). No seasonal or site differences, or trends occurred.

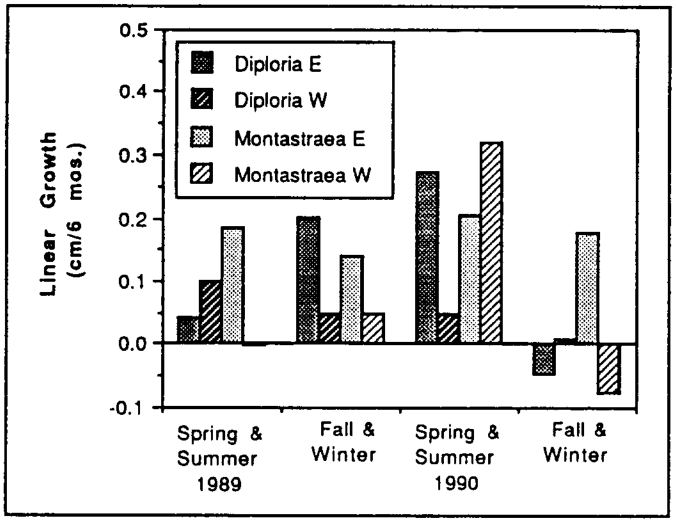

Figure 7.6. Net linear growth rates of *Diploria strigosa* and *Montastraea annularis* at the East and West Flower Garden Banks through winter 1990/1991.

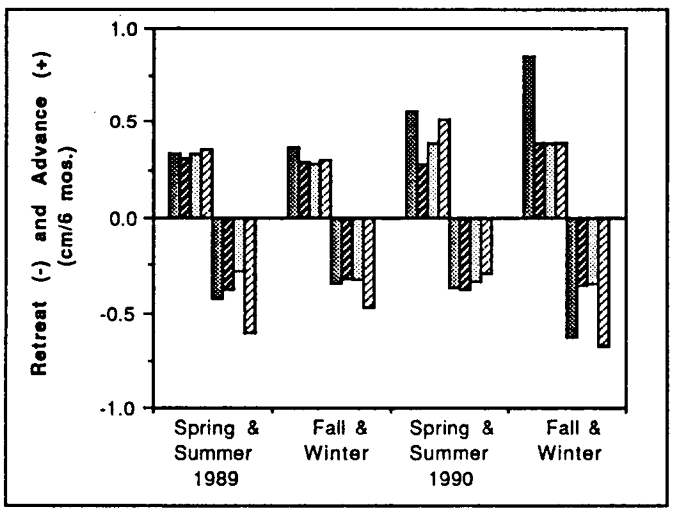

Figure 7.7. Advance rate of growing tissue and retreat rates of tissue lost by *D. strigosa* and M. *annularis* at the East and West Flower Garden Banks through winter 1990/1991. (Legend as in Figure 7.2).

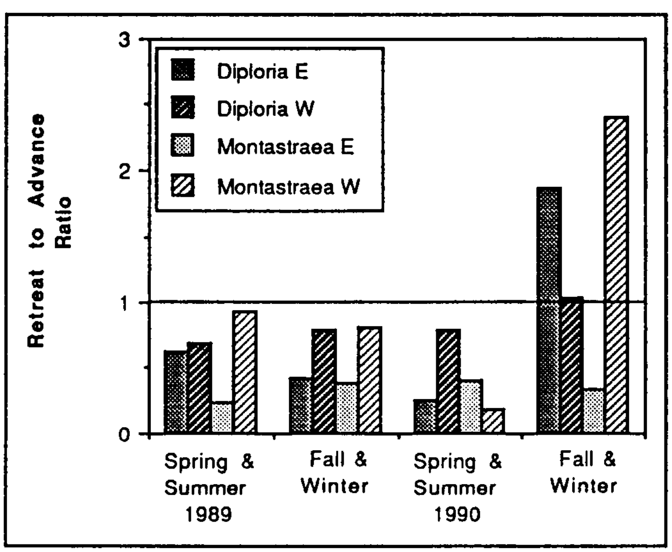

Figure 7.8. Retreat to advance ratios, based on sums of areal measurements of tissue gained and lost, through winter 1990/1991 on *D. strigosa* and *M. annularis.* (Ratio greater than one indicates more tissue lost than gained between time periods).

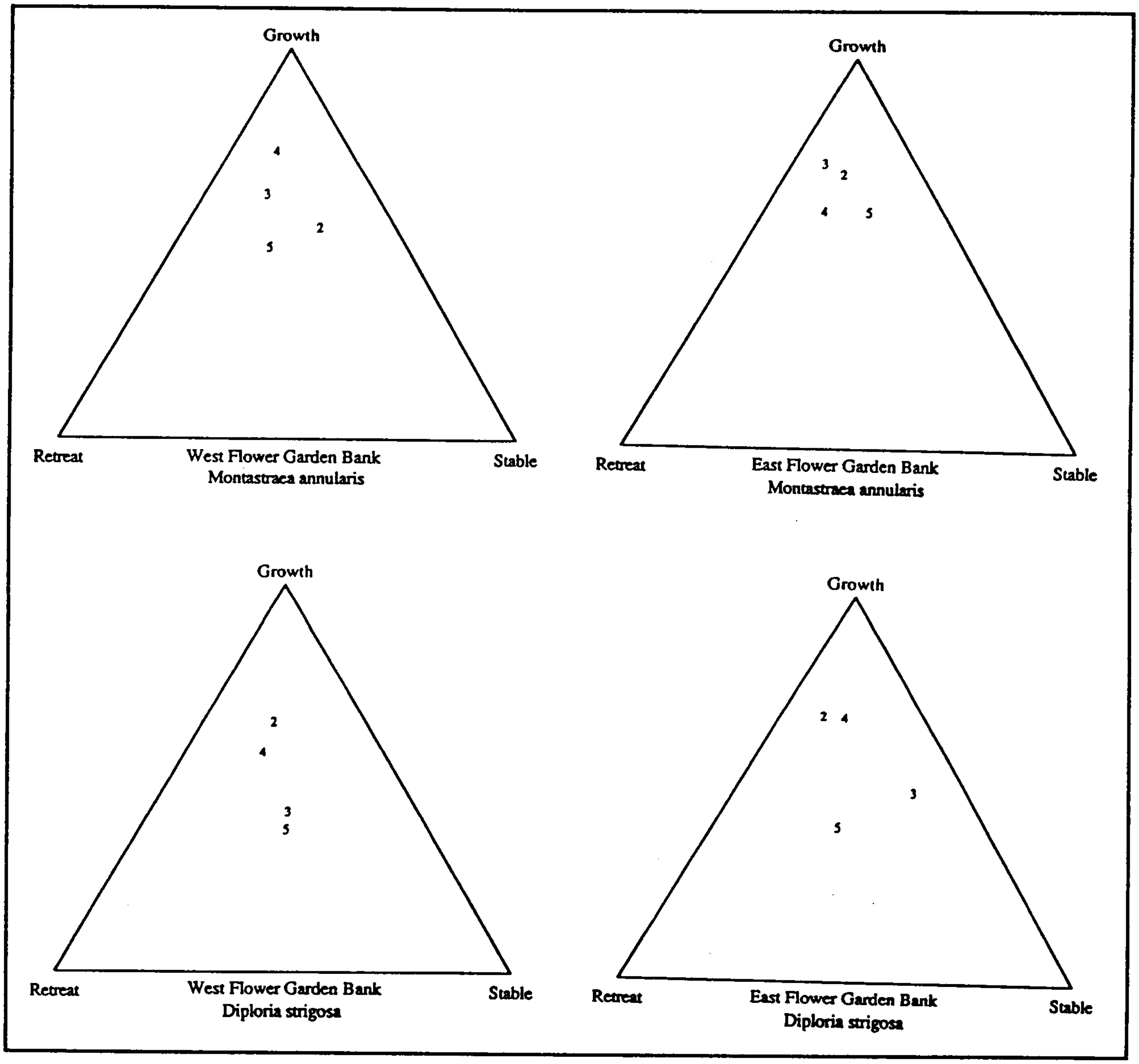

Figure 7.9. Ternary diagrams showing proportions of coral margins advancing, retreating, and remaining stable between cruises through winter 1990/1991. (2 indicates data between Cruises 1 and 2; 3 indicates data between Cruises 2 and 3, and so on).

Repetitive 8 mg Quadrats

This method has proven effective in augmenting random transect data, and for monitoring gradual and acute changes in individual coral colonies. A number of stations remain to be completed, but over 2,000 colonies have been individually analyzed at 40 stations on the EFG through Cruise 5. On 24 stations completely analyzed for cover at the WFG, coral cover averaged 46.1 percent; coral populations averaged between six and seven colonies m^{-2}.

Coral growth was clearly identifiable at repetitive stations, but was difficult to quantify due to the large scale of the stations (1082 occurrences at EFG stations through Cruise 5). Coral mortality was even more clearly identifiable, particularly when

Table 7.4. Accretionary Growth Measured from Growth Spike Installed on 30 *Montastraea annularis* Colonies on Each of the East (EFG) and West (WFG) Flower Garden Banks.

	WFG	EFG
Mean Growth (mm/yr)	6.48	7.19
Range (mm/yr)	2.70-11.36	3.69-12.70
N	26	23
Standard Dev.	2.30	2.45
Mean Sample Period	663 days	616 days

acute. Incidental mortality from all causes, while frequent (738 occurrences; 695 excluding disease), usually occurred on a very limited scale (commonly several cm^2 on a colony between cruises). Nearly all extensive mortality appeared to result from "ridge-crest" or unidentified diseases (?) (41 occurrences at the EFG through Cruise 5, 74 percent resulting in comparatively large-scale tissue mortality by the end of the project period). No black band or white band disease has been identified at the Flower Gardens.

Minimal coral recruitment was identified at repetitive stations during the period of this study. It is likely that juvenile corals require several years (5 to 10) of growth before being identifiable at the scale used in repetitive quadrat photos.

Repetitive photography was useful in examining the extent of coral bleaching and the fate of bleached colonies. Of the 24 WFG stations so far analyzed for cover, bleaching affected 0.3 percent of coral cover during Cruise 2, 1.7 percent on Cruise 4, and slightly less than 0.1 percent on Cruise 6 (all late summer periods). Less than 7 percent (7 of 103) of coral colonies observed to bleach at the EFG through Cruise 5 showed any evidence of mortality. Those that were affected usually exhibited minor tissue loss. Only one small colony out of 103 bleached colonies died entirely. Interestingly, "paling" (pale color that may be due to partial loss of zooxanthellae) or bleaching often recurred in the same colonies and in the same pattern within colonies every summer. Mortality was no higher in colonies that underwent recurrent paling or bleaching than in other colonies. Species most affected by the phenomenon were *Millepora alcicornis* and *Montastraea cavernosa*.

Satellite and Thermograph Data

Temperature data were positively correlated with bleaching events observed on the Flower Garden Banks. During 1990, bleaching was observed on both banks following a period of time when summer bottom temperature peaked above 30°C. During that year, sea surface temperatures were significantly higher than an 11-year mean (calculated from advanced very high resolution radiometer satellite-derived data from 1979-1989; Figure 7.10) for over half the year. No years between 1979 and 1989 exhibited such prolonged excursions.

Ryan TempMentor thermographs were installed on the banks in 1990 to record bottom temperature every two hours (thermographs courtesy of the National Oceanic and Atmospheric Administration, Sanctuaries and Reserved Division). In 1991, coral bleaching was again observed after the summer temperature maximum, but was much more prevalent on the EFG. Thermograph data indicated that water temperature exceeded 30°C for over a week on that bank, but never exceeded 30°C on the West Bank.

DISCUSSION

The data collected during this study appear to confirm that the Flower Garden Banks harbor coral reef communities as viable and active as any existing elsewhere. Coral growth rates are comparable to those reported elsewhere (Rezak *et al.* 1985). Marginal growth conditions may exceed other high latitude reefs. Coral cover and colony development exceed that on many Atlantic reefs. Diseases occur, but are not widespread. Asexual and sexual reproduction occur in both brooding and broadcasting species (Gittings *et al.* in prep.).

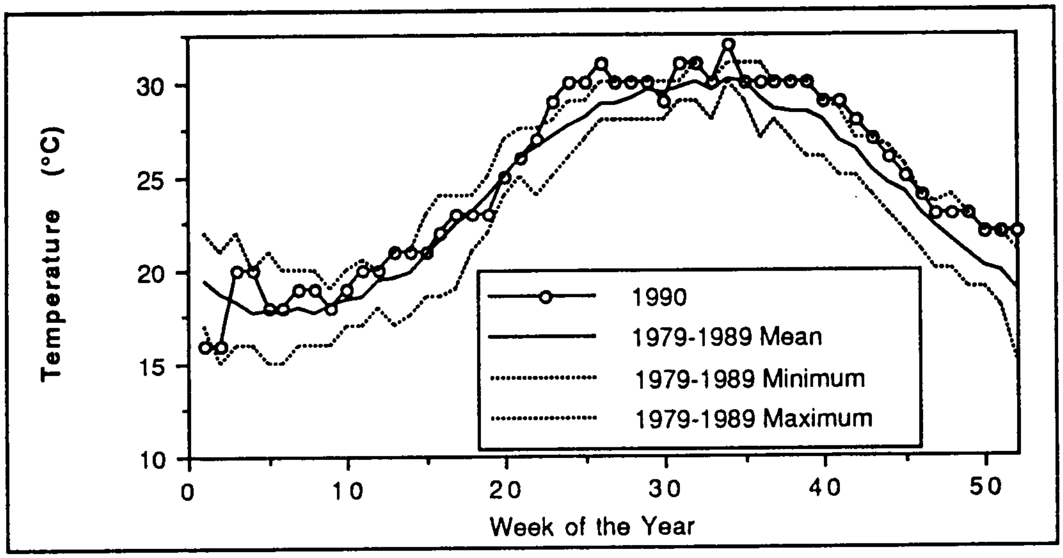

Figure 7.10. Satellite-derived sea surface temperature during 1990 (open circles) compared to an 11-year mean (solid line) based on 1979 and 1989 data. (Also given is the range of values between 1979 and 1989 [dotted lines indicate maxima and minima]).

Recruitment of brooding species is comparable to that measured elsewhere (Baggett and Bright 1985). Further, no trends have been observed that suggest any significant deterioration of habitat quality or community attributes (such as cover, diversity, etc.). Current efforts are being directed toward investigating individual species changes on the banks, comparison of historical data collected at the Flower Gardens, completion and statistical analysis of encrusting growth data, and completion of repetitive quadrats, coral core analyses, and videotape review.

The remote location of the Flower Garden Bank has left them, for the most part, undisturbed. Potential industrial effects caused by offshore development in the northwest Gulf have been monitored, but never detected. It is hoped that designation of the Flower Garden Banks as a National Marine Sanctuary will encourage continued environmental monitoring and foster research on important functional attributes of these unique coral reefs.

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Dr. Steve Gittings is an Assistant Research Scientist at the Geochemical and Environmental Research Group and Graduate Faculty Member in Oceanography at Texas A&M University. He studies the biology and ecology of coral reefs, hard-bottom ecosystems, and human impacts in these environments. He received a B.S. in biology from Westminster College (New Wilmington, Pennsylvania, 1979) and an M.S. (1983) and Ph.D. (1988) in oceanography from Texas A&M University.

Mr. Ken Deslarzes is a graduate student at Texas A&M University pursuing a Ph.D. in oceanography. His current research interests are the analysis of coralla to detect historic water quality trends and coral reef monitoring. He received a Licence of Biology in 1987 and a Diploma of Biology in 1990 from the University of Lausanne, Switzerland.

Mr. Derek Hagman, a graduate student pursuing an M.S. degree in oceanography, is studying long-term biotic changes at the Flower Garden Banks by comparing data sets acquired in the 1970's with recent data. He received a B.S. degree from Texas A&M University at Galveston in 1990.

INCORPORATION OF TRACE ELEMENTS IN THE CORAL *MONTASTRAEA ANNULARIS* AT THE WEST FLOWER GARDEN BANK, NORTHWEST GULF OF MEXICO

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Department of Oceanography
Texas A&M University,
and
Dr. Stephen R. Gittings
Geochemical and Environmental
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Department of Oceanography
Texas A&M University

INTRODUCTION

Trace metals are found in annual growth bands of reef-building corals (Livingston and Thompson 1971). Elemental characteristics of coral skeleton may reflect changes in seawater composition. Thus, seawater composition changes resulting from dissolved materials discarded during industrial activities in the northern Gulf of Mexico may be reflected in coral skeletons on the Flower Garden Banks. More than two million metric tons of barite have been discharged on the Gulf of Mexico Outer Continental Shelf since 1978 (10,000 new wells). There is growing evidence that a significant portion (50% or more) of the barite dissolves, releasing contaminant trace metals, or is rapidly advected to the shelf/slope break. These processes could be altering trace element and organic levels in the fauna of the Flower Garden Banks. Coral skeletal material is particularly well-suited for studies of barium (Ba) because Ba substitutes for calcium during calcification at a fairly rate (ppb range). We chose, therefore, to analyze reefbuilding corals at the Flower Gardens to determine whether they have incorporated increased amounts of Ba following increases in industrial activity. Preliminary results of Ba incorporation from 1910 to 1990 are presented.

METHODS

Skeletal samples of *Montastraea annularis* from the Flower Garden Banks were analyzed by Instrumental Neutron Activation Analysis (INAA) for their trace metal content. The INAA was performed at the Center for Chemical Characterization and Analysis at Texas A&M University. Annual growth bands from 1910 to 1990 were taken from one *M. annularis* core sampled at the West Flower Garden Bank. Sclerochronology (Hudson *et al.* 1976) was applied to core slabs to delimit annual growth bands which were removed and prepared for INAA following Shen and Boyle (1988).

PRELIMINARY RESULTS

The INAA data have been acquired from annual growth bands from 18 years (two years contain replicate samples). Radiation counts after INAA have been done for Ba and calcium (Ca). Measures of Ba/Ca molar ratios in corals at the Flower Gardens and in the Florida Straits (data from Shen and Boyle 1988) are presented in Figure 7.11.

The Ba/Ca molar ratios at the Flower Gardens were generally higher than those from the Florida Straits. No significant trends were found based on these preliminary data. However, 1985 and 1989 replicates show consistently higher ratios than those prior to 1970. This coincides with a significant increase in drilling activity on the Outer Continental Shelf in the vicinity of the Flower Garden Banks (Figure 7.12).

DISCUSSION

It should be noted that the relationship between Ba/Ca molar ratios and drilling activity has not been shown to be statistically significant. Also, increases in Ba/Ca molar ratios at the level observed here have not been demonstrated to have any effect on coral growth or other essential functions. Current efforts include analysis of annual samples not yet analyzed, analysis of three other cores taken from the Flower Garden Banks, increasing the number of replicate samples, and examination of correlations between Ba signals and coral growth rates. Moreover, the level of sensitivity of Ba detection could be increased by isolating Ba from the coral lattice (i.e., separating the incorporated Ba from the coral) by post-irradiation chemistry.

Future INAA radiation counts could also provide time series data for other trace metals such as zinc and chromium, which are also altered by anthropogenic sources. In addition, tissue studies of the Atlantic thorny oyster (*Spondylus americanus*), a reef-dwelling bivalve which filters seawater, and for which data were obtained in the 1970's from the Flower Gardens, may be useful in elucidating possible water quality changes on the Outer Continental Shelf.

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Mr. Ken Deslarzes is a graduate student at Texas A&M University pursuing a Ph.D. in oceanography. His current research interests are the analysis of coralla to detect historic water quality trends and coral reef monitoring. He received a Licence of Biology in 1987 and a Diploma of Biology in 1990 from the University of Lausanne, Switzerland.

Dr. Paul Boothe has been a Research Scientist in Chemical Oceanography at Texas A&M University

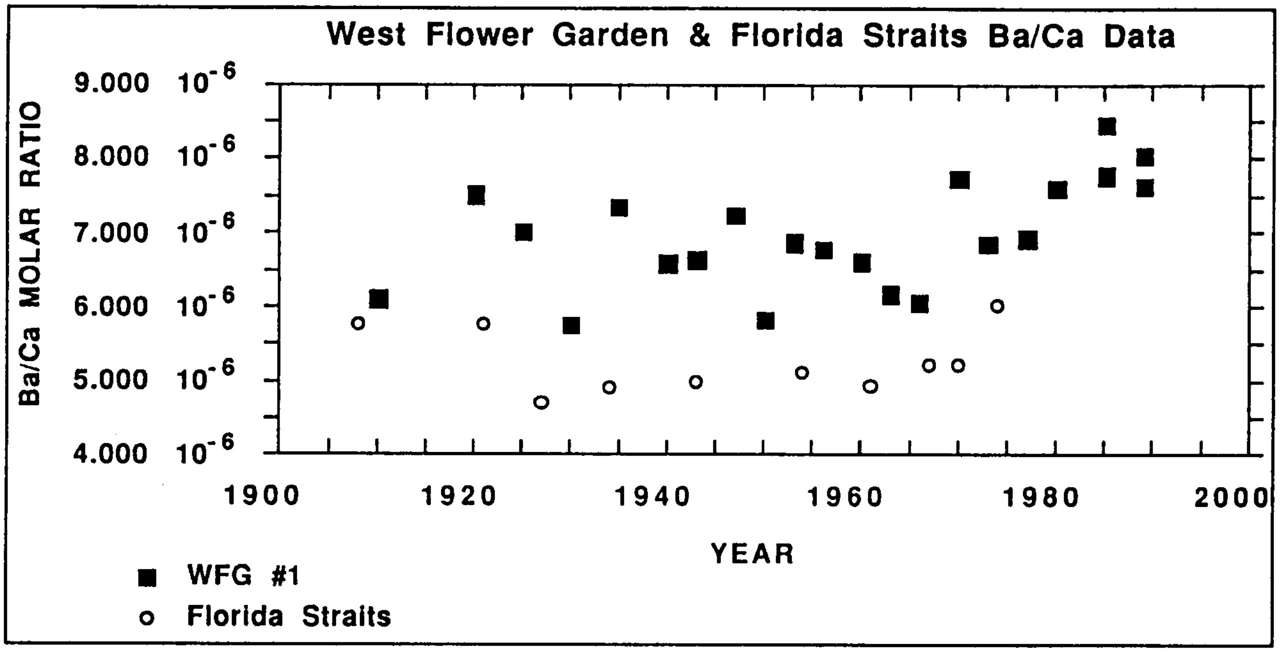

Figure 7.11. Barium to calcium molar ratios in samples taken from a core of *Montastraea annularis* at the West Flower Garden Bank.

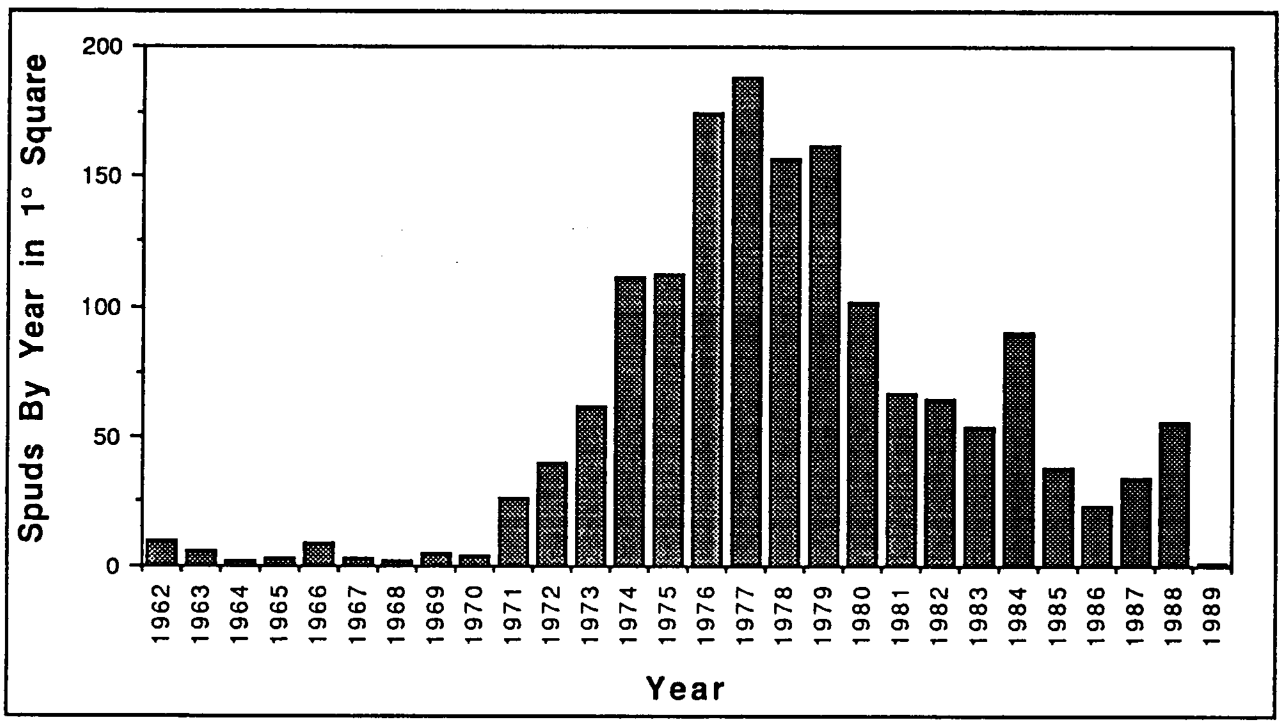

Figure 7.12. Drilling activity (spuds by year) in the region bounded by 28°N and 29°N, and 93°W and 94°W (MMS 1989).

since 1981. His current research includes the biogeochemistry of trace elements in marine systems and environmental chemistry.

Dr. Steve Gittings is an Assistant Research Scientist at the Geochemical and Environmental Research Group and Graduate Faculty Member in Oceanography at Texas A&M University. Dr. Gittings studies the biology and ecology of coral reefs, hardbottom ecosystems, and human impacts in these environments. He received a B.S. in biology from Westminster College (New Wilmington, Pennsylvania, 1979), and M.S. (1983) and Ph.D. (1988) degrees in oceanography from Texas A&M University.

THE EFFECTS OF OIL SPILLS ON THE CORALS OF THE GULF OF EILAT, RED SEA

Dr. Yossi Loya
Faculty of Life Sciences
Tel Aviv University

No abstract will be submitted due to prior publication.

Dr. Yossi Loya is a professor at the Tel Aviv University, Tel Aviv, Israel, where he also serves as the Dean of the George S. Wise Faculty of Life Sciences. Professor Loya has been conducting research on corals and coral reefs for nearly 20 years. His specific interests include the effects of oil on, and the reproductive ecology of, the hermatypic corals of the Red Sea.

MISSISSIPPI-ALABAMA CONTINENTAL SHELF ECOSYSTEM STUDY: SUMMARY AND SYNTHESIS

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and
Dr. James M. Brooks
Geochemical and Environmental
Research Group
Department of Oceanography
Texas A&M University

INTRODUCTION

Along the coast of eastern Louisiana, Mississippi, and Alabama the marshlands, bays, sounds, and continental shelf together comprise a major ecological system of interrelated sub-units. This system is bound together through the exchange of water, inorganic and organic materials, and living organisms. Portions of the system are subject to natural catastrophic events including floods, droughts, cold waves, storms and hurricanes, red tides, and hypoxia. During the past two decades human pressure upon the system has been mounting to the detriment of the biological populations. In advance of possible further intrusion into shelf waters through the expansion of oil and gas related activities, the Minerals Management Service has commissioned a study of major aspects of the continental shelf ecological system. This study is now complete, and the present report summarizes some of the salient findings interpreted in light of the historical literature.

Regular sampling and measurement of environmental factors were carried out on three winter and two summer cruises during the period January 1987 - February 1989, and data on the physical environment and topographic features were obtained during additional cruises. On the regular cruises, sampling and study stations were made at four depths (20 m, 60 m, 120 m, and 200 m) along each of three transects (Chandeleur, Mobile, and DeSoto Canyon). Data and specimens are processed in the laboratory, and the resulting information has been synthesized to provide a coherent picture of the shelf ecological system.

THE WATER COLUMN

During the winter months the water column is thoroughly mixed, nutrients are fairly high, and phytoplankton populations achieve maximum abundance. Standing crops and productivity levels, although higher than those of the open Gulf, are considerably lower than those of the shelf west of the Mississippi River Delta. With the availability of an abundant food supply, zooplankton populations achieve highest levels in late winter and early spring. River discharge becomes elevated in February, peaks in March, and falls to low levels by May. This outflowing fresh water brings to the shelf considerable quantities of fine sediment and terrestrial plant debris. During the summer months the shelf waters are thermally stratified, but there is no evidence of major hypoxia such as occurs on the shelf west of the Mississippi River Delta. By late summer or early fall, with breakdown of stratification and reestablishment of vertical mixing, a second and smaller phytoplankton bloom occurs. Mobile fish and invertebrate species which use the bays and estuaries as nursery areas during the winter and spring begin to reappear on the shelf during early summer and continue to emerge through the fall months when the major emigration takes place. Larger predatory nektonic fish species, which overwinter in more tropical waters, become summer residents and utilize the Mississippi-Alabama shelf as summer feeding grounds before heading south in the fall. Major storms may strike the shelf at any season, and Gulf Loop Current intrusions apparently sweep the shelf several times a year, partially or completely replacing the shelf waters and removing much of the fine sediments to the deeper Gulf.

BENTHIC ENVIRONMENT AND BIOTA

Surface sediments consist of an extensive sand sheet over the northeast half and finer silts and clays over the southwest half of the shelf. Calcium carbonate is an important constituent at deeper stations near DeSoto Canyon. Organic carbon is low in shallow waters and elevated at the deeper stations. The delta carbon 13 values are highest during the summer months indicating an influx of terrestrial plant debris during the spring outflow of river water. High molecular weight hydrocarbons tend to be most concentrated along the Chandeleur transect and at deeper stations of the other transects, and this same pattern is shown by the heavy metals. Concentrations of both hydrocarbons and heavy metals are quite low indicating a relatively unpolluted shelf.

Infaunal invertebrate populations were generally highest in the sandy sediments of the northeast and lowest in the finer sediments of the southwest, and this pattern held true for the dominant groups, the polychaetes and crustaceans. The more mobile epifaunal invertebrates, particularly the shrimp, were most abundant at all depths of the Chandeleur transect during the summer. In the winter they were rare in shallow water and peaked at the two deepest stations of the Chandeleur transect and the deepest station of the Mobile transect. During the summer the demersal fish populations achieved greatest density at the three shallowest stations of the Chandeleur transect and at the 60 m station of the DeSoto Canyon transect. In the winter they were more widely dispersed at the three shallower stations and rare at the deepest stations of all transects.

Topographic features in the 60-120 m depth range, including flat-top reefs and pinnacles, were found to be inhabited primarily by attached, live-bottom communities of sponges, soft corals, and crinoids, as well as associated echinoderm and fish faunas. Lying largely below the euphotic zone, these communities are trophically dependent upon imported zooplankton and organic detritus. Most of the fauna of the topographic features is locally unique and was not found on the surrounding soft bottoms.

CATASTROPHIC EVENTS

During the winter of 1989 collections of epifaunal invertebrates and fishes revealed dramatically reduced populations at most stations, the values in many cases being only from 2 to 25 percent of the normal winter catch. Environmental data reveal that the previous months were characterized by a major drought, two tropical storms, three hurricanes, and two Loop Current intrusions. Of all these events, the September hurricane which passed directly through the area is considered to have been the most locally devastating factor.

MANAGEMENT IMPLICATIONS

Information deriving wholly or in part from the present project which should be particularly relevant to management needs includes the following.

- Normal variation--The seasonal patterns of physical and biological events and their variations have been characterized.
- Chemical pollution--The relative absence of chemical pollution by high molecular weight hydrocarbons and heavy metals has been established.
- Natural catastrophism--The episodic occurrence of natural catastrophic events affecting inshore and shelf biological populations has been documented.
- Biological resiliency--The ability of the biological populations to recover from the effects of natural catastrophic events has been demonstrated or inferred.
- Areas of special concern--Areas of unique and/or sensitive biological communities were found to include those associated with topographic high features (flat-top reefs and pinnacles) as well as the DeSoto Canyon area.
- Research needs--Additional information is needed on a number of topics of which the following appear to be the most critical: water currents and the inducing factors, Loop Current intrusions, summer stratification, inshore/shelf interactions, and physical and biological characteristics of the DeSoto Canyon area.

Dr. Rezneat M. Darnell is professor of Oceanography at Texas A&M University. He has investigated ecosystem composition and dynamics of streams, estuaries, and continental shelves. Recently, he has examined the distribution of demersal fish and shrimp populations of the U.S. Gulf of Mexico continental shelf in an effort to discern the structure of shelf communities and to develop appropriate management implications. He has also studied factors responsible for the transport of larval fishes, shrimp, and crabs and has contributed to the understanding of estuarine and marine food webs.

Dr. James M. Brooks is a Senior Research Scientist and Director of the Geochemical and Environmental Research Group in the Department of Oceanography at Texas A&M University. He is Project Manager for the Mississippi/Alabama Marine Ecosystem Study. His expertise is in trace contaminant analysis and marine chemistry. He has authored over 100 papers.

SOCIAL AND ECONOMIC STUDIES AND ISSUES

Session:	SOCIAL AND ECONOMIC STUDIES AND ISSUES
Co-Chairs:	Ms. Linda Castaño-Vélez Mr. John Greene
Date:	November 6, 1991

Presentation	Author/Affiliation
Social and Economic Studies and Issues: Session Introduction	Ms. Linda Castaño-Vélez and Mr. John Greene Minerals Management Service Gulf of Mexico OCS Region
Socioeconomic Impacts of Declining Outer Continental Shelf Oil and Gas Activities in the Gulf of Mexico	Mr. Lawrence S. McKenzie, III Applied Technology Research Corp.
The Environmental Costs of Outer Continental Shelf Oil and Gas Development and Marine Oil Spills	Mr. Garry L. Brown Kearney/Centaur Division A.T. Kearney, Inc. and Mr. Richard Winnor Minerals Management Service Headquarters
Impacts of Oil and Gas Exploration, Development, and Production on the Recreation and Tourism Off the Florida Straits	Mr. Garry L. Brown Kearney/Centaur Division A.T. Kearney, Inc.
An Economic Perspective on the Theory and Practice of Social Impact Assessment: Economic Focus	Dr. F. Larry Leistritz North Dakota State University, Fargo
A Socio-Cultural Perspective on Theory and Practice of Social Impact Assessment: Social Focus	Dr. C. Hobson Bryan The University of Alabama
Minerals Management Service Socioeconomic Workshop Plans	Dr. Shirley Laska University of New Orleans and Dr. Robert Gramling University of Southwestern Louisiana

SOCIAL AND ECONOMIC STUDIES AND ISSUES: SESSION INTRODUCTION

Ms. Linda Castaño-Vélez
and
Mr. John Greene
Minerals Management Service
Gulf of Mexico OCS Region

Social and economic concerns regarding the potential impacts from Outer Continental Shelf (OCS) oil and gas activities are significant to the government of those States bordering the Gulf of Mexico. Each Gulf State holds a particular mix of social, economic, and environmental characteristics which provide a unique set of circumstances for socioeconomic analysis and decisionmaking regarding the OCS Program.

In efforts to strengthen the existing socioeconomic information base and to respond to concerns expressed by state government and other interested parties regarding social and economic impacts from potential OCS activities, the Minerals Management Service (MMS) has undertaken a number of study initiatives in this area. Presentations on the results of three such studies are part of this Information Transfer Meeting session. They are a study of the socioeconomic impacts of declining oil and gas activity in the Gulf of Mexico, a study of the environmental costs of OCS oil and gas development and marine oil spills, and a study of the impacts of oil and gas development on the recreation and tourism off the Florida Straits.

Another MMS initiative in this area is a conference on the impacts of offshore oil production on Gulf Coast communities which is scheduled for late spring or early fall next year in New Orleans. Plans for this conference will be discussed during our last presentation this morning.

The remaining two presentations in this session will address the theory and practice of socioeconomic impact assessment. One will provide an economic perspective and the other a social focus on the issue.

Ms. Linda Castaño-Vélez is an economist with the Leasing Activity Section of the Minerals Management Service Gulf of Mexico OCS Region. Prior to her association with the Minerals Management Service, Ms. Castaño-Vélez worked as a planning engineer and as a forecast analyst for Entergy Corporation in New Orleans. She earned a B.S. degree in engineering from Tulane University in 1984.

Mr. John Greene received his B.A. in anthropology from the University of New Orleans in 1979. From 1980 to 1988, Mr. Greene worked for the Archaeological and Cultural Research Program of the University of New Orleans, as well as performing private consulting. While working as a research associate, Mr. Greene completed classwork for an M.S. in geology at the same university. Mr. Greene has authored or co-authored over 20 research reports on the archaeology, geology, and history of southeast Louisiana.

SOCIOECONOMIC IMPACTS OF DECLINING OUTER CONTINENTAL SHELF OIL AND GAS ACTIVITIES IN THE GULF OF MEXICO

Mr. Lawrence S. McKenzie, III
Applied Technology Research Corp.

Two objectives of the project were:

- to determine and analyze the socioeconomic impacts of the early and mid 1980's price related decline in Outer Continental Shelf (OCS) oil and gas activities; and
- to use the results to evaluate the impacts of a resource depletion decline including an evaluation into what areas of the Gulf of Mexico (GOM) will be most affected.

The study area covers 49 counties and parishes located along the GOM and adjoining inland metropolitan area counties and parishes

(Figure 8.1). The area extends from Brownsville, Texas, to Gulf Shores, Alabama.

The impacts analyzed were associated with the drop in the price of oil and gas which occurred between 1981 and 1982 and during 1985 (Figure 8.2). Significant changes in population growth accompanied the price drop.

From 1981 to 1982, the population in the study area increased at a rate of nearly four times the national average (Figure 8.3). Two years later, the rate of population increase in the study area was half that of the United States.

In southwest Louisiana (coastal area C1), the annual percentage change in population shifted from three times the national average to a net population loss in a two year period (Figure 8.4). Along the upper Texas coast, the population growth rate was five times the national average in 1982 but was reduced to one-third the national average by 1985 (Figure 8.5).

Between 1981 and 1982, the net change in population associated with migration was in excess of 200,000 people (Figure 8.6). Net migration dropped to approximately 64,000 between 1982 and 1983. In the following year, the net migration amounted to a negative 61,000 (the equivalent of 167 people or about 67 families per day).

The socioeconomic impacts determinations involved regression analyses using oil and gas activity indicators from the seven planning areas as independent variables and demographic and economic data from the 49 counties and parishes in the study area aggregated by coastal analysis area (Figure 8.7). The assignment of OCS activity was performed using the Minerals Management Service (MMS) Allocation Impact Model based on data from plans of exploration.

The initial regression analysis (number of OCS exploratory wells drilled by number of mining sector jobs and OCS barrel equivalents production by number of mining sector jobs) revealed a string of outlyers associated with the upper Texas coast (coastal area W2) for (Figures 8.8 and 8.9). These outlyers contributed to low r-square values (.08 and .12, respectively). Significant increases in r-square values resulted when data for the upper Texas coast (coastal area W2) were excluded from the analysis (Figure 8.10).

The results from the initial analysis pointed to the need to redefine the impact area within the study area and to include those counties and parishes strongly impacted by OCS activity in further analysis.

Data from the U.S. Bureau of Economic Analysis showed that 206,140 mining sector jobs existed within the study area during 1984 (Figure 8.11). About half of these jobs were located in Harris County, Texas (Houston), 9 percent in Lafayette, Louisiana, and 8 percent in New Orleans, Louisiana.

Select data for 1984 were reviewed from the Year One Study entitled "Indicators of the Direct Economic Impacts Due to Oil and Gas Development in the Gulf of Mexico." Data for that study were obtained from member companies of the Offshore Operators Committee. Approximately 23,935 person-years employment at production companies associated with GOM offshore oil and gas activities was documented.

New Orleans was identified as the work site for 45 percent (10,219) of the OCS offshore production workers identified in the Year One study (Figure 8.12). Other areas with relative large proportions of workers included: St. Mary Parish, 3,577 (16%); Plaquemines Parish, 2,439 (11%); Lafourche Parish, 1,669 (7%), Lafayette Parish, 1,289 (6%). Only 1 percent (301 workers) were identified as having their work site located in Harris County, Texas.

Offshore production jobs were expressed as a percent of mining jobs by place (county or parish) of work (Figure 8.13). Note that the offshore production jobs identified in the Year One Study accounted for not more than 1 percent of the mining jobs in Harris County, Texas. The low proportion of offshore production jobs as a percent of all mining jobs in the W2 coastal area was determined to account for the outlyers. The area does have many mining industry jobs, but relatively few associated with the GOM/OCS.

The Year One Study data was especially beneficial since data were provided on offshore production worker place of residence. Of offshore production workers covered in the study, 78 percent (18,682)

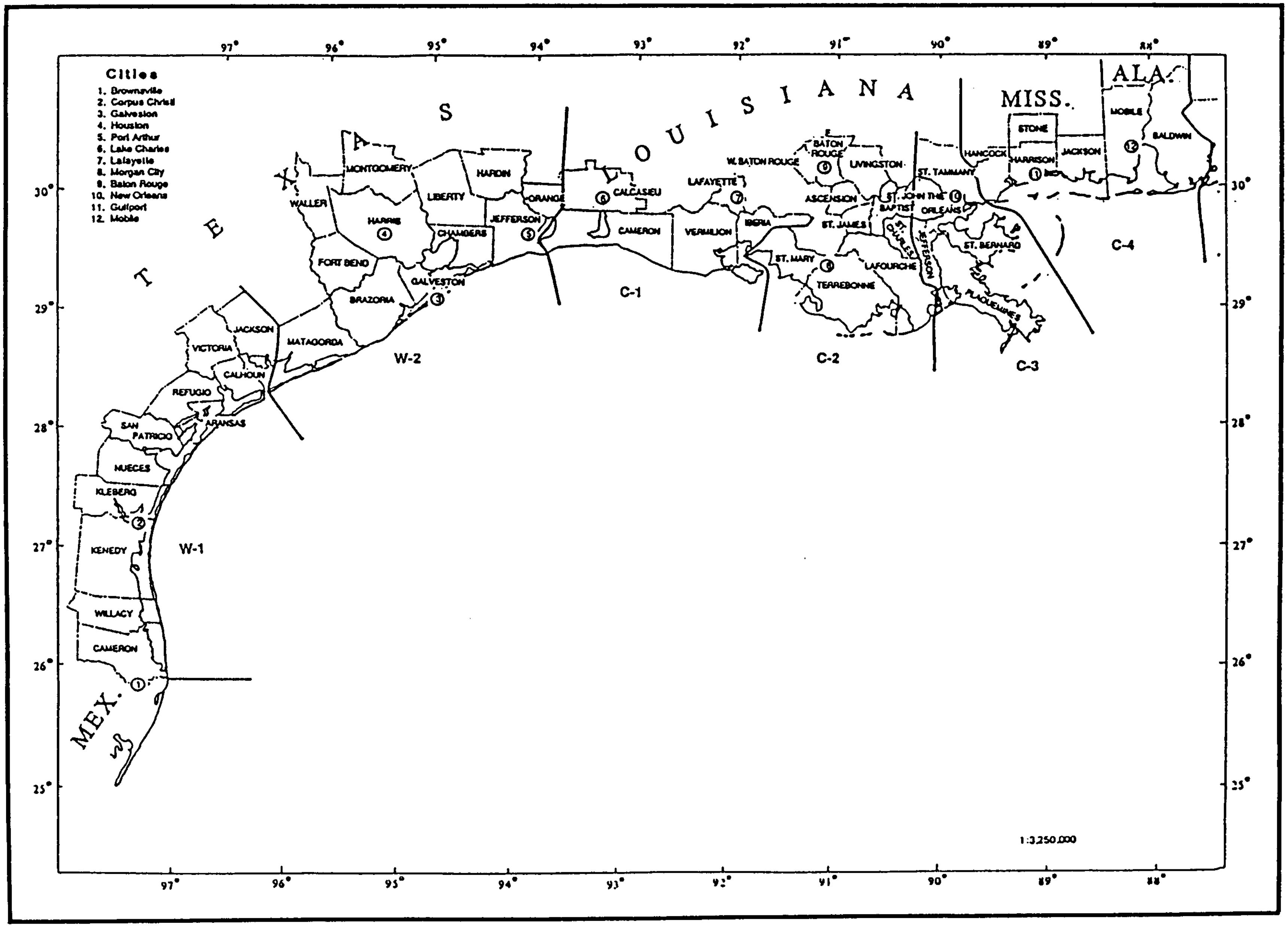


Figure 8.1. Study area map.

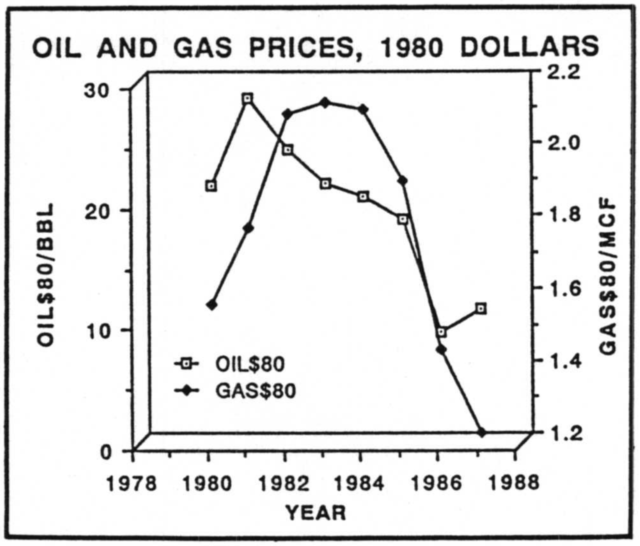


Figure 8.2. Oil and gas prices, 1980 dollars.

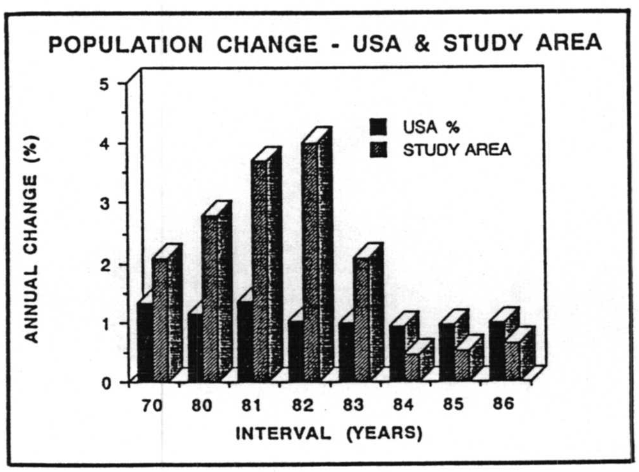


Figure 8.3. Population change - USA and study area.

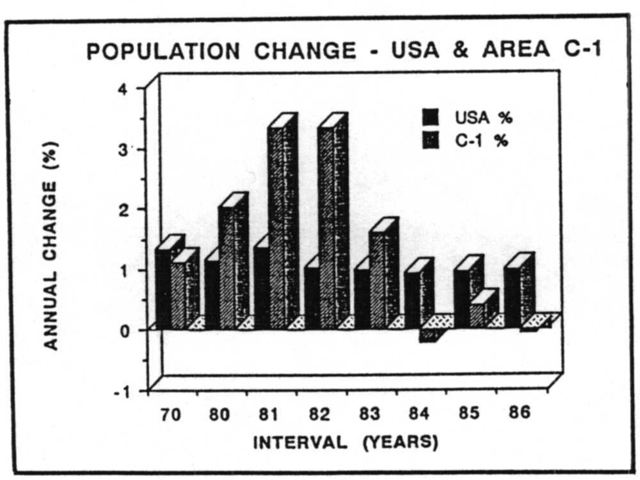


Figure 8.4. Population change - USA and area C1.

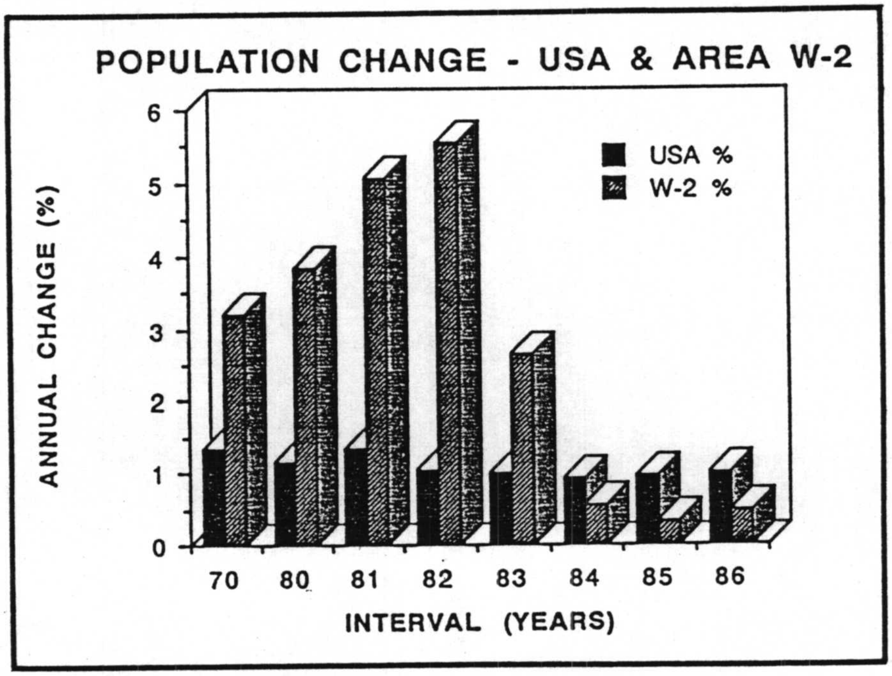


Figure 8.5. Population change - USA and area W2.

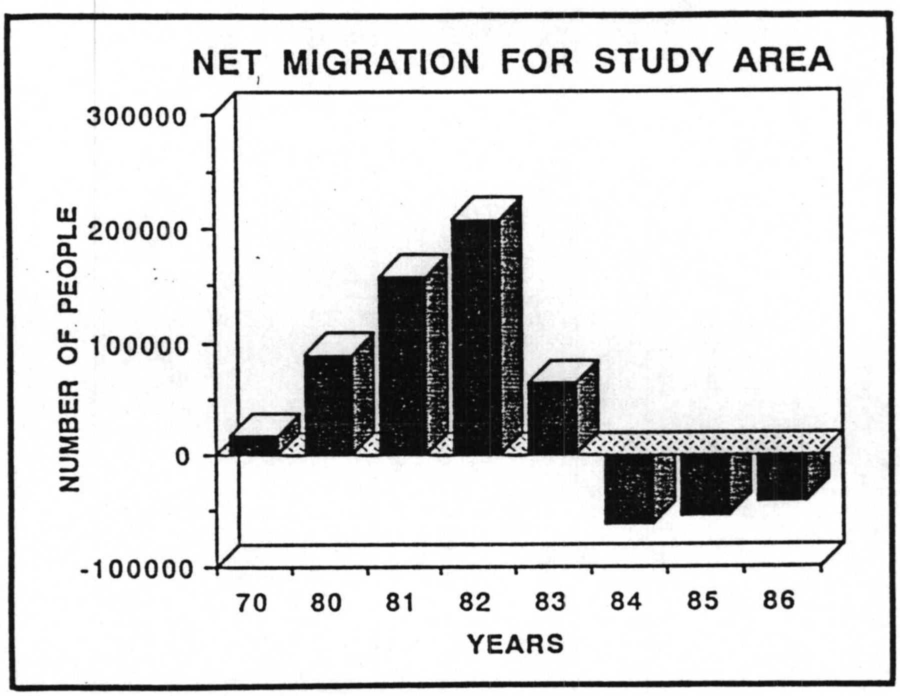


Figure 8.6. Net migration for study area.

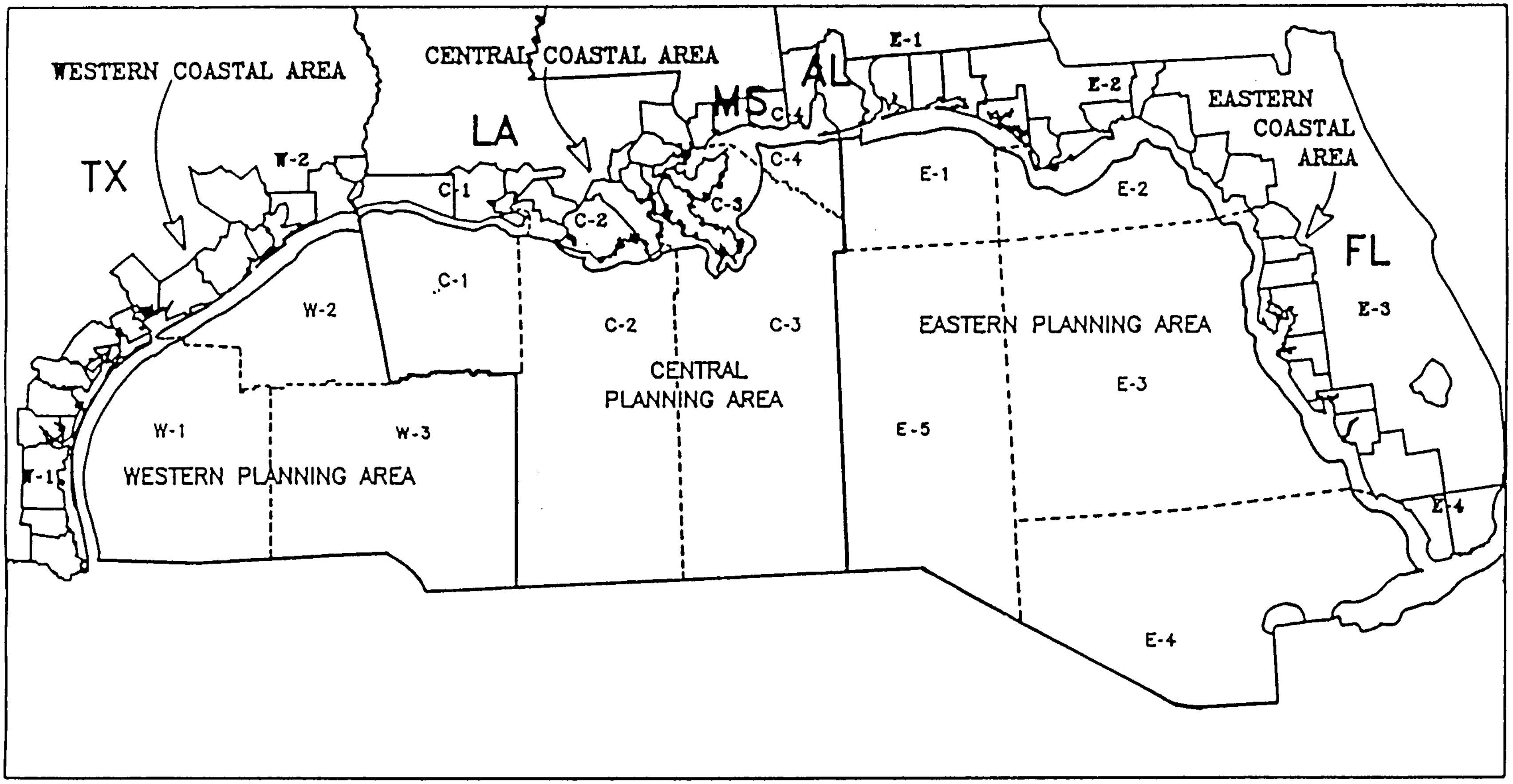
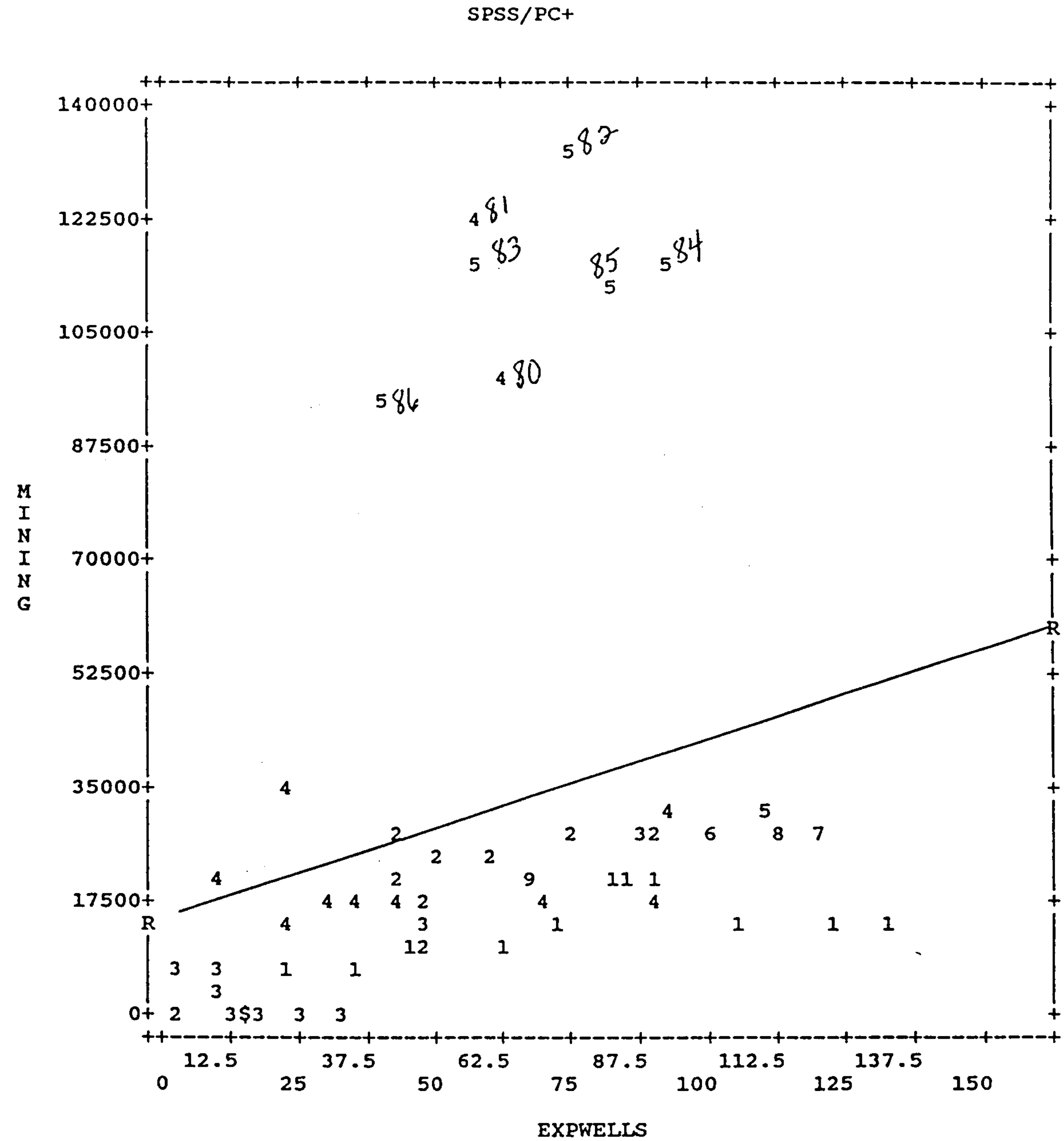


Figure 8.7. Gulf of Mexico OCS Region Planning and Analysis Areas.

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54 cases plotted. Regression statistics of MINING on EXPWELLS:
Correlation  .28384 R Squared  .08057  S.E. of Est 33309.6390 Sig.  .0375
Intercept(S.E.) 12989.4611(8673.8213)  Slope(S.E.)  281.05279(131.66444)
Use first digit of $CASENUM as plotting symbol and $ for multiple occurrence.
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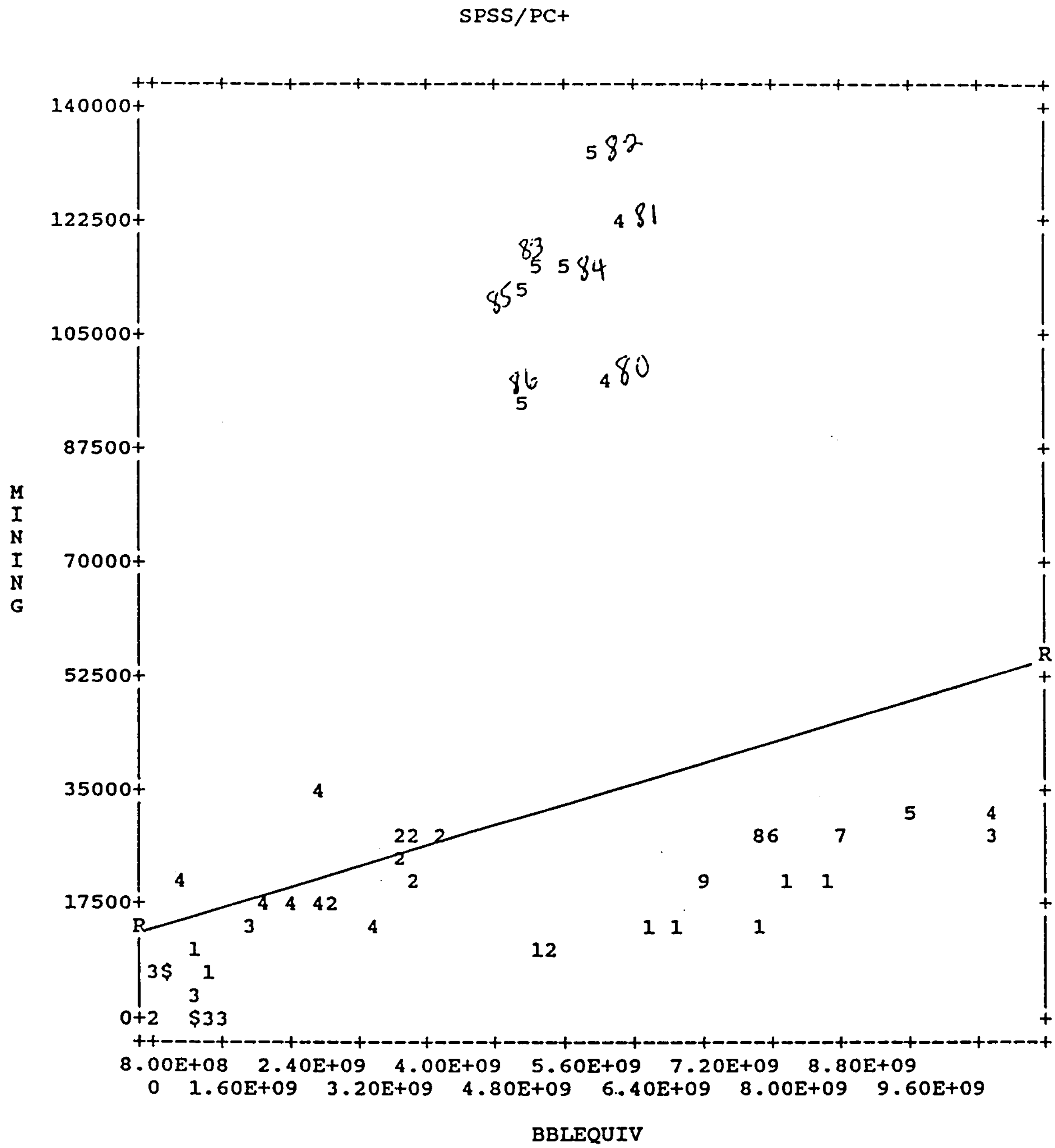
Figure 8.8. Plot of mining with EXPWELLS by $CASENUM.

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54 cases plotted. Regression statistics of MINING on BBLEQUIV:
Correlation  .34344 R Squared  .11795  S.E. of Est 32625.4468 Sig.  .0110
Intercept(S.E.) 14023.0591(7142.0400)  Slope(S.E.)      .00000(    .00000)
Use first digit of $CASENUM as plotting symbol and $ for multiple occurrence.
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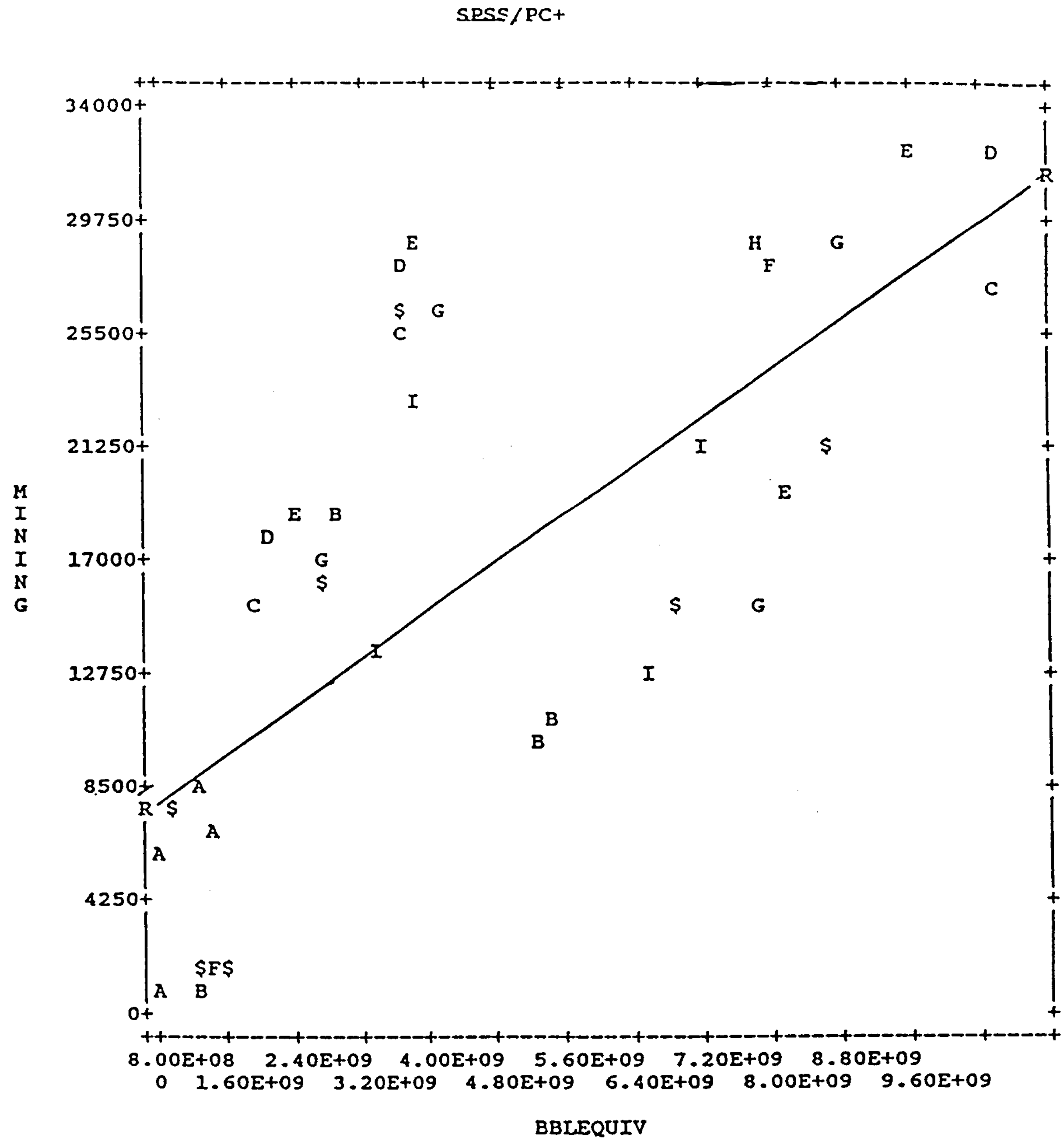
Figure 8.9. Plot of mining with BBLEQUIV by $CASENUM.

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45 cases plotted  Regression statistics of MINING on BBLEQUIV:
Correlation   .70563 R Squared   .49791   S.E. of Est 7195.65472 Sig.   .0000
Intercept(S.E.) 7640.12228(1640.3551)  Slope(S.E.)       .00000(    .00000)
A:A          B:B          C:C          D:D          E:E          F:F
G:G          H:H          I:I          $:Multiple occurrence
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Figure 8.10. Plot of mining with BBLEQUIV by year.

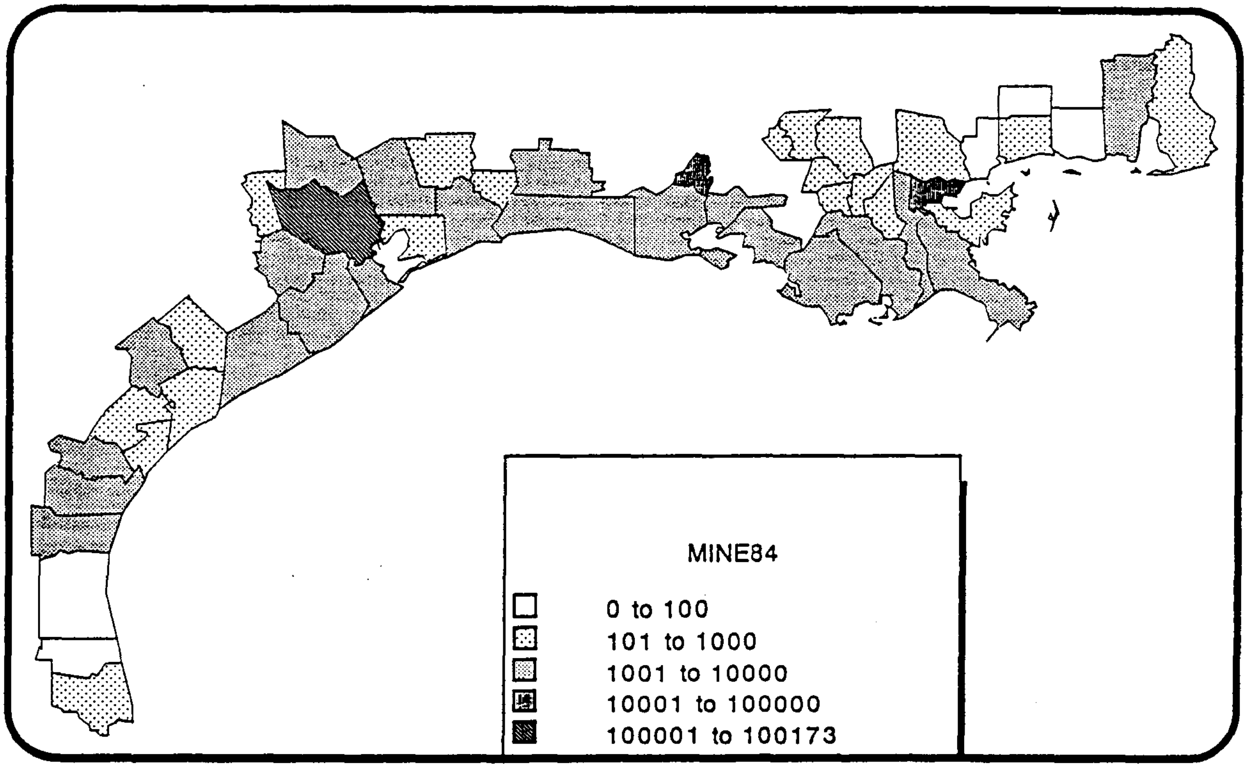

Figure 8.11. Number of mining jobs by county/parish of work, 1984.

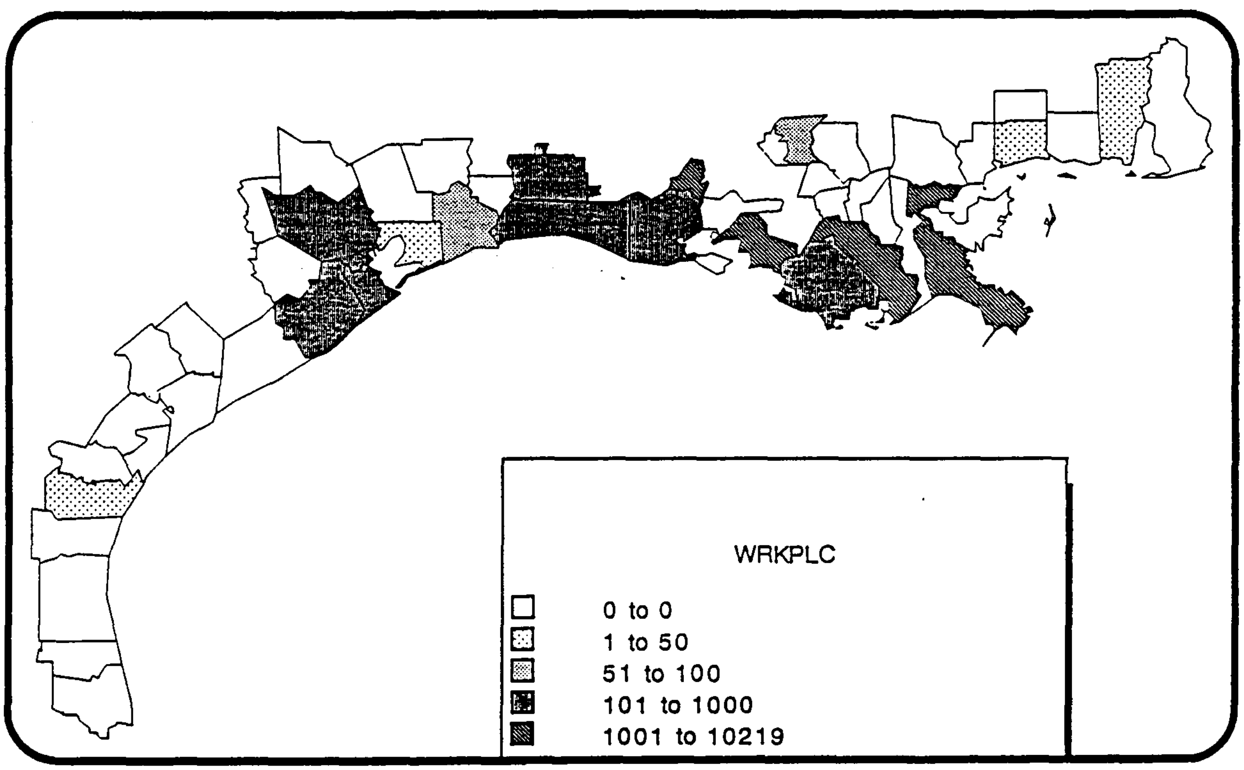

Figure 8.12. Number of offshore production workers by county/parish of work site, 1984.

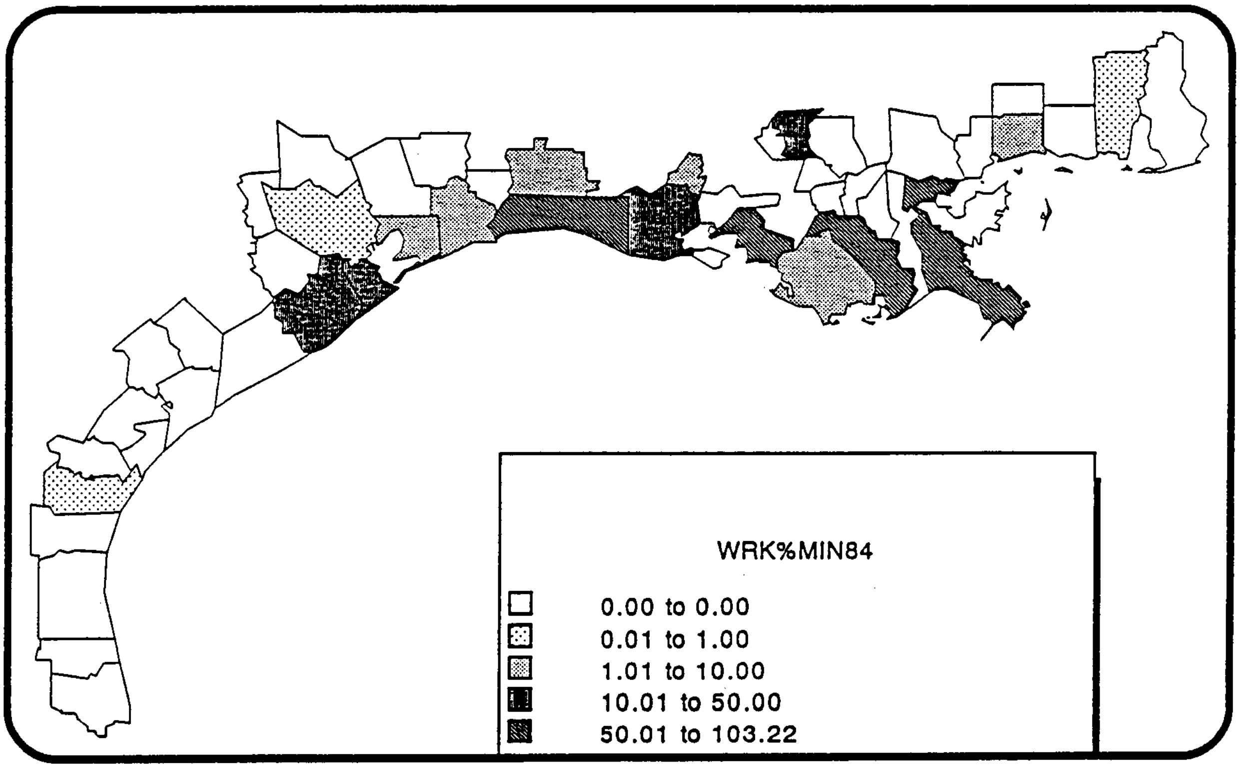

Figure 8.13. Offshore jobs as a percent of mining jobs by county/parish of work, 1984.

reported being a resident of the 49 county or parish study area (Figure 8.14). Over half (9,678, 52%) of the workers resided within the New Orleans metropolitan area (Orleans, Jefferson and St. Tammany). Other areas with relatively large numbers of workers included: Lafayette Parish, 1,524; Lafourche Parish, 974; St. Mary Parish, 879; and Harris County, 435 (2%).

To obtain a measure of the relative economic impact on the local economy, earnings from offshore production work was calculated as a percent of total earnings by place of residence (Figure 8.15). The resultant values ranged from 0 to 9.29 percent in Cameron Parish, Louisiana. A total of 13 counties (all of which were located in coastal areas W1 and W2) were 0.05 percent or less.

A revised definition of the OCS impact area was prepared by deleting the 13 counties where earnings from offshore production work accounted for 0.05 percent or less of total earnings by place of residence. Data associated with the revised impact area exhibited stronger statistical relationships with OCS indicators (Figures 8.16 and 8.17).

CONCLUSION

Data from the Year One Study together with the analyses performed under the socioeconomic impact study have led to a better understanding of the relationship between OCS activities and onshore impacts along the Gulf Coast. The area of OCS oil and gas activity impact within the study area is not contiguous. Although most of the counties and parishes within the study area exhibit socioeconomic characteristics closely associated with the oil and gas industry, the association in select areas appears more aligned with non-OCS oil and gas activities.

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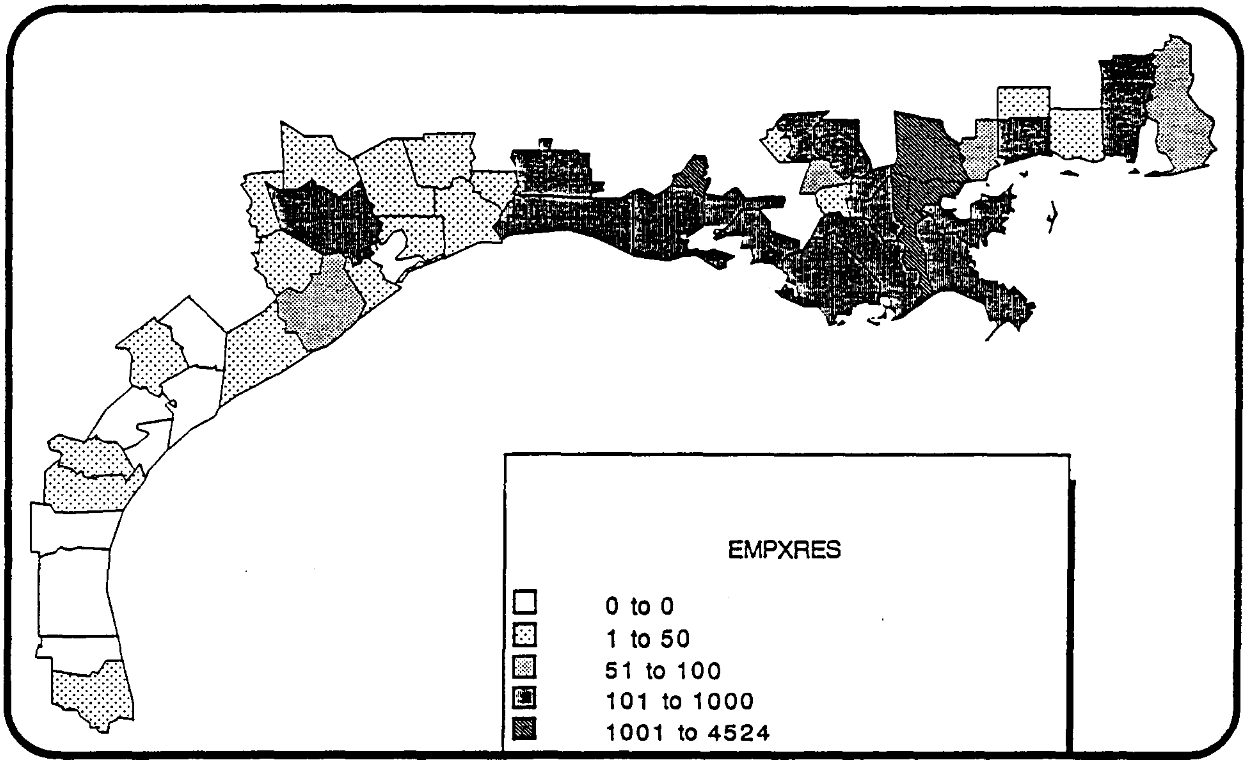


Figure 8.14. Number of offshore production workers by county/parish of residence, 1984.

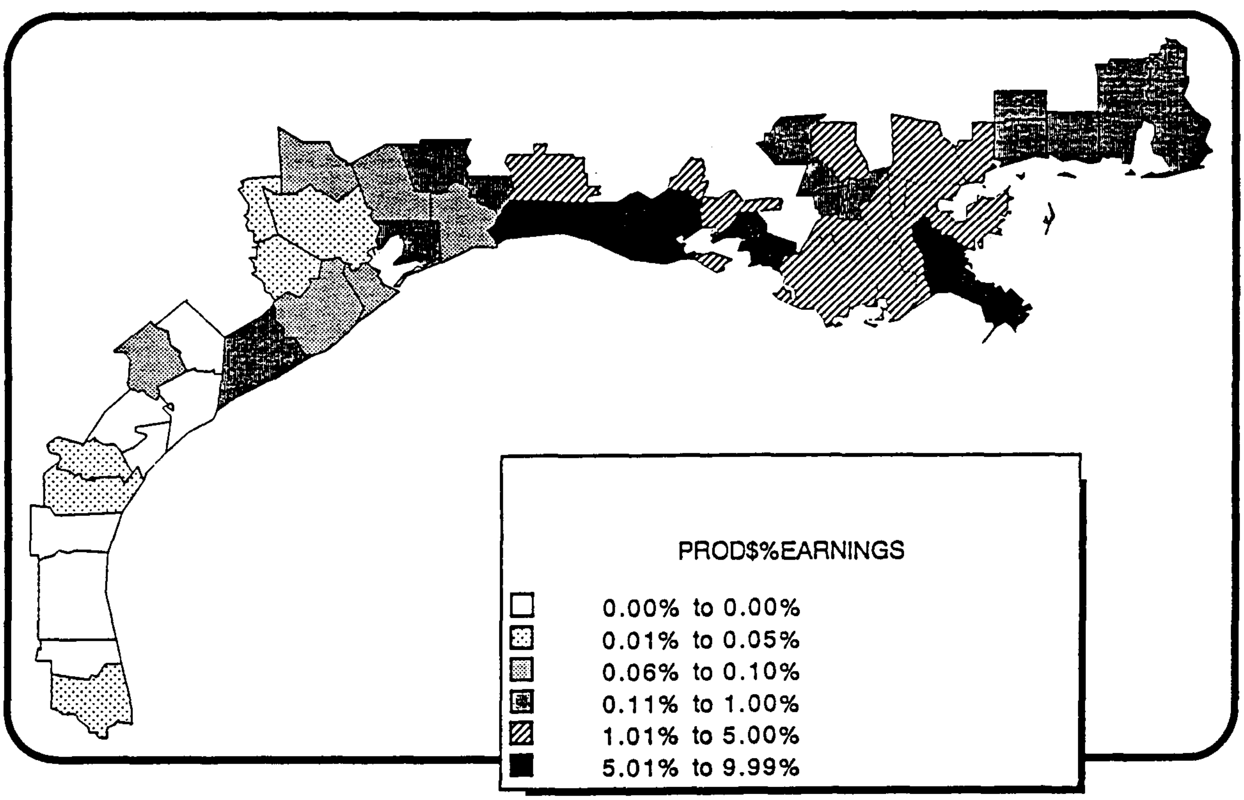
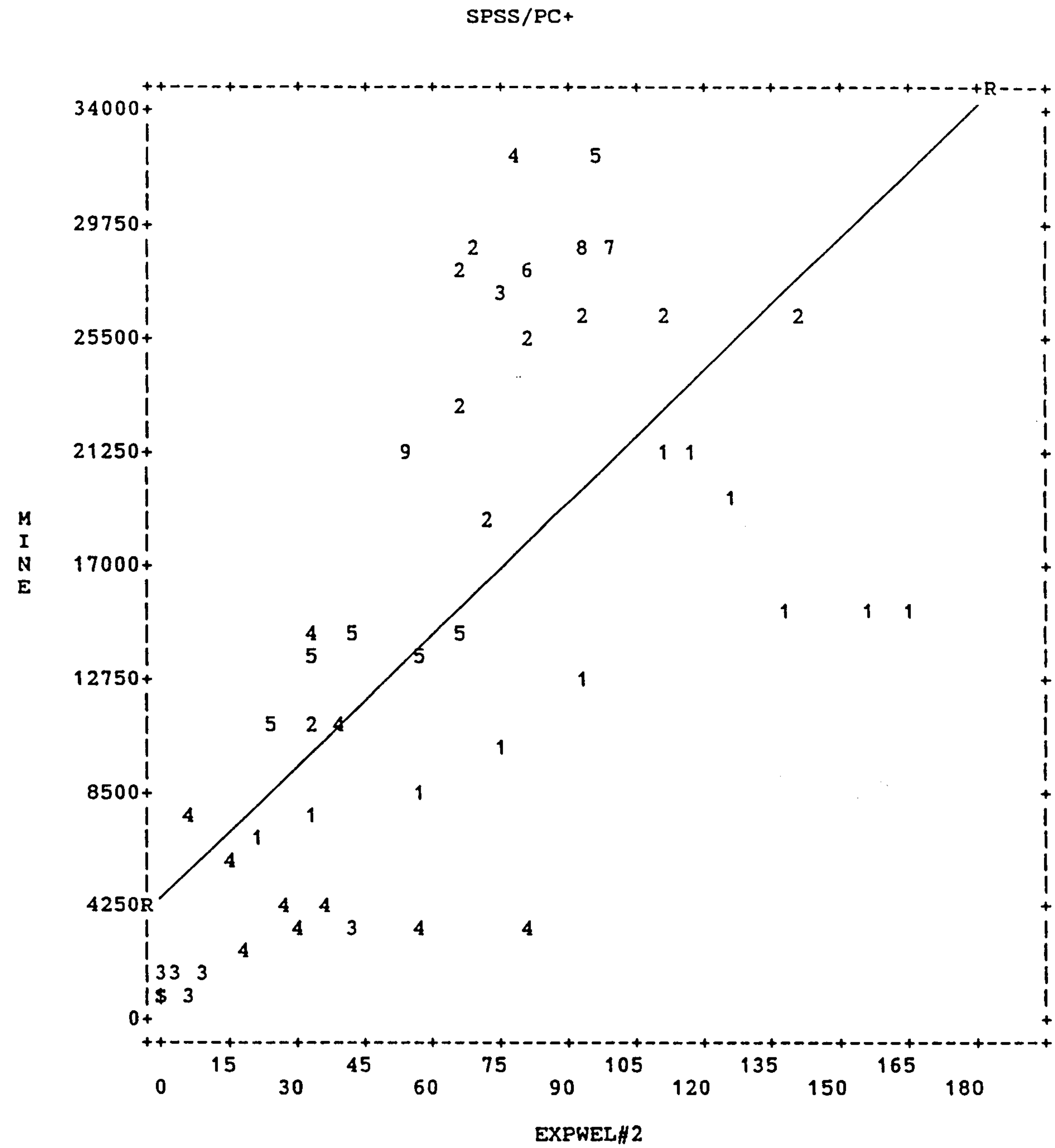


Figure 8.15. Earnings from offshore production work as a percent of total earnings, 1984.




```
54 cases plotted. Regression statistics of MINE on EXPWEL#2:
Correlation   .70654 R Squared   .49921  S.E. of Est 7354.41936 Sig.   .0000
Intercept(S.E.) 4067.15290(1615.8416)  Slope(S.E.)  162.61284( 22.58619)
Use first digit of $CASENUM as plotting symbol and $ for multiple occurrence.
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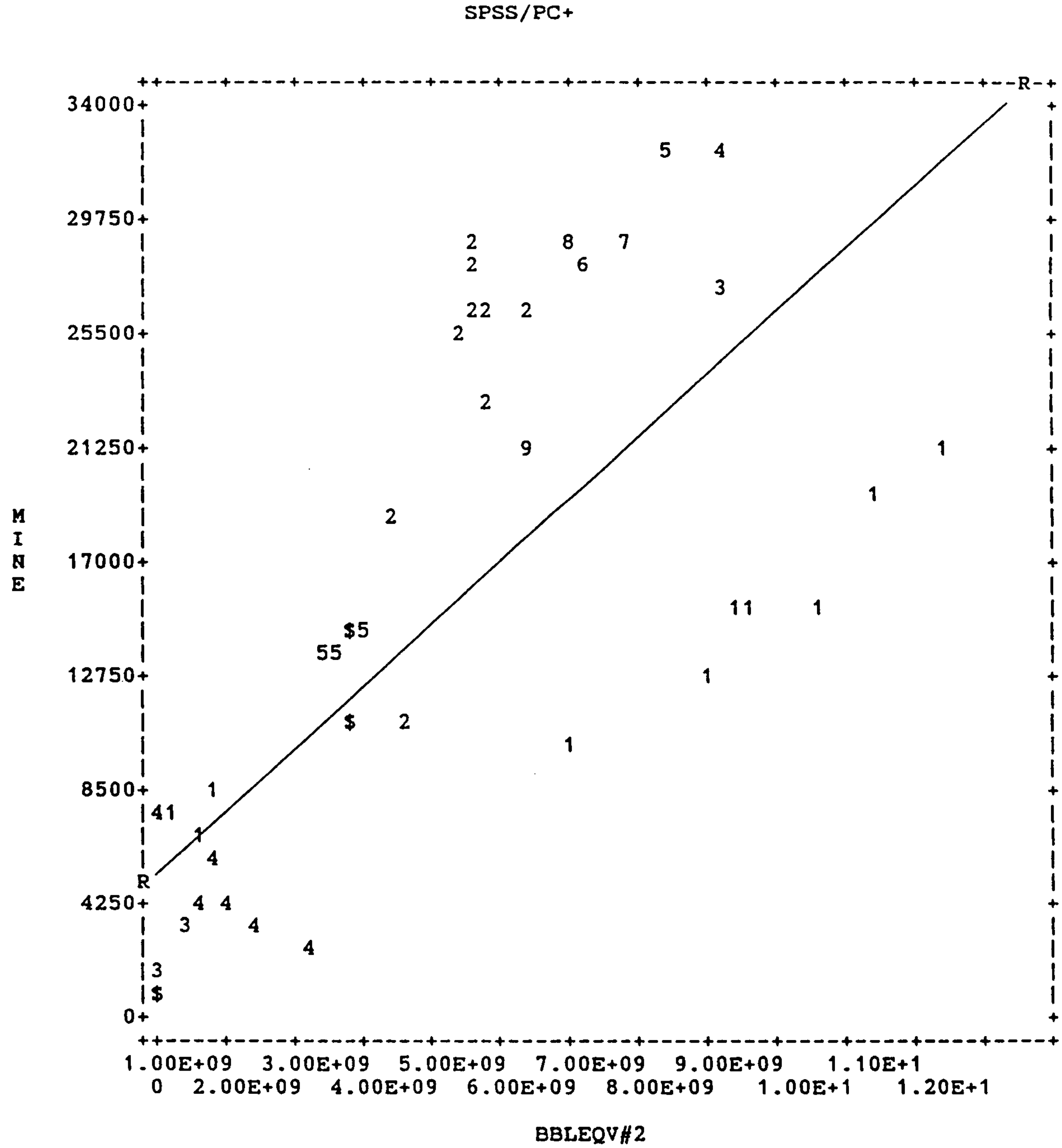
Figure 8.16. Plot of mine with EXPWEL#2 by $CASENUM.




```
54 cases plotted. Regression statistics of MINE on BBLEQV#2:
Correlation  .75142 R Squared  .56464  S.E. of Est 6857.16878 Sig.  .0000
Intercept(S.E.) 5091.66120(1358.5863)  Slope(S.E.)      .00000(    .00000)
Use first digit of $CASENUM as plotting symbol and $ for multiple occurrence.
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Figure 8.17. Plot of mine with BBLEQU#2 by $CASENUM.

From 1982 to 1986, he served on the faculty at Louisiana State University as an adjunct assistant professor. He served on Louisiana's Governor's Community Development Advisory Committee. Mr. McKenzie is project director on a MMS Study entitled "Socioeconomic Impacts of Declining Outer Continental Shelf Oil and Gas Activities in the Gulf of Mexico."

THE ENVIRONMENTAL COSTS OF OUTER CONTINENTAL SHELF OIL AND GAS DEVELOPMENT AND MARINE OIL SPILLS

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Kearney/Centaur Division
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and
Mr. Richard Winnor
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Headquarters

BACKGROUND AND NEED FOR ENVIRONMENTAL COST ANALYSIS

The production of oil and natural gas on the U.S. Outer Continental Shelf (OCS) creates costs not included in the traditional accounting of production costs. These costs, which can be termed environmental costs, are linked to concerns such as compliance with new government regulations, unavoidable degradation of natural resources, and the consequences of oil spills. Consideration of environmental costs is an important step in evaluating the suitability of leasing the nation's OCS resources for energy development.

The OCS Lands Act Amendments (OCSLAA) mandate that the Department of the Interior develop a series of 5-year Leasing Programs to aid in the management and decisionmaking of OCS lease sales to private industry. The development of the 5-year program requires an assessment of the net social value of the prospective development of offshore oil and gas resources. The determination of net social value involves weighing the market value of oil and gas resources against the costs of production and the costs of potential economic, social, and environmental damages. In turn, quantifications of net social value for each planned area of OCS development aids in the process for selection and determination of potential lease sales for future oil and gas development.

Beginning with the initial 5-year OCS Leasing Program (1980-1985), concerns raised by several petitioners led to a court challenge which focused on the adequacy of environmental cost analyses performed under Section 18 of the OCSLAA (California vs. Watt [I]). This subsequently led to a challenge to the second 5-year Leasing Program (California vs. Watt [II]) whereby the Leasing Program was again disputed on the basis of the cost analyses.

The most recent legal initiative, which questioned the validity of the third OCS Leasing Program (1987-1992), was the Natural Resource Defense Council's challenge of this program. The court's decision and ruling in this case found deficiencies in the environmental cost analysis of the current Leasing Program, specifically in the social cost calculations, and required that future environmental cost analyses address and remedy these deficiencies.

The present environmental cost analysis, prepared in support of the mid-1992 to mid-1997 Leasing Program, broadens the scope of the previous social cost analysis in two significant ways. The analysis quantifies additional cost types, including costs associated with regulatory controls, the cost of mitigating adverse impacts, and associated administrative costs, and analyzes social cost estimates in greater depth. The environmental costs are estimated using the General Purpose Environmental Cost Model (GPECM).

OVERVIEW OF THE GENERAL PURPOSE ENVIRONMENTAL COST MODEL

The purpose of the GPECM is to produce and document estimates of the environmental costs related to the development of leased and unleased (i.e., residual) oil and gas resources in the 26 OCS Planning Areas. The model accomplishes this by providing estimates of up to 15 user-selected separate cost elements by each of the 26 OCS Planning Areas. Within each OCS Planning Area, and for each cost element, costs are allocated to one or more of three cost types: regulatory, substitution, and social.

DEFINITION OF COST TYPES

The following summarizes the definition of each cost type, with respect to OCS oil and gas development. Figure 8.18 is an overview of cost types by cost element.

Production/Direct Regulatory Control Costs

This is the cost required to comply with the applicable consolidated and other offshore regulations. It captures only costs above those not reflected in traditional cost of production. An example of a direct regulatory control cost is the cost of purchasing and installing equipment to reduce emissions of air pollutants from power generating equipment on oil and gas platforms.

Substitution Costs

This type of cost refers to measures taken to mitigate and/or compensate for environmental impacts by replacing or providing substitute resources. Substitute costs often take the form of in-kind offsets, which are considered savings in pollution from one process purchased by the owners of another polluting process. The cost of purchasing these offsets in order to mitigate environmental impacts caused by the process represents a form of substitution cost.

Social Costs

This cost type includes any external costs imposed on society from adverse environmental impacts including both those for which compensation is paid and is unpaid. These can be categorized as oil spill-related and non-oil spill-related.

COST ESTIMATING TECHNIQUES

The estimation of environmental costs associated with OCS development largely involves the analysis of associated market values for specific impact areas or cost elements. The analysis of market values in determining costs was employed for a number of cost elements, including wetland losses, property value losses, and commercial fishing losses associated with OCS development. However, market prices may not always reflect the full value of a resource or good, and in cases where indirect value is substantial, such as the visual aesthetic component of air quality, market prices are not always relevant.

Production-related direct regulatory control costs, those incurred by industry as a result of meeting or exceeding regulatory controls, are derived by estimating the incremental production costs of a given phase of OCS development. The general methodology employed for estimating this cost type identifies and quantifies all regulatory control costs for the period 1992 and beyond which are not part of current standard industry operating procedures.

The general approach used to estimate substitution costs compares the market prices of substitute or replacement resources. For example, estimates of substitution costs for mitigating increased levels of air emissions measure costs of obtaining emission offsets. The incremental cost of substitution measures represents the cost of purchasing emission reduction credits, where required, to offset emission levels after applicable control technology has been applied. The methodology used to estimate substitution costs varies among cost elements.

Estimating the social losses attributable to increased OCS development can involve the measurement of both direct and indirect costs. The use of market prices was a common approach to value the direct costs of unmitigated environmental impacts associated with OCS operations. However, the loss of associated indirect values, also considered to be a decrease in consumer surplus, is more difficult to quantify and valuation of such losses can often dictate the application of more ambiguous measurement techniques. Techniques employed to estimate indirect or nonmarket values can include the travel cost method, hedonic pricing technique, alternative cost approach, and the contingent valuation method. These valuation techniques attempt to measure the lost social value of a resource, representing the lost consumer surplus to those who actively or indirectly use the damaged resource.

Regulatory-Type Cost Elements	Regulatory Control Costs	Substitution Costs	Social Costs
Regulatory control costs for air emissions	●	●	●
Regulatory control costs for OCS effluent discharges	●		
Regulatory control costs for spill avoidance	●		
Non-Spill Type Cost Elements			
Non-recovered infrastructure costs		●	●
Fishing ground preemption and gear loss		●	●
Wetland losses	●	●	●
Property value losses			●
Spill-Related Cost Elements			
Oil spill control and clean-up costs			●
Spill-induced tourism and recreation losses		●	●
Spill-related commercial fisheries losses			●
Spill-related wildlife and ecological losses			●
Spill and non-spill subsistence losses			●
Spill-related legal costs			●
Administrative and spill-related research costs			●

Notes cost elements presented as representative of research supporting each cost element

Figure 8.18. Overview of cost types by cost element.

SUMMARY OF RESULTS FROM THE 1991-1997 COMPREHENSIVE PROGRAM

The summary results from the 1992-1997 Comprehensive Program using moderate and high cost assumptions are shown in Figure 8.19. This exhibit compares the total program costs for control, substitution, and social costs to those for the Gulf of Mexico. The Gulf of Mexico accounts for a larger percentage of the control costs under the moderate cost assumptions and a slightly higher percentage of both substitution and social costs under the high cost assumptions.

EXAMPLES OF OTHER APPLICATIONS OF THE GPECM

The GPECM and methodology have a wide range of alternative applications. These include: (1) benefits of marine safety regulations, including tanker double hull requirements and vessel traffic services, (2) oil spill reduction benefits of offshore marine terminals, (3) benefit estimate of improved spill response programs, and (4) estimation of industry oil spill liabilities for marine terminals, onshore oil and gas development, and transportation.

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Mr. Richard Winnor is an economist and fisheries biologist who started working on the OCS leasing program in 1974 with the Office of the Secretary, Department of the Interior. He has worked on the environmental issues associated with OCS leasing. His most recent work was the development of plans for the economic analysis of environmental costs for the OCS Natural Gas and Oil Resource Management Comprehensive Program for 1992-1997.

IMPACTS OF OIL AND GAS EXPLORATION, DEVELOPMENT, AND PRODUCTION ON THE RECREATION AND TOURISM OFF THE FLORIDA STRAITS

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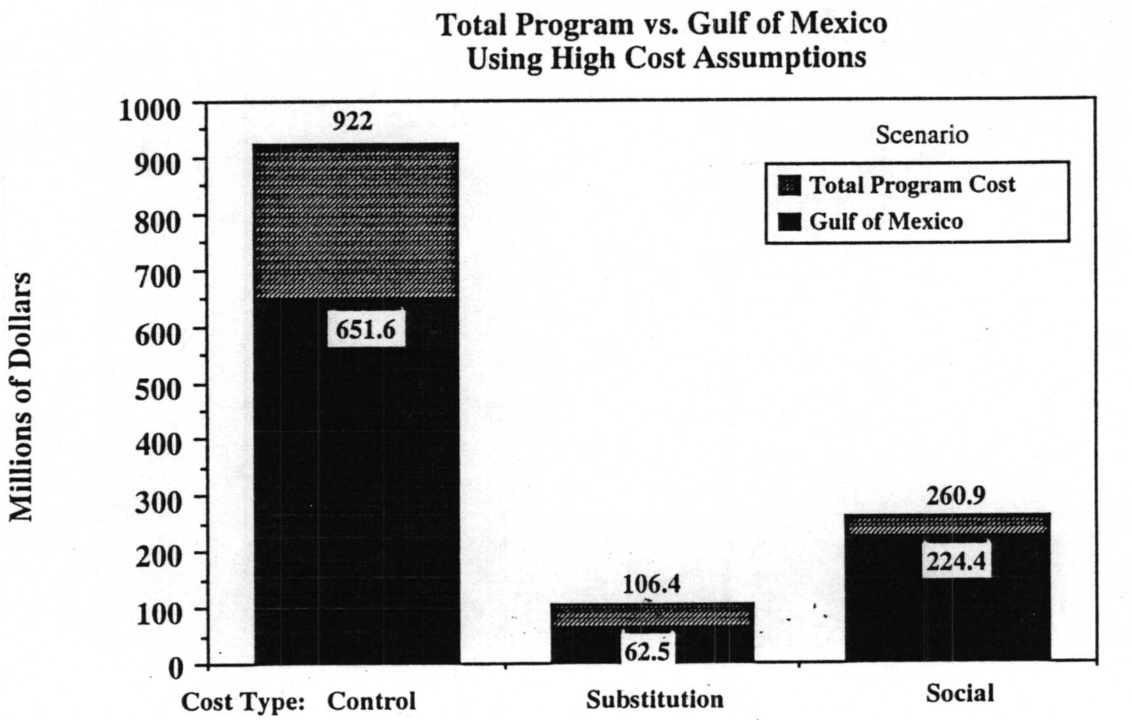
Kearney/Centaur Division
A.T. Kearney, Inc.

The local economy of the Florida Keys and the Everglades National Park is among the most dependent in the United States on tourism and marine-dependent recreation opportunities. Minimal alternative base economic sectors exist. Outer Continental Shelf (OCS) operations which change the character of the region, or a catastrophic oil spill, have the potential to critically impact the base economy of Monroe County, Florida, site of the Florida Keys and the Everglades National Park. The study results are designed to be used by Minerals Management Service (MMS) analysts in the preparation of Environmental Impact Statements (EIS') and other socioeconomic analyses required of the agency by the National Environmental Policy Act of 1969 and the Outer Continental Shelf Act. This methodology was also designed as a demonstration project of the feasibility of predicting the economic effects of oil spills on a before-the-fact basis.

STUDY OBJECTIVE

The objective of the study was to develop the data, analytical framework, and model necessary to forecast the relationship between OCS operations and spills on the tourism and recreation-related economy of Monroe County. Because of public sensitivities to oil spills, special attention was paid to both small and catastrophic oil spills.

The project produced a PC-based regional economic impact model to estimate the change to tourism and recreation-related economic activities from OCS development. Virtually all of the model parameters/assumptions are default settings and can be easily changed or updated by the user. The project documentation includes a report which includes baseline data, estimates of visitation and expenditure patterns, the relationship between



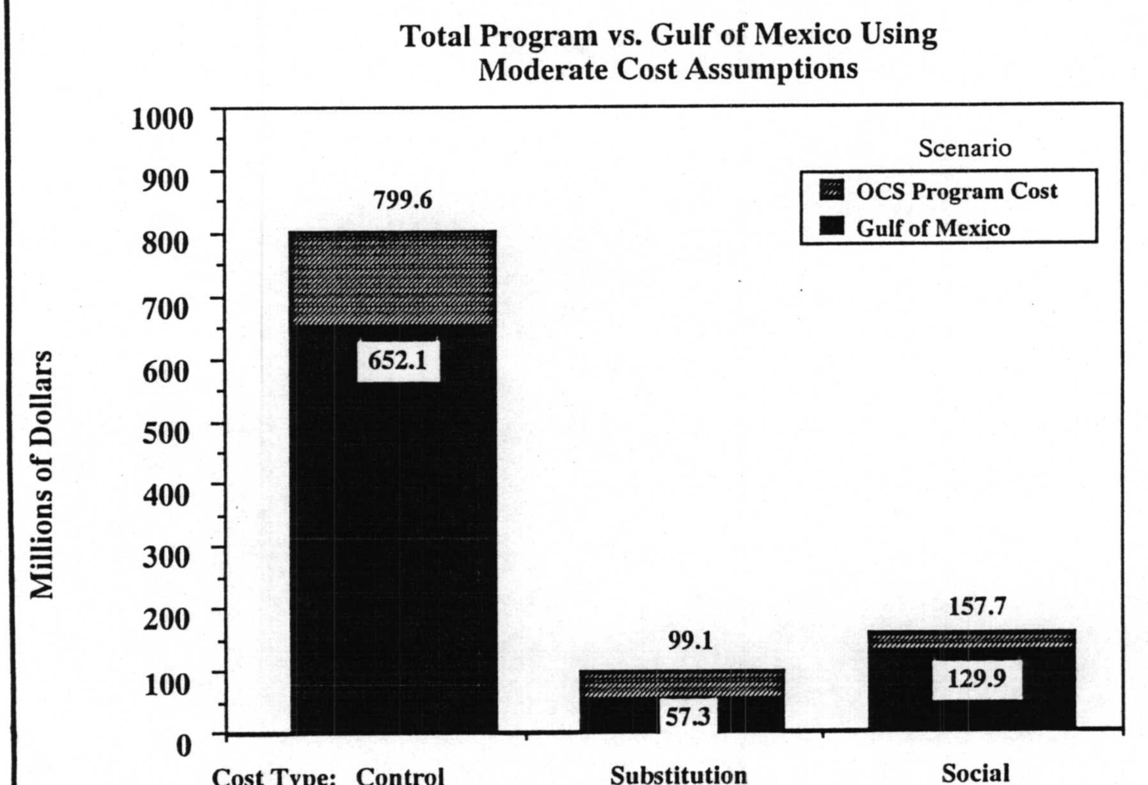


Figure 8.19. Summary results from 1992-1997, Comprehensive Program.

hypothetical development scenarios and tourism and recreation activity patterns, documentation for the regional economic impact model and instructions for using the model.

OVERVIEW OF METHODOLOGY

The focus of this study was an interactive computer-based model; however, in order to construct it the following six steps were required.

- Quantified the natural resources and manmade infrastructure supporting marine dependent (or enhanced) recreation/tourism in South Florida.
- Collected primary data on visitation patterns/expenditures for tourism/recreation activities and tourist sensitivity to indicators of environmental degradation.
- Developed and applied a series of analytical methodologies for predicting the effect that various OCS related activities would have on recreational participation, tourism visitation, and associated expenditures in the region.
- Integrated the above data with a series of OCS visitation translators, and a regional economic model to quantify the contribution of recreation/tourism to the regional economy. The dependence of the regional economy on these activities was also assessed.
- Developed a menu-driven model to simulate the effects of various OCS shoreside facilities, visible platforms, vessel and helicopter traffic, and various types of oil spills on tourism visitation, expenditures, and net economic activity. Economic activity was measured in terms of business sales, employment, personal income, and taxes.
- Evaluated and documented the model for long-term use by MMS' Atlantic and Gulf of Mexico OCS Regional Offices. The project concluded with Kearney/Centaur validating both the model-predicted baseline and predicted impacts to retrospective oil spill-tourism studies.

The study includes a baseline of economic activity and a baseline of marine dependent tourism and recreation infrastructure in the region. The results of the South Florida Interview Program, a primary data collection effort in the Florida Keys, are used in the regional economic impact model as estimates of visitation, expenditure patterns, and to provide the relationship between hypothetical development scenarios and tourism and recreation activity patterns.

STUDY RESULTS

Model runs were demonstrated for a number of OCS scenarios which included various levels of onshore industrial facilities, visible degradation due to the siting of OCS structures, helicopter overflights, and oil spills. Tests were demonstrated for each of the six unique geographic zones contained in the model. In general, losses due to visual degradation were negligible, industrial development caused a reduction in visitation of about 5,000 tourists, and a 10,000 barrel oil spill resulted in a loss of approximately 45,000 visitors. These declines were also expressed in terms of reduced expenditures and regional employment. The employment loss from a 10,000 barrel spill in a high visitation zone (Key West) was about 500 full-time equivalent jobs. In most other areas, this spill resulted in a loss of employment of about 25 to 100 full-time equivalent jobs. These estimates assumed a peak season spill.

Predicted study results for a number of scenarios were validated by comparing model prediction to the conclusions reached in a number of on-site retrospective oil spill studies. The "moderate" model-generated scenario produced tourism expenditure losses of between $79 and $108 per barrel spilled. Oil spill losses were, however, highly sensitive to the interrelationship between the spill and tourism facilities, and varied from $653 to only $13 in lost tourism expenditures per barrel spilled. After normalizing losses based on expenditures lost per barrel spilled in 1990 dollars, our moderate impact runs were consistent with the losses quantified by the on-site post spill investigations for *Exxon Valdez*, *Amoco Cadiz*, and Santa Barbara spills.

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head of Kearney's Marine Economics Practice. Mr. Brown has undertaken economic studies of OCS-related issues since 1979 and has completed studies for MMS in all of the OCS planning areas.

AN ECONOMIC PERSPECTIVE ON THE THEORY AND PRACTICE OF SOCIAL IMPACT ASSESSMENT: ECONOMIC FOCUS

Dr. F. Larry Leistritz
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Proposals to develop large-scale energy resource extraction or conversion projects, like plans for other major resource development or industrial projects, often lead to questions concerning the nature and extent of social impacts that may result. The social (or socioeconomic) impacts of development projects and programs have been categorized in a number of ways. One classification of such impacts identifies (1) economic impacts (including changes in local employment, business activity, earnings, and income), (2) demographic impacts (changes in the size, distribution, and composition of the population), (3) public service impacts (changes in the demand for and availability of public services and facilities), (4) fiscal impacts (changes in revenues and costs of local government jurisdictions), and (5) social impacts (changes in the patterns of interaction, the formal and informal relationships resulting from such interactions, and the perceptions of such relationships among various groups in a social setting) (Leistritz and Murdock 1981; Leistritz and Ekstrom 1986). This paper provides a brief overview of the conceptual bases, methodological alternatives, and assessment techniques that are commonly utilized in assessing the first four categories of impacts (i.e., economic, demographic, public service, and fiscal impacts). (For a much more detailed discussion, see Leistritz and Murdock 1981).

ECONOMIC IMPACT ASSESSMENT

The purpose of an economic impact assessment is to estimate the changes in employment, income, and levels of business activity (typically measured by gross receipts or value added) that may result from a proposed project or program. As with the assessment of other categories of impacts, the general approach involves projecting the levels of economic activity that would be expected to prevail in the study area with and, alternatively, without the project. The difference between the two projections measures the impact of the project.

Export base theory (also termed economic base theory) provides the conceptual foundation for all operational economic impact assessment models. A fundamental concept of the export base theory is that an area's economy can be divided into two general types of economic units. The basic sector is defined as those firms which sell goods and services to markets outside the area. The revenue received by basic sector firms for their exports of goods and services is termed basic income. The remainder of the area's economy consists of those firms which supply goods and services to customers within the area. These firms are referred to as the non-basic sector or sometimes as residentiary or local trade and service activities.

A second key concept in export base theory is that the level of nonbasic activity in an area is uniquely determined by the level of basic activity, and a given change in the level of basic activity will bring about a predictable change in the level of nonbasic activity. This relationship is known as the multiplier effect.

The basis for the multiplier effect is the interdependence (or linkages) of the basic and nonbasic sectors of an area's economy. As the basic sector expands, it requires more inputs (for example, labor and supplies). Some of these inputs are purchased from local firms and households. As the firms in the nonbasic sector expand their sales to the basic sector, they too must purchase more inputs, and so on. Increased wages and salaries paid to labor and management by the basic sector, together with similar payments by the nonbasic sector, lead to increases in the incomes of area households. Some of this additional income is spent locally for goods and services, some is saved, and some leaves the area as payments for imported goods and services (or as additional tax payments to government). To the extent that additional income is spent locally for goods and services, the output of local firms is increased and additional cycles of input purchases and expenditures result. This cycle of spending and respending within the local economy is the basis for the multiplier effect.

The magnitude of the multiplier effect is determined by the proportion of a given dollar of additional income that is spent locally. High multiplier values are associated with high levels of local spending, which in turn imply a diversified, relatively self-sufficient economy. Larger regions tend to have higher multiplier values.

When estimating the magnitude of secondary effects for a specific project in a given area, most analysts employ either an export base model (employment or income multipliers) or an input-output (I-O) model. In recent years, input-output models have been applied with increased frequency in impact assessment. Some reasons for the increasing use of I-O models are (1) this technique provides more detailed impact estimates (e.g., business volume and employment by sector) than other approaches and can better reflect differences in expenditure patterns among projects and (2) data bases and data management systems are now available that enable development of I-O models tailored to local conditions but based largely or totally on secondary data sources. Two commonly used I-O models of this type are REMI (Treyz *et al.* 1977) and IMPLAN (Alward *et al.* 1989). Recent evaluations of these and similar I-O models are provided by Crihfield and Campbell (1991) and by Brucker *et al.* (1987).

Whatever modeling system is used, the analyst will need specific information about the proposed project in order to prepare an assessment of its economic impacts. The magnitude and distribution of impacts from any project are dependent on many factors, but among the most important of these are (1) work force requirements, including temporary vs. permanent workers, timing of employment patterns (e.g., duration of construction peaks), earnings, and skill requirements, (2) capital investment, (3) local input purchase patterns, (4) output, and (5) resource requirements (Murdock and Leistritz 1979; Leistritz *et al.* 1982). Obtaining reliable information on these topics can be a major task and may require not only extensive consultation with project officials but also examination of experience in developing analogous projects in similar areas. On the other hand, much of the information is useful in assessing other impact dimensions as well.

DEMOGRAPHIC IMPACT ASSESSMENT

As noted previously, demographic impact assessment deals with evaluating the effect of a project on the size, distribution, and composition of an area's population. Determining these effects of project development is one of the most important steps in the socioeconomic assessment process because estimating the demographic impacts is essential for assessing other population-related effects such as public service demands and fiscal impacts. In fact, to many planners and decisionmakers the magnitude of population impacts is synonymous with the magnitude of all impacts.

Population projection techniques can be classified into five types: (1) extrapolative, curve-fitting, and regression-based techniques, (2) ratio-based techniques, (3) land use techniques, (4) economic-based techniques, and (5) cohort component techniques. The rationales for choosing one or another of these techniques appear to lie in the factors of data availability, the desire for detail in demographic outputs, and the need for an acceptable level of realism in simulating demographic processes (Leistritz and Murdock 1981).

While all of the five types of population projection techniques have strengths and are appropriate for certain applications, most impact assessment efforts now appear to use economic-based techniques, cohort component techniques, or in many cases a procedure that integrates these two (Leistritz *et al.* 1986). The essence of the integrated approach is that (1) a cohort technique is used to project births, deaths, and the aging of the population during each projection period, (2) labor supply is determined by applying age and sex-specific labor force participation rates to age and sex-specific population projections, and (3) labor demand projections from the economic impact assessment are then matched with labor supply, and in- or out-migration is assumed to occur to balance supply and demand.

Several project-related factors affect the nature, magnitude, and distribution of demographic impacts.

These include (1) project characteristics, (2) site-area characteristics, and (3) attributes of the inmigrating workers. For example, projects located close to relatively populous areas with large labor forces are likely to draw more of their workers from the local area and are less likely to require extensive inmigration of new workers. The direct employment requirements of the project obviously play a major role in determining population impacts, with larger employment requirements leading to higher levels of inmigration and population growth. In addition, projects that lead to higher levels of secondary employment (resulting from the multiplier effect) will have greater impacts on population growth. At the same time, the timing of project phases (specifically the length of construction and operation phases) will affect the patterns of population change. Finally, the extent to which local residents are hired for project-related employment will affect population growth. The developer's policies toward such hiring and the availability of training programs for local residents may have marked effects on the number of locals employed in the facility and, thus, on the extent of inmigration and population growth (Leistritz and Murdock 1986).

The characteristics of the project site may also affect population growth and its distribution within the affected area. Among these characteristics are (1) the local population's labor force skills and availability, (2) the number and characteristics of possible settlement sites, and (3) local communities' growth preferences.

The characteristics of workers who inmigrate to the site area represent yet another dimension that must be considered. Such characteristics as marital status, average family size, and age and sex distribution of workers, spouses, and dependents as well as their community service and settlement preferences will affect the total level of population growth, the characteristics of the new population, and its distribution (Murdock *et al.* 1986).

PUBLIC SERVICE IMPACT ASSESSMENT

The public service impacts are a major area of concern in socioeconomic impact assessments. Changes in availability and quality of public services are among the most visible and widely noted impacts of many resource development projects, particularly those located in rural areas, and these effects have been discussed extensively in the impact literature (Murdock and Leistritz 1979; Branch *et al.* 1984).

Although the specific techniques employed vary substantially from one assessment to another, most reflect one of two basic approaches. These are (1) approaches that project service demands for the new population only, utilizing averages per unit of new population and either national, statewide, or local service standards and (2) approaches that attempt to take existing services into account and project new service requirements on the basis of marginal demands (that is, demands above those that can be met by existing service bases). Whichever of these approaches is adopted, the analyst must also determine a specific set of standards for projecting the service demands that will accompany the new population. The two major conceptual approaches appear to be (1) use of local or comparable area service standards or (2) use of generalized (e.g., national, regional, state) standards.

The range of dimensions addressed in public service assessments is often broad and may include (1) housing, (2) education, (3) medical and mental health, (4) law enforcement, (5) fire protection, (6) water supplies, (7) water treatment, (8) solid waste disposal, (9) transportation, (10) social welfare, (11) libraries, and (12) recreation. For an extensive discussion of conceptual bases and specific methods for assessing public service impacts, see Chapter 4 of Leistritz and Murdock (1981).

FISCAL IMPACT ASSESSMENT

The purpose of fiscal impact assessment is to project the changes in costs and revenues of governmental units that are likely to occur as a result of a development project. The government units of primary interest are those local jurisdictions that may experience substantial changes in population and/or service demands as a result of the project. The fiscal implications of a new project are determined by the interaction of a number of factors including project characteristics (e.g., the magnitude of investment, the size and scheduling of the work force) and site area characteristics (e.g., state and local tax structure, the capacity of existing service delivery systems) and by the nature of the economic and demographic effects resulting from the project. Further, because the fiscal impacts of a project are of considerable interest both to local officials and their constituents and to developers, the fiscal impact assessment should be designed to produce information in a form that is most useful to policy makers (Leistritz and Murdock 1988).

Some issues that frequently concern policy makers relate to the distribution of project-related costs and revenues, both over time and among jurisdictions, and the risks to which local governments may be exposed because of uncertainty regarding the future of the project and/or the nature of its impacts. The problem of cost and revenue timing, frequently referred to as "the front-end financing problem," arises because during the early years of a project, local public sector costs frequently increase more rapidly than project-induced revenues. While project-related revenues may exceed project-related costs over the life of the project, local jurisdictions may face short-run cash flow problems. These problems can be exacerbated if local governments are unable to obtain funds to offset revenue shortfalls through borrowing. Uncertainty associated with a proposed project also may discourage local officials from incurring financial obligations, even though borrowing might seem a logical approach to financing new infrastructure. Questions concerning (1) whether a project will actually be developed, (2) whether it may be abandoned prematurely, and (3) what will be the actual magnitude and distribution of project-related growth may make local officials reluctant to make commitments.

The interjurisdictional distribution problems may be as severe as those associated with cost and revenue timing. The project facilities that generate most of the new public sector revenues may be located in one county while most of the project-related population lives in a different school district, county, or even a different state. Fiscal impact assessments should be designed to identify these intertemporal and interjurisdictional distribution problems in advance so that decisionmakers can have the opportunity to devise strategies for coping with them.

Specific techniques employed to estimate the fiscal impacts of new projects or programs differ somewhat in the details of the estimation procedure, and assessments differ substantially in the scope of costs and revenues addressed. However, most assessment approaches apply relatively simple procedures in translating the characteristics of the project and the estimates of its economic, demographic, and public service effects into projections of project-related costs and revenues. (For a detailed discussion, see Chapter 5 of Leistritz and Murdock 1981).

CONCLUSIONS AND IMPLICATIONS

The objective of this paper was to provide an overview of the conceptual bases, methodological alternatives, and assessment techniques that are commonly utilized in assessing the economic, demographic, public service, and fiscal impacts of proposed projects or programs. It is important to point out, however, that each of these impact dimensions represents a major field of study in itself. Books and monographs have been devoted to each area while a number of works address the general topics of socioeconomic impact assessment or impact assessment generally. Readers desiring to become familiar with the area should take the opportunity to review some of these resource materials. (In addition to works previously cited, see Bowles 1981; Canter *et al.* 1985; Finsterbusch *et al.* 1983; Lang and Armour 1981; Rossini and Porter 1983; Weber and Howell 1982).

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Dr. Larry Leistritz is a Professor of Agricultural Economics at North Dakota State University. He has been a faculty member since 1970. He has directed a number of research projects assessing the economic, demographic, and fiscal impacts of large scale projects. He is the author or editor of nine books, including *The Socioeconomic Impact of Resource Development: Methods for Assessment* (Westview 1981), *Socioeconomic Impact Management: Design and Implementation* (Westview 1984), *Social Impact Assessment and Management: An Annotated Bibliography* (Garland 1986). Dr. Leistritz received his B.S., M.S., and Ph.D. in agricultural economics from the University of Nebraska-Lincoln.

A SOCIO-CULTURAL PERSPECTIVE ON THEORY AND PRACTICE OF SOCIAL IMPACT ASSESSMENT: SOCIAL FOCUS

Dr. C. Hobson Bryan
The University of Alabama

HISTORICAL CONTEXT

The purpose of this presentation is to describe the present concepts and strategies of social impact assessment as the process has evolved over the past 20 years. Although there are numerous approaches to social impact assessment (see, for example, Bryan and Hendee 1983; Burdge 1985; Freudenburg 1986; Wolf 1983), the approach described is one that evolved specifically out of the author's experience with the U.S. Forest Service and then was broadened to a wider international context to work with his colleagues in New Zealand (Taylor *et al.* 1990).

Historically, social impact assessment was formalized with the signing of the National Environmental Policy Act (NEPA) in 1969. While the Santa Barbara Oil Spill in the United States was a catalyst for environmental procedures as we know them today in this country, the catalyst for such action for a number of other countries occurred around the same time period. For example, impetus for New Zealand's 1973 Environmental Protection and Enhancement Procedures was initiated from controversy around the proposed raising of Lake Manapouri for the generation of electricity in the late 1960's. With these and other incidences around the world, a note of widespread public discord led to a number of environmental assessment requirements, including the social assessment of environmental alteration and development. But in this and other countries the specific requirements for social impact assessments were vague or lacking. In the period from 1969 to 1979 social impact assessments were characterized by their absence, or by being done after-the-fact. The social impact assessments were frequently confused with economic analyses and political feasibility studies. These studies were frequently unfocused and encyclopedic or unfocused and sparse, but seldom directly useful in the decision process. In the late 1970's, the Council on Environmental Quality (CEQ) undertook a review of environmental impact assessments (EIAs) and concluded that EIAs were not uniform, that they were obscured by technical language, that the documents had become ends in themselves, that they were too encyclopedic, that there were excesses in paperwork, delays, and duplication of effort. The social impact assessments tended to reflect these deficiencies in the extreme. In 10 years approximately 12,000 EIAs had been conducted, with 1,200 lawsuits contesting the EIAs. Yet with few exceptions, the social impact assessment parts of these documents had little effect on the decision process.

In the author's judgment, the U.S. Forest Service was a lead agency in responding to the CEQ critique to improve EIAs generally and social impact assessments specifically. In 1979, the emphasis in this agency turned toward making the EIA an integral part of the decision process, explicating the procedures for social impact assessments, and making sure that these processes were analytic and issue-driven. But for the United States generally (and including the Forest Service and other natural resource-associated agencies), in the past 10 years the emphasis for these processes has been more on process than substance, with frequent litigation in the courts. This trend has not necessarily been the case in other countries with different political climates. For example, in New Zealand impetus for a viable and proactive role for social impact assessment in particular has come from the massive restructuring and reform of their public service and resource economy. In the United States, a more broad-based and socially sensitive EIA process now seems to be on the verge of evolving in the face of "mainstream" or "grassroots" demands from communities for full participation in the decision process. Consequently, social impact assessment is likely to play a much more vital role than formerly in the broader contexts of project planning, implementation, mitigation, and monitoring of effects.

CONCEPTUAL/METHODOLOGICAL STRATEGIES FOR SOCIAL IMPACT ASSESSMENT

At least two levels of definition and scope can be identified for social impact assessment. The first is driven by NEPA requirements with emphasis on social impact assessment as part of a "systematic and interdisciplinary approach, to ensure that there is an integration of the natural and social sciences within the environmental design and planning in decisions that may have an impact on the environment." More specifically, social impact assessment is the assessment of the social ramifications of environmental alteration. But social impact assessment can also be viewed from a larger management perspective. From this perspective, more emphasis is given to negotiation among different stakeholders for a project or plan, and on the continuing monitoring and mitigation over the life of the activity.

The social impact assessment logic and process follows that of the EIA. Social variables are conceptualized as falling into the following categories: population/land use; lifestyles; attitudes, beliefs, and values; and social organization. Likely intervening variables in the analysis include proximity of people affected, social class, work (occupation), gender, ethnicity, and kinship. Cost effectiveness and value of social impact assessments can be enhanced by restricting focus on key issues and relying as much as possible on secondary data. The primary variable for the disaggregation of collected data is in terms of the major constituencies or stakeholders affected by the project or plan.

Analysis and interpretation of data are driven by an analytic inductive/deductive process, whereby models of change are formulated by the investigator and continually revised in the face of discrepant data until most of the data can be accounted for by the model. Social effects estimations are then made using trend projections and a variety of economic and population multipliers. The social impact assessment is typified as a process of continual negotiation and re-negotiation with publics as scenarios are posed, publics react, and scenarios are re-posed. Therefore, if properly implemented, social impact assessment can be a valuable management as well as assessment tool. The process in larger context can be viewed as a means of empowerment, education, and negotiation for all constituencies concerned, with the potential result of a better decision and management process.

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Dr. C. Hobson Bryan has been with The University of Alabama since 1970 and has served as Professor and Chair of the Department of Sociology since 1983. He was Program Leader for Social Impact Assessment for the U.S. Forest Service from 1979 through 1981, and was awarded a Senior Fulbright Research Fellowship to New Zealand in 1984 to help develop social impact assessment policies and procedures for that country. He teaches, conducts research, and writes on the social implications of natural resource policy and social impact assessment. Dr. Bryan received his B.A. in sociology from Vanderbilt University and his M.A. and Ph.D. in sociology from Louisiana State University.

MINERALS MANAGEMENT SERVICE SOCIOECONOMIC WORKSHOP PLANS

Dr. Shirley Laska
University of New Orleans
and
Dr. Robert Gramling
University of Southwestern Louisiana

No papers will be submitted due to the scoping nature of the presentations.

Dr. Shirley Laska teaches sociology at the University of New Orleans. She is currently Associate Professor of Sociology and Director of the Environmental Social Science Research Institute there. Her areas of interest and research are urban and environmental issues. Dr. Laska received her B.S. from Boston University and her Ph.D. from Tulane University.

Dr. Robert Gramling is Director of the Center for Socioeconomic Research at the University of Southwestern Louisiana in Lafayette, Louisiana. He received his Ph.D. in sociology from Florida State University. Dr. Gramling's principle research interests include socioeconomic impact assessment, microsociology, and the sociology of marriage and the family. He is particularly familiar with the south Louisiana "cajun" culture, and has conducted and published research on the impacts of offshore oil and gas, and OCS activities on the people and communities of southern Louisiana.

THE SEA GRANT COLLEGE PROGRAM: A NATIONAL PERSPECTIVE AND GULF OF MEXICO REGIONAL INITIATIVES

Session:	THE SEA GRANT COLLEGE PROGRAM: A NATIONAL PERSPECTIVE AND GULF OF MEXICO REGIONAL INITIATIVES
Co-Chairs:	Dr. Robert M. Avent Mr. Dennis Chew
Date:	November 6, 1991

Presentation	Author/Affiliation
The Sea Grant College Program: A National Perspective and Gulf of Mexico Regional Initiatives: Session Introduction	Dr. Robert M. Avent and Mr. Dennis Chew Minerals Management Service Gulf of Mexico OCS Region
National Oceanic and Atmospheric Administration/Office of Oceanic Research National Sea Grant College Program	Mr. Robert Shephard Office of Oceanic Research Programs National Sea Grant College Program
Texas Sea Grant's Marine Advisory Service Program and 1991-93 Research Program Addressing the Needs of Gulf of Mexico Marine Industries	Mr. Dewayne Hollin Sea Grant College Program Texas A&M University
Louisiana Sea Grant College Program	Mr. Ronald Becker Sea Grant College Program Louisiana State University
Mississippi-Alabama Sea Grant Consortium	Dr. Jesus B. Tupaz Mississippi/Alabama Sea Grant Consortium
Impact on Florida: The Florida Sea Grant College Program	Dr. James C. Cato Florida Sea Grant College Program University of Florida

THE SEA GRANT COLLEGE PROGRAM: A NATIONAL PERSPECTIVE AND GULF OF MEXICO REGIONAL INITIATIVES: SESSION INTRODUCTION

Dr. Robert M. Avent
and
Mr. Dennis Chew
Minerals Management Service
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The purpose of the Information Transfer Meeting (ITM) is to foster sharing of information among participants about current research and education programs, and/or issues of concern to the Minerals Management Service (MMS), other Federal and state agencies, and academic institutions. Presentations at the ITM pertain in a general sense to the MMS Gulf of Mexico Outer Continental Shelf (OCS) oil and gas program, but in a broader sense also address regional environmental, social, or economic concerns, or report current OCS industry activities or technologies. The Sea Grant College Program is a joint enterprise among States, National Oceanic and Atmospheric Administration (NOAA), and academic institutions. This year the MMS invited representatives from the National Sea Grant Program and the four Gulf States' Sea Grant programs. In attendance were Mr. Robert Shephard (National Program), Mr. Dewayne Hollin (Texas), Mr. Ronald Becker (Louisiana), Dr. Jesus Tupaz (Mississippi-Alabama), and Dr. James Cato (Florida).

Because other ITM sessions received the bulk of the ITM attendees, the cochairs and speakers elected to change the session format from one of formal presentations to a round-table discussion of Sea Grant College Program history, its mandates, objectives, organization, and programmatic direction. Some emphasis was placed on possible areas for future cooperation between the NOAA Sea Grant Program and the MMS. Following this introduction are the summaries prepared by the invited participants.

Dr. Robert M. Avent received his Ph.D. in biological oceanography in 1973 from Florida State University. His main field of interest is marine physiological ecology. He has pursued investigations on the biological effects of hydrostatic pressure, animal zonation, and reef morphology. He is an oceanographer with the Environmental Studies Section, MMS Gulf of Mexico OCS Region where he came in 1981 from the National Marine Fisheries Service.

Mr. Dennis Chew is Chief of the Offshore Unit, Environmental Assessment Section, MMS Gulf of Mexico OCS Region. He holds an M.S. degree in biological sciences and has worked as an estuarine and marine ecologist in the Gulf of Mexico area since 1970, specializing in wetlands and fisheries.

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION/ OFFICE OF OCEANIC RESEARCH NATIONAL SEA GRANT COLLEGE PROGRAM

Mr. Robert Shephard
Office of Oceanic Research Programs
National Sea Grant College Program

Housed in the National Oceanic and Atmospheric Administration's Office of Oceanic and Atmospheric Research is the Office of Oceanic Research Programs. It is composed of both the National Sea Grant College Program and the National Undersea Research Program.

The National Sea Grant College Program was created by legislation in 1966 to foster the development and wise use of the nation's ocean and Great Lakes resources. It works within a core of 29 Sea Grant colleges and institutions which encompass more than 300 universities and other marine organizations in coastal and Great Lakes States. A unique federal-state-university partnership, Sea Grant funds research, education, and public outreach projects that cover all areas of the marine sciences. Before being funded, Sea Grant scientific projects are competitively evaluated for scientific merit, possible benefits to society, and programmatic concerns.

The National Sea Grant Office is organized into five divisions which support work at universities on: Environmental Studies; Technology and Commercial Development; Non-Living, Living, and Human Resources. Virtually every marine issue is covered under one of the five divisions.

ENVIRONMENTAL STUDIES

Environmental studies focus on such topics as: nutrient and carbon dynamics, habitat dynamics, human health, and environmental management. In a Sea Grant-funded environmental management project, University of Rhode Island scientists have completed an organized research program on coastal lagoons as the first step toward developing a comprehensive management plan. It involved studies of the circulation, eutrophication levels, and fisheries productivity of coastal lagoons. The results showed that, with appropriate management, development around the ponds can continue in an environmentally sound manner.

Another Sea Grant environmental studies research project addressed a major concern of Great Lakes citizens--the impact of toxic organic compounds on human health and the living resources of the Great Lakes. Michigan and Wisconsin scientists supported by Sea Grant carried out an extensive multi-project program to assess the inputs, fate, and effects of polychlorinated biphenols in the Great Lakes.

TECHNOLOGY AND COMMERCIAL DEVELOPMENT

Sea Grant technology and commercial development studies include research projects related to marine transportation, ocean engineering, marine economics, and marine recreation and tourism. Sea Grant-funded ocean engineering projects have led to the development of a remotely operated vehicle frame by engineers at Massachusetts Institute of Technology and have supported training for fishermen at the David Taylor Research Center in Bethesda, Maryland. Sea Grant marine recreation and tourism projects focus on expanding recreation opportunities through the more efficient use of marine resources.

NON-LIVING RESOURCES

Mineral resources, coastal processes, and diving physiology are non-living resources marine issues. Researchers on the west coast are involved in Sea Grant-supported projects that are studying black smokers, vents which emit plumes of sulfide--enriched gas, as potential sources of strategic minerals. In Hawaii, by virtue of its proximity to an extensive belt of highgrade ferro-manganese nodule deposits, Sea Grant research projects are focussed on exploiting these valuable minerals.

Coastal processes projects encompass oceanic forcing processes such as waves, currents, and tides, and the resulting changes of the coast and seafloor. In this area, Sea Grant research on erosion in local communities and the use of vegetation to stabilize shorelines provided information to adjust building setbacks in North Carolina, with an estimated $1 million saved from property damages and remedial action.

Understanding the fundamental requirements for increasing man's capacity to both perform underwater scientific research and to enjoy the water on a recreational basis is the focus of Sea Grant efforts in diving physiology and safety.

LIVING RESOURCES

Sea Grant living resources projects focus research on animal and plant aquaculture, fisheries, seafood technology, and biotechnology. Ten years of aquaculture research at Sea Grant programs on the hybrid striped bass have resulted in a new industry meeting consumer demands for high quality seafood. Atlantic and Gulf menhaden, the nation's largest fishery in terms of volume but rather low in value per pound, are being studied by Sea Grant scientists as possible candidates for use in surimi, a minced fish product that can be reconstituted into various seafood products. Sea Grant research in food science is aiding the fishing industry by improving processing technology and methods for assuring safety of seafood.

HUMAN RESOURCES

Human resources is the outreach arm of the Sea Grant Program dedicated to ensuring that the results of research are transferred to those individuals that can use them. Marine advisory services, education and training, marine policy and social sciences, ocean law, and communications are the components of this outreach arm. In this area, Sea Grant supports the Marine Advisory Services Program. It is a network of about 300 agents and specialists affiliated with Sea Grant universities who work in the field to provide a link between the people who live and work in coastal areas and the Sea Grant researchers at the universities.

Through its network of participating academic institutions, Sea Grant has been actively involved in increasing the supply of well-trained and educated specialists in marine science and marine affairs. The number of students supported by Sea Grant to date is approaching 10,000. Concurrently, hundreds of thousands of people are reached with information on ocean and Great Lakes resource concerns through Sea Grant's communications program.

To meet challenges faced by the nation's coastal and Great Lakes resources, Sea Grant in its third decade of operation is continuing its role of supporting relevant research in all areas of marine science and of transferring the results to coastal and marine businesses and government decisionmakers.

Mr. Robert J. Shephard, a marine and electrical engineer, is Acting Deputy Director for the Office of Oceanic Research Programs and the National Sea Grant College Program. Prior to joining Sea Grant in 1975, Mr. Shephard spent 20 years in the private sector associated with Westinghouse Electric Corporation, Trident Engineering Associates, and Quanta Systems Corporation. He served as president of Quanta's wholly-owned subsidiary, Washington Technological Associates.

Mr. Shephard received his undergraduate degree from Massachusetts Maritime Academy in 1954 and served in the U.S. Navy aboard a destroyer as engineering officer. He also served for two years as an industry staff member for the President's Commission on Marine Science Engineering and Research. This commission addressed the state of oceanography in the United States and set forth recommendations for a more uniform implementation of set goals. As a result of this commission, National Oceanic and Atmospheric Administration was formed in 1970.

During his tenure in the National Sea Grant Office, he has been competitively awarded a LEGIS Fellowship to Congress, where he served in the Office of Senator Claiborne Pell as a legislative aide focusing on marine affairs and education.

TEXAS SEA GRANT'S MARINE ADVISORY SERVICE PROGRAM AND 1991-93 RESEARCH PROGRAM ADDRESSING THE NEEDS OF GULF OF MEXICO MARINE INDUSTRIES

Mr. Dewayne Hollin
Sea Grant College Program
Texas A&M University

BACKGROUND

The Marine Advisory Service (MAS) is the extension arm of the Texas A&M University Sea Grant College Program, and, as such, fulfills the public service role of the Sea Grant program along the Texas coast. The MAS provides a technology transfer function for Sea Grant and also facilitates other educational efforts for the marine industry and the general public. One of the important industry groups that MAS personnel work with is the offshore industry and the MAS marine business management specialist provides several advisory programs each year for this group of industry professionals.

MARINE SAFETY SEMINAR

For the past 14 years, Texas A&M University Sea Grant has sponsored the Marine Safety Seminar for offshore and marine safety professionals. Safety is especially important in the marine/offshore industry due to the potentially hazardous and treacherous environment surrounding the workplace. As new technology changes the workplace and as new personnel enter the industry's workplace for the first time, safety and training activities become even more important. Along with these changes are new regulations and requirements that will further impact the industry and safety and training activities and programs.

To help meet the challenges presented to the marine/offshore industry and to help ensure good quality safety and training programs for industry personnel, the Sea Grant annual Marine Safety Seminar addresses major safety and personnel training issues affecting the industry and provides interpretation and insight from experienced professionals with safety, personnel management, and legal backgrounds. Explanation and interpretation of new and proposed federal and state regulations are covered by regulatory enforcement agency administrators from the U.S. Coast Guard, Minerals Management Service, Occupational Safety and Health Administration, the U.S. Environmental Protection Agency, and others.

In the 14 year history of the Marine Safety Seminar over 1,600 safety professionals and industry leaders have attended the annual program. Many critical issues have been addressed by seminar participants. Some of these include drug and alcohol testing; hazardous waste training requirements; safety and survival regulatory initiatives for offshore operations; marine oil and chemical spill control; clean up and training; offshore cargo handling safety; helicopter safety, offshore personnel transfer, and evacuation procedures; accident investigation procedures; marine/offshore material handling and equipment loading safety; and in-the-water survival training.

GULF COAST FISHING VESSEL SAFETY TRAINING

An outgrowth of the Marine Safety Seminar was the creation of the safety training program for commercial fishermen. The Gulf Coast Fishing Vessel Safety Program is designed for vessel captains, crews, fleet owners, and others concerned with safety and training in the Gulf Coast fishing industry.

The Gulf Coast Program covers basic safety procedures, addresses the operational concerns of the region's commercial fishermen, and provides training to enhance vessel safety. The program covers Safety and Survival, Medical Emergencies, Fire Prevention and Firefighting, U.S. Coast Guard Standards and Procedures, Navigation, Seamanship, Watchkeeping, and Rules of the Road.

The *Gulf Coast Fishing Vessel Safety Manual* serves as the curriculum outline and a reference text for Gulf Coast-wide safety and training efforts. The Gulf Coast Manual and the 12-hour training program provide basic as well as technical and operational training and education needed to help reduce accidents, insurance claims, and casualties through better identification and analysis of safety problems.

MARINE/OFFSHORE INDUSTRY OUTLOOK CONFERENCE

For the past 15 years Texas A&M University Sea Grant, through the MAS, has presented an annual outlook conference designed to assist industry observers, managers, and leaders by providing useful business planning information on industry developments, trends, and critical issues for the next 2-3 year period.

The offshore oil and gas industry has gone through many changes in recent years and the need to provide insight into future industry developments is very difficult. The conference focus is on oil and gas industry planning for future offshore drilling and production activities. A panel of recognized marine/offshore industry leaders discusses future development in equipment utilization, regulatory policy, personnel and training, financial constraints, and technological changes. Industry segments covered include offshore construction, offshore drilling, marine/offshore transportation, commercial diving, and marine equipment/supplies.

TEXAS SEA GRANT RESEARCH PRIORITIES

Major areas of emphasis in our 1991-1993 research program continue to be in aquaculture, fisheries, environmental areas, seafood sciences, and marine engineering pertinent to aquaculture.

Aquaculture

The proposed aquaculture research program for 1991-1993 will be primarily responsive to the pressing need for information relating to development of red drum culture in Texas. Studies will be conducted on essential elements of red drum reproductive endocrinology, larval nutrition, dietary influence on growth, disease resistance, and overwintering.

Sea Grant researchers have pursued development of a strain of oysters for cultchless culture. The research has ended and we propose a concerted demonstration during 1991-1993 to commercialize the effort, with the cooperation of a private oyster leaseholder. This pattern of several years of developmental research followed by Sea Grant-assisted commercialization or application is one the Sea Grant administration will pursue actively in the future.

Research on neuroendocrine control of reproduction in shrimp shows promise of significant results in the near future and will be continued through the 1991-1993 cycle.

Shrimp aquaculture is now a marginally viable but growing industry in Texas. Sea Grant emphasis is beginning to shift more strongly into the technology transfer and infrastructure support phases for aquaculture industry.

Fisheries

Sea Grant has sponsored research on the Kemp's ridley and other sea turtles for more than 12 years. This research focused on sea turtle behavior, reproductive biology, physiology of hibernation, and migratory habits in an effort to understand and protect these animals better. During 1991-1993 the Sea Grant program development component will assist the sea turtle research team in its attempt to locate breeding grounds for this endangered species by aerial survey.

Sea Grant is now embarking on a program to address issues relating to shrimp bycatch. Advisory specialists and agents are working with commercial fishermen and research into genetics of the impacted red snapper stock is proposed for 1991-1993. Other proposed finfish research is related to natural predation of red drum larvae and bears upon natural recruitment and attempts by the state and conservation organizations to restore red drum populations in open bays by restocking.

Oyster fishery issues continue in Texas. Sea Grant support has facilitated development of a numerical model that accounts for the effects of various factors, including diseases, on oyster population survival. Program development funds are being used to demonstrate the application of this model for management.

Environment

Sea Grant is sponsoring research in an attempt to determine the biological pathways of heavy metals and impacts on the ecosystem resulting from a variety of activities that causes resuspension; i.e., dredging, trawling, floods, storms, and hurricanes. These studies and another on eutrophication processes will take place in Galveston Bay, and will substantially augment the management-oriented research sponsored by the Galveston Bay National Estuary Program.

A basic investigation of carbon/nitrogen cycles in seagrass beds in Laguna Madre will continue. The occurrence of persistent "brown-tides" in the study area has apparently affected the health and condition of seagrasses in this highly productive finfish habitat and nursery ground.

We propose to continue another project, started in the previous cycle, relating to viruses that infect marine phytoplankton, including brown and red-tide species. This imaginative and interesting study may have application to environmental management as well as aquaculture.

Seafood Science And Technology

Advisory activities in seafood safety and marketing are ongoing efforts. One research effort is proposed for 1991-1993, which will result in more rapid DNA-based methods for differentiation between imported and domestics species of commercial shrimp. This will have immediate application by U.S. Customs agents in their attempt to prevent practices leading to mislabelling and misrepresentation of imported shrimp as higher quality domestic varieties.

Marine Engineering

As marine aquaculture develops in Texas, it is increasingly apparent that closed recirculation systems will play a larger role than they do today. Future intensive culture is indicated for shrimp, redfish, tropical aquarium fish, and cephalopods. One 1991-1993 Sea Grant project, already underway with program development funds, will apply computer expert system technology to management of water quality in intensive recirculating seawater systems.

Mr. Dewayne Hollin has been Marine Business Management Specialist for the Sea Grant College Program at Texas A&M University since 1972. He received both his BBA and MBA from University of Houston. He currently provides advisory services for marine-related businesses operating along the Texas Gulf Coast; plans and coordinates training programs and seminars in the areas of safety, business management and economics, marketing, environmental issues, recreational boating and commercial fishing, and conducts basic research on environmental issues, recreational boating, mariculture economics, marine industrial development, and commercial fishing industry safety.

LOUISIANA SEA GRANT COLLEGE PROGRAM

Mr. Ronald Becker
Sea Grant College Program
Louisiana State University

The National Sea Grant College Program was established by Congress in 1966. Encompassing three major components - scientific research, advisory services, and education – the program was designed to marshal university resources to address problems and issues in the marine and coastal environment: fisheries, aquaculture, seafood processing, wetland management, coastal land loss, marine industry, recreation, economics, marine education, and law. Today, the program has grown to a network of 30 programs in universities and research institutions nationwide.

Louisiana's Sea Grant program began at Louisiana State University (LSU) in 1968; 10 years later, its high quality and comprehensive scope won the university official designation as the nation's 13th Sea Grant college. For almost 25 years, Louisiana Sea Grant has consistently dedicated its energies to serving the people. In laboratories, in classrooms, in the workplaces of the state's citizens, and in marshes, bays, and waterways, Sea Grant research has concentrated on solving Louisiana problems of regional and national significance.

Sea Grant has sponsored more than 500 research projects through LSU, the University of Southwestern Louisiana, Tulane University, the University of New Orleans, Nicholls State University, the Louisiana Universities Marine Consortium, and other institutions. The Sea Grant concept of applied marine research, education, and advisory services and its multidisciplinary approach to problems require scientists who can bridge the gap between fundamental research and its application to practical problems. To qualify for Sea Grant support, projects must be scientifically sound, practical, both locally and nationally relevant, and capable of being completed within two to four years. Over the past decade, Sea Grant has sponsored research that has resulted in regional as well as national benefits. These include the development of microorganisms that destroy hazardous wastes from oil spills to toxicants such as polychlorinated biphenols; a quick and reliable test for the presence of cholera in seafood and seafood-producing waters; processes that recover valuable by-products from shellwaste wastes; and computer-controlled, recirculating water systems and efficient biofilter techniques for aquaculture.

Through seminars and workshops, publications of all kinds, newsletters, educational videos, and, most importantly, people talking to other people, Louisiana Sea Grant's Marine Advisory Service extends the practical results of university research to the people of Louisiana. Sea Grant marine advisory agents, who live and work in Louisiana's coastal areas, are sources of knowledge and assistance to their communities in almost every area that concerns coastal regions--aquaculture, seafood processing and marketing, mariculture, marine recreation, marine economics, environmental management, and fisheries technology. These agents are assisted by marine specialists based on the LSU campus who have special expertise in seafood technology, marine economics, marine engineering, and aquaculture. Sea Grant's communications program, legal advisory service, and administrative offices are also located on the LSU campus.

Sea Grant supports projects designed to encourage and improve marine education content and offerings at all levels of the State's educational system. Besides its dominant role in forming the graduate-level Department of Marine Sciences at LSU, Sea Grant has produced multimedia classroom materials for use in Louisiana vocational-technical schools, elementary schools, and high schools. Through statewide training workshops conducted by Sea Grant marine educators, teachers learn how to use the materials in their classrooms.

Louisiana Sea Grant activities are administered through the Office of Sea Grant Development, headed by an executive director under LSU's Office of Research and Economic Development. Sea Grant research is supported by federal funds and matching state funds. In 1990, these totalled over $2.4 million.

Mr. Ronald Becker joined the Louisiana Sea Grant College Program at LSU in 1970, and has served as the program's associate director since 1979. Before coming to LSU, Mr. Becker was employed by Texas Instruments, Inc. and the U.S. Army Corps of Engineers. He holds the geological engineer degree from the Colorado School of Mines and a master's degree in geotechnical engineering from Purdue University.

MISSISSIPPI-ALABAMA SEA GRANT CONSORTIUM

Dr. Jesus B. Tupaz
Mississippi/Alabama
Sea Grant Consortium

The National Sea Grant College Program was established by Congress on October 15, 1966, by Public Law 89-688. Its purpose was to accelerate the development of the nation's marine resources, including their conservation, proper management, and wise use. Sea Grant in Mississippi and Alabama is administered through the Mississippi-Alabama Sea Grant Consortium (MASGC). The MASGC is one of about 30 State Sea Grant Programs along our coastal areas including the Great Lakes. The MASGC comprises eight institutions of higher learning: Auburn University, University of Alabama, University of Alabama at Birmingham, University of South Alabama, University of Mississippi, Mississippi State University, University of Southern Mississippi, and the Gulf Coast Research Laboratory.

The Sea Grant Program is a federal/state matching grant program of two federal dollars to each state dollar. There is a shared program management and fiscal responsibility between the National Sea Grant College Program Office (NSGCPO) and the States sea grant programs. The MASGC responds to state, regional, and national needs through an infrastructure of research, education, and advisory or technology transfer service.

The Sea Grant College Program is relatively small in terms of federally-funded marine programs. Therefore, competition for the finite Sea Grant funds is keen. To be competitive in Sea Grant, research projects must be unique and innovative exhibiting the originality and creativeness of the investigators. Sea Grant research should focus on advancing the "state of the art" in a particular field of the marine sciences. It should also strive to develop applications and products that are useful beyond a local region. Technology developed through Sea Grant should be transferable to other areas of the country. Sea Grant proposals are processed within a tri-level review process: extramural written peer review, on-site review, and review by the NSGCPO. Proposals should have sufficient intellectual content for university level academic research and should provide for effective technology transfer to the user community.

Range of research within the MASGC includes genetic engineering, biotechnology, polymer science, coastal erosion, seafood processing, fisheries science, aquaculture, legal, economics, and sociological activities. Selected examples of current research include:

- Algal Genetic Engineering - purpose is to develop a system for genetic transformation of marine microalgae to improve protein quality;

- Stone Crab Physiology - to explain differences in habitat preference, juvenile recruitment characteristics, and variability in population dynamics;

- Importance of Epiphytic Algae in Mississippi Seagrass Beds - to test importance of these organisms in the food chain to animal species in the Mississippi Sound; and

- Corrosion Inhibition - to evaluate natural and synthetic peptides as inhibitors of steel corrosion in seawater.

Coastal change in the 1990's and into the next century is the foremost concern and focus of the MASGC. Population growth along the coastal areas will significantly influence this coastal change. Approximately 50 percent of the U.S. population lives within 50 miles of the coast, including the Great Lakes coastal areas. By the turn of the century, approximately 70 to 80 percent of the American people will be living within this narrow band of 50 miles of the coast. Population growth coupled with developmental needs of the nation will cause dramatic changes along the coast. Physiographic and demographic changes will result in the alteration of the marine habitat, and degradation of both coastal/estuarine water quality as well as coastal ground water quality and supplies, and ultimately in reducing coastal biological productivity. Sea Grant must lead the way to help mitigate this projected adverse impact. Our success will depend on the Sea Grant Program's robustness and creativity, on the program's ability to use and exploit the evolving technology, and on the availability of resources, i.e., funds and talented people.

Primary factors affecting the coastal ocean environment are coastal water quality, coastal wetlands habitat loss, and coastal marine productivity. Coastal water quality is affected by natural and man-made activities, i.e., industrial, agricultural, and domestic. Wetlands loss is also dependent on both natural processes as well as man's development activities. In addition, wetlands play a major role as hatcheries and nurseries to many marine species. As a result, floral and faunal productivity are closely linked to both water quality and wetlands loss.

We need to be perceptive and very creative in the 1990's in order to preserve, enhance, and re-establish degraded wetlands. Continued research is needed to understand the physical, chemical, and biological processes involved in maintaining the delicate balance within marine wetland ecosystems. Such research includes circulation of the water mass, i.e., the advection or transport of sediments, pollution, turbidity, and nutrients and their variability; the input and output of pollutants; nutrient production and its variability; and, the mass structure of the water, i.e., salinity and temperature. We need to "make smart" use of various technological tools, such as: computer ecosystem circulation models, remote sensing (satellite and aircraft), innovative and automated observational instrumentation for making measurements and monitoring, and state of the art computer processing.

We need to continue our research in marine biotechnology, i.e., the use of marine organisms or their components to provide products or services. This includes such research as: bio-organic chemistry; cell culture, bioreaction, and bioprocessing; biofouling, biocorrosion, and biosensors; and molecular genetics of algae, fishes, and invertebrates. We also need to expand our fishery and aquaculture programs to include identifying underutilized species with commercial and recreational value; determine optimum sustainable yields; restore and enhance exploited stocks through genetic engineering; develop efficient seafood processing technologies; develop optimum fishery marketing strategies; and seafood safety. Seafood safety is very important for seafood is highly susceptible to viral and bacterial contamination. Another area for continued research is ocean engineering. In particular, engineering support is needed for aquaculture production. Currently, aquaculture is very labor intensive. Improved pumping/circulation and water quality recovery/recycling systems are needed in the aquaculture operation. In addition, Sea Grant research focuses on producing useful products to benefit people. With a growing population along our coasts, continued research is needed in social, economic, legal and policy issues, and implications.

Education and Advisory/Extension Service are two other very important components of Sea Grant. Education and training efforts are focused on making the public aware of relevant and evolving marine technology by way of formal and informal educational programs. The classroom forum, field trips, and structured informal programs are directed to elementary and high school students and their teachers. At the college level, fellowships are awarded to deserving graduate students doing research in the marine sciences. Advisory and Extension is the public service arm for Sea Grant. It provides for the transfer of technology from the researchers to the user community, i.e., the fishermen, sportsmen, boaters, seafood processors, chemical, and medical industries. This extension of technology takes place through direct liaison: informal personal and individual contacts, and public group meetings and workshops.

In summary, Sea Grant promotes the development, proper management, and conservation of the nation's marine resources. Sea Grant is committed to wisely investing public funds for public benefit through academic institutions. The Mississippi-Alabama Sea Grant Consortium is a two-state, multi-institutional (eight member) system under single management. Our broad charter is solid and meaningful research, education, and advisory service in the marine environment and marine resources which contribute to the Sea Grant mission for public benefits.

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Dr. Jesus B. Tupaz retired from the U.S. Navy on July 1, 1991 after 31 years of active naval service. He recently joined the Mississippi-Alabama Sea Grant Consortium as their Associate Director. His areas of interest are marine meteorology and numerical weather/ocean prediction. Dr. Tupaz received his B.S. in naval science from the U.S. Naval Academy, his M.S. in meteorology and oceanography from the U.S. Naval Postgraduate School, and his Ph.D. in meteorology and applied mathematics from the U.S. Naval Postgraduate School.

IMPACT ON FLORIDA: THE FLORIDA SEA GRANT COLLEGE PROGRAM

Dr. James C. Cato*
Florida Sea Grant College Program
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INTRODUCTION

This summarizes the coastal setting in Florida and Florida Sea Grant's impact on the coast. The uniqueness of Florida Sea Grant's marine academic programs is indicated, followed by a description of Florida Sea Grant's multi-institutional and multidisciplinary focus, funding sources, and priority program areas.

*This summary is based on materials developed by the author and program materials from Florida Sea Grant documents prepared by staff members.

THE COASTAL SETTING

Coastal change is of major concern in Florida. The state has 10 percent of the nation's coastal population and a 12 million plus total population. Over 40 million tourists come to visit annually. Florida's shoreline is nearly the same length as all of the other Atlantic coast states combined. Visit our shores and you will find incomparable natural beauty and also intense competition for resource use. You will see diverse tropical and subtropical sport and commercial fisheries, year-round beach activities, one in every seven families owning a boat, marinas fighting with other uses for water access, and shoreline views that offer both buildings and birds. Eighty-five percent of Florida's population is considered urban and most is on the coast. The rural coastline that is left is suffering from encroachment processes and the impacts of its uphill neighbors. Near the coast, managing boat traffic to protect manatees, people, and the environment; and offshore, the debates about proposed minerals development; have produced many conflicts. Demands for the use of all of Florida's coastal resources through the economic and social lives of our residents and visitors have combined to place the development and management of Florida's resources in a fragile balance.

FLORIDA SEA GRANT'S IMPACT

What is the potential impact of all these people on the demand for these resources and how does Sea Grant fit into the equation to make sure that the resources are used wisely while being conserved for future generations? To educate our tourists and residents, we have produced a year-long series of 52 news videos on the environment, being shown in the major television markets statewide. We are developing Sea Grant Extension programs in waterfront development and allocation. The estuaries are used by 85-95 percent of our fisheries. Research being conducted on various stresses in the estuaries includes light limits on seagrasses, nutrient loads and contaminants, and productivity. Habitat enhancement and water quality is Sea Grant Extension program priority.

Sports fishermen in Florida generate well over 60 million angler days of activity. A series of educational posters is being developed to teach the need for management and consideration of many stressed species. The commercial seafood industry, combined with the recreational fisheries, makes Florida's fisheries the most valuable in the nation in terms of economic activity generated. Florida Sea Grant is conducting research on how management issues affect traditional fishing families, on fisheries recruitment, and on such safety and quality issues as pathogens in shellfish. Major demonstration projects have determined what to do with wastes from blue crab and calico scallop processing plants. Major educational programs are ongoing in seafood safety and quality. Florida has about 700 thousand registered boats and over 1500 public and private marinas. Work is in progress on managing boat traffic and to predict the demand for launching ramps.

With 1,350 linear miles of coast and 800 miles of high energy beaches, the use of beaches generates about 4 percent of Florida's employment. Florida has more beach building projects than any other state and research focuses on evaluating the effects of beach restoration on corals, coastal water turbidity, beach equilibrium, and sand transport. A major Sea Grant Extension program focuses on shoreline stabilization using native plants. Aquaculture is a young and growing industry. Sea Grant has conducted research on the effects of clam farming on seagrass, the economics of clam farming, and ways to improve shrimp reproduction in the hatchery, and aquaculture continues to be one of the major Sea Grant Extension areas of work.

Part of the debate concerning the impact of offshore oil development on existing and predicted uses of Florida's unique coastal resources focused on the economic and social values of these resources. Florida Sea Grant was the principal source of economic values used during these debates on tourism from beach use, wetlands, recreational fishing, artificial reefs, the seafood industry, and boating and marinas. Florida Sea Grant has made many other major impacts at the local, state, regional, and national level. This paper provides just a sample of them.

UNIQUE TO MARINE ACADEMIC PROGRAMS

Since its inception in 1972, the Florida Sea Grant College Program has provided a program that is unique to all of Florida's academic marine programs. The uniqueness comes from the fact that Sea Grant uses the three part approach of conducting research, education, and extension programs. In research, over 160 faculty in 22 public and private institutions have conducted about 250 major projects to date. A total of 10 federal, 8 regional, 37 county, and 8 city government units, and 43 private organizations, in addition to the state have provided support. Output levels have been high. In addition to making an impact in industry and government, these projects have resulted in about 25 scientific journal articles per year, and an ongoing publications program in bulletins, fact sheets, and reports for the general public.

In education, Sea Grant support has created a source of student productivity. Over 300 students have participated in Sea Grant projects as research assistants, doing work that was a part of their graduate degree requirements. Sea Grant has also generated over $120 thousand in private support to fund 22 graduate scholarships since 1986. A total of 13 Florida students have won Knauss Marine Policy Fellowships since 1982. All these students are now productive participants in business and government. On another education level, Florida Sea Grant has served as a catalyst for establishing the 4-H Marine Program in Florida. In 14 years, over 100,000 youth and 10,000 adults have participated. Environmental education training was provided to over 1,600 teachers just last year, which will multiply to about 50,000 students.

Sea Grant also provides the window for marine academic public service (Land-Grant for the Coast). The Sea Grant Extension Program has four state-wide specialists in seafood technology, marine economics, coastal engineering, and communications who support 12 agents located strategically in the state. The specialists and agents hold about 150 workshops, conferences and/or demonstrations per year, conduct ongoing educational programs, provide information to researchers about research needs on the coast, and transmit research findings back to the people who need it in a form they can use. The communications area of Sea Grant produces both research and extension publications, videos for educational programs, a quarterly FATHOM magazine, and provides vital education support and contact to the mass audiences who need and use Sea Grant generated information.

SEA GRANT IS "MULTI"

Florida Sea Grant is both multidisciplinary and multi-institutional. Over 30 academic disciplines have participated in Florida Sea Grant programs. This fact illustrates another unique attribute of Sea Grant. Today's problems require an integrated approach to solve them. No longer can just one discipline provide the answer. The problems are so complex that multidisciplinary efforts are required. Participants in Florida Sea Grant's research and educational programs have possessed expertise ranging from music to geography to zoology to economics, as well as the traditional marine science fields. Today's problems also require a multi-institutional approach. Consequently, all nine state universities, three private universities, and two research laboratories are permanent participants in Florida Sea Grant's programs, with the program administered from the University of Florida, on behalf of the State University System. Others participate when faculty talents match identified problems. Participants are

- State
  - University of West Florida
  - University of Central Florida
  - Florida A&M University
  - University of South Florida
  - Florida State University
  - Florida Atlantic University
  - University of North Florida
  - Florida International University
  - University of Florida
- Private
  - Florida Institute of Technology
  - University of Miami
  - Nova University
  - Mote Marine Laboratory
  - Harbor Branch Oceanographic Institution

FUNDING

The principal source of Sea Grant funding is the federal competitive proposal, prepared on a biennial basis. For Florida Sea Grant, this is about $1.6 million annually, with participants also providing the required 2:1 federal:state match. Sea Grant funding in Florida is also generated from state and county appropriations, private support, and from grants prepared for extramural sources of funding. The total Florida Sea Grant budget ranges from $3.5 to $5 million annually.

All Budget Sources

Federal NOAA Sea Grant	Extramural Grants
State Appropriations	Local
Faculty Match	State
Direct Funding	Federal
County Governments	Private

A PRIORITY DRIVEN PROGRAM

Florida Sea Grant uses three categories of input for setting program goals and conducting programs. These are user groups including industry and other private and public interests (both through our statewide advisors and local marine extension program advisory committees), the faculty (through both our formalized campus coordinator group and targeted faculty groups assigned to set priorities in certain program areas), and through agency advisors (scientists, managers, and regulators).

All Florida Sea Grant activities are judged against three simple but tough criteria: rationale, scientific merit, and application. There must be a strong need and identified problem to be resolved, the work must be conducted by the best scientific and educational methods and contribute to those methods, and there must be a clear indication that the results can be used to solve the problem. All funding is competitively determined.

Over the years, Florida Sea Grant research programs have been grouped into the four general areas of: living marine resources, coastal processes and development, marine industries, and education. Each of these contain a number of sub-program areas of focus. For the past four years, seven areas received priority. These were aquaculture, beaches and shores, coastal construction and ocean engineering, coastal recreation and tourism, estuarine habitat productivity and restoration, fisheries, marine and coastal policy and seafood technology. Sea Grant extension program areas have been designed to complement the research areas. The six current areas of program focus are aquaculture, environmental quality, recreation, seafood, shorelines and habitat, and waterfront development.

SUMMARY

Needless to say, the wants, needs, and dollars represented by the huge numbers of people who "use" Florida's coastal resources all combine to make understanding and managing one of the most fragile environments on Earth a difficult and often controversial undertaking. Florida Sea Grant has a vital role to fill in this complex endeavor. Through Sea Grant research efforts, the transfer of information via the Sea Grant Extension Program, and the outreach provided by Sea Grant educational efforts, Floridians and tourists can begin to better understand the state's unique environment, how we do and should use our coastal resources, and to better appreciate their impact on the quality of the environment. This understanding is essential for Floridians to rationally manage continued growth in the coastal zone, as well as to equitably resolve the ever increasing competition for coastal resources. Florida Sea Grant has assumed a statewide and national leadership role in the creation of a better informed and more responsible populace -- one that recognizes the need for Sea Grant programs and uses the findings of such programs to make Florida a better place to live.

Dr. James C. Cato has worked at the University of Florida for the past 22 years and presently serves as the Director of the Florida Sea Grant College Program. He is also a Professor of Food and Resource Economics. His areas of research and education interest include fisheries economics and the use and allocation of coastal and marine resources. Dr. Cato received his B.S. and M.S. in agricultural economics from Texas Tech University and his Ph.D. in food and resource economics from the University of Florida.

MINERALS MANAGEMENT SERVICE/LOUISIANA UNIVERSITIES MARINE CONSORTIUM "UNIVERSITY RESEARCH INITIATIVE"

Session:	MINERALS MANAGEMENT SERVICE/LOUISIANA UNIVERSITIES MARINE CONSORTIUM "UNIVERSITY RESEARCH INITIATIVE"
Co-Chairs:	Dr. Richard Defenbaugh Dr. Paul Sammarco
Date:	November 6, 1991

Presentation	Author/Affiliation
Minerals Management Service/Louisiana Universities Marine Consortium "University Research Initiative": Session Introduction	Dr. Richard Defenbaugh Minerals Management Service Gulf of Mexico OCS Region
A Review and Reexamination of Outer Continental Shelf Spatial-Temporal Variability as Determined by Previous Minerals Management Service Studies in the Gulf of Mexico	Dr. Robert S. Carney Coastal Ecology Institute Louisiana State University
Comparison of Nekton Habitats Associated with Pipeline Canals and Natural Channels	Dr. Lawrence P. Rozas Louisiana Universities Marine Consortium Marine Research and Education Center
Influence of Hypoxia on the Interpretation of Effects of Petroleum Production Activities	Dr. Nancy N. Rabalais Louisiana Universities Marine Consortium
Fate and Transport of Particle-Reactive Normal, Alkylated and Heterocyclic Aromatic Hydrocarbons	Dr. Jay C. Means and Ms. Debra J. McMillin Department of Physiology and Toxicology School of Veterinary Medicine Louisiana State University
Effect of Shoreline and Shallow Habitat Contamination and Loss on Dominant Infaunal Invertebrates	Dr. Darryl Felder Department of Biology University of Southwestern Louisiana
Effect of Oil Spills on Recovery of Coastal Wetlands	Dr. Irving A. Mendelssohn, Mr. Mark W. Hester Wetland Biogeochemistry Institute Center for Wetland Resources Louisiana State University, Mr. Wayne Grip Aero-Data Corporation, and Dr. John M. Hill Houston Advanced Research Center

MINERALS MANAGEMENT SERVICE/ LOUISIANA UNIVERSITIES MARINE CONSORTIUM "UNIVERSITY RESEARCH INITIATIVE": SESSION INTRODUCTION

Dr. Richard Defenbaugh
Minerals Management Service
Gulf of Mexico OCS Region

During 1988-1989 the Minerals Management Service (MMS) planned and developed novel "University Initiative" study programs. The purposes of these programs are to foster studies of issues associated with long term production of oil and gas on the Outer Continental Shelf (OCS); to encourage innovation in approaches to these study issues; to maximize the participation of the affected States in the collection of information valuable to both the MMS and the States; and to benefit the decisionmaking process for oil and gas activities in State waters. The specific objectives of these programs are to provide a basis for identification and implementation of innovative ideas for studies of the issues; to foster interdisciplinary investigations of offshore issues in a peer review environment; to encourage and train students in environmental research applicable to decisionmaking; and to foster multiple small interdisciplinary investigations.

In late 1988 letters were sent by MMS to the Governors of Gulf Coast States and California (areas with historic and active offshore oil and gas production) seeking nominations of educational institutions to compete for management of these programs. Requests for proposals were sent to all institutions nominated by the Governors, proposals were submitted by the institutions, and awards were eventually made (in mid-1989) to the Louisiana Universities Marine Consortium (LUMCON) for the Gulf Coast program, and to the University of California at Santa Barbara for the Pacific Coast program.

Each program solicits study proposals from the academic community, with emphasis on certain "framework issues" which pertain to an understanding of the environmental, social, or economic effects of a long history of oil and gas production in the region. Within the Gulf University Initiative Program, study proposals are screened by the University Initiative administrators, both within the system (by a Technical Steering Committee composed of academic members and State agency heads) and by external academic peer review (by a Scientific Committee of academic scientists selected because of their stature and expertise relative to the proposals under consideration). Study proposals which survive both levels of review are forwarded to the MMS for further review by agency scientists, managers, and members of the MMS OCS Advisory Board's Scientific Committee. During a site visit, at which researchers describe their proposed projects, funding decisions are made by consensus discussions involving LUMCON and MMS program managers and scientific advisors.

Seventeen Gulf of Mexico projects have been awarded during the three years the program has been in operation. One multi-study project, entitled "The impact of the "boom and bust" cycles of offshore petroleum extraction on social institutions," was the subject of a session at the November 1990 Information Transfer Meeting. This session is intended to showcase other projects awarded during Year I of the program.

Dr. Paul Sammarco, LUMCON Executive Director and MMS/LUMCON University Initiative Program Manager, provided a brief overview of the program and introduced each researcher's presentation.

Dr. Richard Defenbaugh is Deputy Regional Supervisor for Leasing and Environment within the Gulf of Mexico OCS Regional Office. His graduate work at Texas A&M University on the natural history and ecology of Gulf of Mexico estuarine and continental shelf invertebrates led to an M.S. in 1970 and a Ph.D. in 1976. He began his career in the Federal service in the Bureau of Land Management's (BLM) New Orleans OCS Office in 1975 and has been involved with BLM/MMS environmental studies and assessment programs since then. He served as Chief, Environmental Studies Section from October 1981 to September 1991, when he moved into his current position.

A REVIEW AND REEXAMINATION OF OUTER CONTINENTAL SHELF SPATIAL-TEMPORAL VARIABILITY AS DETERMINED BY PREVIOUS MINERALS MANAGEMENT SERVICE STUDIES IN THE GULF OF MEXICO

Dr. Robert S. Carney
Coastal Ecology Institute
Louisiana State University

INTRODUCTION

The history of Outer Continental Shelf (OCS) sampling programs is one in which there has been continuing improvement in sampling technology but little substantial improvement in statistical design and informative analysis of data. As a result, we are now at a point where samples of the highest possible quality are being taken, but they contribute little more to the decisionmaking process than cruder techniques did 20 years ago. Realizing this critical weakness in OCS study design, it is the purpose of this project to examine existing benthic faunal data for the explicit purpose of improving future designs and analyses.

In simplest terms, this project is documenting the variation found in past faunal sampling programs in the Gulf of Mexico. By determining how species counts and community parameters vary over time and from place to place, it will be possible to design more efficient studies. However, in practice, the project has two complications: one procedural and one theoretical. Procedurally, what is an effective means of analyzing the massive data sets typically produced by an OCS study? Theoretically, what are the important questions that management needs to ask of OCS data, and how does natural variation affect the ability to answer these questions?

MANIPULATION OF MASSIVE OCS DATA SETS

The OCS studies usually produce very large data sets. In the biological results alone, well over 500 species may be encountered in a few hundred samples. Often, the data set is so large that analytical efforts focus upon reducing it to some comprehensive summary, and in the process discard all the relevant variation. A prime example of this is the use of cluster analysis. Therefore, to fully understand the pattern of variation in benthic data, it is necessary to adopt a more effective means of handling data.

During the initial stages of this project, it was decided to make use of data handling routines which fall into the general category of scientific visualization. Scientific visualization exploits the hardware and software developed for image analysis and advanced graphics computer workstations. Rather than limiting exploratory analysis to graphs and charts of summary data in the traditional manner, scientific visualization builds images of an entire data set. Such computer images can then be displayed on high resolution terminals for interactive examination. For examination of OCS-type benthic data, we developed the following system: MicroVax 3500 Workstation running PV-WAVE in a VMS operating environment.

Precision Visuals Workstation Analysis and Visualization Environment (PV-WAVE) is a very powerful and fast suite of data handling routines. These Fortran-like routines can be used to write complex programs which read raw data tapes and produce a working image-like representation of data. Our programs were developed making use of the Minerals Management Service (MMS) California Monitoring Program (CAMP) benthic data of 301 samples and 1,084 species. This 301 x 1084 matrix was converted to a rectangular image in which each pixel represented the count of a given species at a given sample. Reordering the sequence of samples and species allows easy identification of similarity patterns while preserving all inherent variation in the data.

Currently, we are working with NODC data tapes for the following projects: South Texas, MAFLa, SouthWest Florida, and Northern Gulf of Mexico Continental Slope Study. We will add to this list the Central Gulf Platform Study and The Buccaneer Field Study (Environmental Protection Agency) if available. While the NODC archives do provide a valuable source of previous data, the header card/data card format of the NODC files provides little information as to the rationale of the sampling design. Therefore, the task of going from NODC tape to useful data can be long and tedious.

THEORETICAL CONSIDERATIONS

When a particular statistical procedure is anticipated, such as comparisons among means or a partitioning of variance, then the type of information needed about sample variation is easily identified. Minimally, you need to calculate standard deviation of the parameter concerned, determine the nature of this distribution, and determine the interdependencies between this variation and location, time, and abundance. However, since classification has assumed such an important role in interpretation of OCS survey data, it is important that the effects of variation upon stability of classifications also be determined.

Using the CAMP data set for trial purposes, we have developed programs in the PV-WAVE environment which determine both the nature of variation in the traditional sense and the effect of variation upon stability of classifications. These analyses will be applied to the Gulf of Mexico data sets. At this point one general conclusion can be drawn. The OCS benthic samples may contain over 1,000 species, but that there is very strong dominance by as few as 10 species. Typically, the most abundant species in a sample will exceed the tenth most abundant by up to two orders of magnitude (1,000 specimens versus 10 specimens). Species below the rank of tenth may be very patchy and absent in the majority of samples (count=0). Therefore, all traditional analyses which are affected by variation will be dominated by only a few percent of the species present. Due to the range in abundance of dominants and subdominants, as well as the numerous zero counts in the data set, transformation of counts will do little to eliminate the effect of dominants upon analyses.

Any successful analytical design must deal with the dual problems of very strong dominance and numerous zeros. At this point in the project, it can be suggested that the most effective approach would be to classify species by their rank abundance and then conduct separate analyses at specified levels of abundance. In this way, dominants and subdominants are treated separately and the information from each group is obtained without being obscured by the more dominant species.

Dr. Robert S. Carney is Director of the Coastal Ecology Institute at Louisiana State University. His major research interests include spatial ecology of benthic systems, ecology of deep-sea megafauna, environmental planning for the deep sea, and effective management of research efforts. He has participated in numerous research projects particularly of deep-sea fauna and communities; has served on many national-level policy boards, commissions, and scientific review boards; and has served as a National Science Foundation program director for biological oceanography. Dr. Carney received his B.S. in zoology from Duke University, his M.S. in biological oceanography from Texas A&M University, and his Ph.D. in biological oceanography from Oregon State University.

COMPARISON OF NEKTON HABITATS ASSOCIATED WITH PIPELINE CANALS AND NATURAL CHANNELS

Dr. Lawrence P. Rozas
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Marine Research and
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INTRODUCTION

Canals are a ubiquitous feature of the Louisiana coastal zone. The average density of canals and associated dredge-material levees in coastal Louisiana is approximately 10 percent of the marsh area, about the same density as natural channels (Turner 1987). Most canals were constructed for navigation, to access oil and gas drilling sites, or as corridors for laying pipelines (Davis 1973). Although the impact of deep navigation channels on estuaries and coastal wetlands can be significant (Ward 1980), canals constructed for developing petroleum resources (access and pipeline canals) have had a greater direct impact on coastal wetlands in Louisiana because they are so much more numerous than navigation channels (Turner and Cahoon 1987).

Both access and pipeline canals are commonly surrounded by dredge-material levees. Placement of this material alongside canals converts marsh to upland, an environment unavailable to aquatic organisms except during extreme tides. Dredge material can also form a barrier causing ponding behind levees and limiting exchanges between canal waters and marshes to infrequent, high-water events (Swenson and Turner 1987). Such a disruption of marsh hydrology is thought to accelerate marsh erosion, i.e., the conversion of marsh to open water (Turner *et al.* 1982; Turner and Cahoon 1987). Additionally, where canal density is high, marshes can become enclosed by levees and isolated from the rest of the estuary, resulting in a loss of habitat function for some species. Dredging also converts marshes and shallow subtidal areas to canals which may have very different physical properties than the former habitats. Newly dredged canals are typically straight, deep (2.4 m), and steep-sided (Wicker *et al.* 1989), whereas natural channels meander and contain shallow sloping banks which provide refugia and foraging areas for marsh nekton (McIvor and Odum 1988).

Adkins and Bowman (1976) found that the nekton assemblages in pipeline canals open to tidal exchange were similar in species composition to a nearby natural embayment. However, canals closed to tidal exchange had fewer species and individuals than open areas (Adkins and Bowman 1976). Similarly, Neill and Turner (1987a) found significantly lower densities of transients (species that spawn outside the estuary, but use estuarine nursery areas as postlarvae and juveniles) in closed canals than open canals. However, even a small opening permitting regular tidal exchange allowed access by transient species, many of which are commercially and recreationally important (Gilmore *et al.* 1981; Neill and Turner 1987a).

Many species residing in canals are known to occupy the vegetated marsh surface of Atlantic and Gulf of Mexico marshes when they are flooded at high tide (Talbot and Able 1984; Zimmerman and Minello 1984; Rozas and Odum 1987; McIvor and Odum 1988; Hettler 1989). Although under most conditions these organisms are precluded from using marshes behind canal levees, nekton can access narrow (< 10 m wide) fringing marshes that occupy the intertidal area between canals and associated levees. In this paper I examine the degree to which these fringing marshes function as nursery habitat for nekton residing in canals by comparing densities of nekton on marshes adjacent to pipeline canals and natural tidal creeks. In addition, I compare shallow subtidal habitats in the two environments (canals and natural channels) by (1) sampling nekton along the marsh edge at low tide and (2) measuring predator encounter rates in both habitats.

STUDY AREA AND SAMPLE SITES

The study area was within the Terrebonne/Timbalier estuary and the Mississippi Deltaic Plain. Sample sites were near latitude 29°14'N and longitude 90°40'W, approximately 4 km southwest of the Louisiana Universities Marine Consortium (LUMCON) Marine Center (Figure 10.1). Tides in the estuary are predominantly diurnal and have a mean range of approximately 0.4 m (Shirzad *et al.* 1989; U.S. Department of Commerce 1990). Marshes within the study area are classified as saline (Chabreck and Linscombe 1978). Marsh vegetation was dominated by *Spartina alterniflora* Loisel, although *Spartina patens* (Aiton) Muhl and small patches of *Juncus roemerianus* Scheele were also present. *Distichlis spicata* (L.) Greene was common on marshes of slightly higher elevation (e.g., on the natural levees of tidal creeks).

Three pipeline canals constructed using either of two methods (push or flotation) were studied. The push method causes less habitat modification because it requires excavation of a relatively narrow (1.2-1.8 m), shallow (2.4-3.0 m) trench that is usually backfilled after pipeline installation (Tabberer *et al.* 1985). Because a portion of the dredge material volume is lost through compaction and organic decomposition, backfilling does not completely fill the trench, but the final depth is usually < 1 m (Neill and Turner 1987b; Abernethy and Gosselink 1988). The flotation method requires a canal large enough to accommodate a pipe-laying barge, 12.1-15.2 m wide and 1.8-3.6 m deep (Tabberer *et al.* 1985). Therefore, most pipeline canals constructed using the flotation method are deeper than pipeline trenches and have levees, as they are seldom backfilled.

Initially, I selected sample sites on a shallow flotation canal, a pipeline trench, a tidal creek of

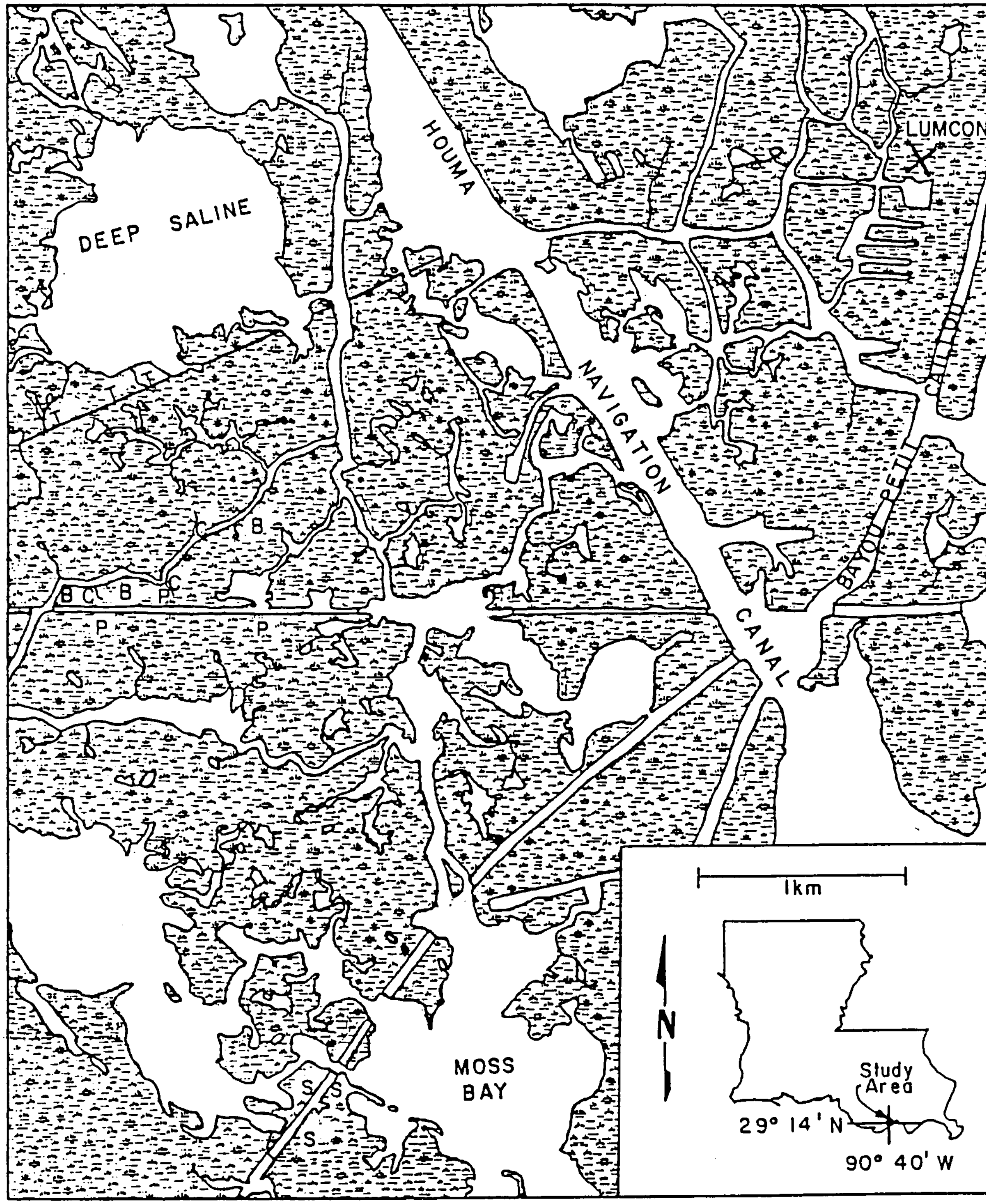

Figure 10.1. Locator map showing study area and sampling sites on trench (T), tidal creek (B), tributaries (C), shallow canal (P), and deep canal (S). (Inset shows location of study area relative to Louisiana.)

order 3 and three, order-2 tributaries of the tidal creek having maximum depths of approximately 1.9, 0.8, 1.8, 0.8, 0.4, and 0.8 m, respectively. For general characteristics of tidal creeks related to stream order, see Odum (1984). In January 1991 I added sample sites on a deep (3.6 m) flotation canal and discontinued flume sampling of order-2 creeks; however, trawl collections were continued at these sites. All study canals were open to tidal exchange. Henceforth, the flotation canals will be referred to as shallow or deep canals, the pipeline trench as trench, the order-3 tidal creek as tidal creek, and the order-2 tidal creeks as creek tributaries.

MATERIALS AND METHODS

Water temperature and salinity were monitored at each sample site (at high tide when flumes were sampled and at low tide when trawling) with a Beckman RS-5 salinometer, except June-August 1990 when a YSI Model 33 S-C-T meter was used. Nekton was sampled on marshes and in channels along the marsh edge at each site using flumes (McIvor and Odum 1986) and a small trawl, respectively. Flumes were similar to those described by Rozas and Odum (1987), except wider (2 m vs. 1.5 m), and walls were constructed of plastic rather than nylon netting. Flume length was 20 m, except along canals where the length of each flume was equal to the marsh width (5-8 m). The procedure for sampling flumes was similar to that described by Rozas and Odum (1987), except end nets were deployed from a remote location as follows. No fewer than 3 hours prior to sampling, each flume end net was positioned above the flume entrance and held in place by small wooden pegs inserted into holes drilled into end posts. A nylon cord was tied to each peg and a small wooden post 5 m away. At high tide the pegs were pulled out, and the end net dropped into place, blocking the flume entrance.

Samples of the entire water column along the marsh edge were taken in tidal creeks, the trench, and canals using a trawl pulled by hand (Rogers 1989). The trawl was constructed of 3-mm mesh nylon netting attached to an aluminum frame (1 m wide x 0.6 m high) and mounted on aluminum skids to allow sampling over soft sediments. Trawl tows of 15 m were made at each flume site during daylight when the marsh surface was not flooded.

Samples were collected approximately twice monthly from June 1990 through May 1991 for a total of 25 flume and 23 trawl sampling events. The contents of each sample were preserved in 20 percent formalin for at least 72 hr, washed in running water for 24 hr, and placed into 70 percent ethanol for storage. Organisms were separated from detritus, identified, and counted; each (except for grass shrimp, *Palaemonetes pugio* Holthuis) was also measured (i.e., standard length (SL) for fishes, total length for shrimp, and carapace width for crabs). All individuals of each species were weighed together to the nearest 0.1 grams (g).

Tethering experiments were conducted to compare predator encounter rates in canals and natural channels (Heck and Thoman 1981; McIvor and Odum 1988; Rozas and Odum 1988). Gulf killifish (*Fundulus grandis* Baird and Girard, 38-90 mm, $\bar{x}$= 56 mm SL) were used in these experiments because they were numerically dominant in the study area, easily captured, and tethering had little effect on their swimming behavior. Fish were collected in baited minnow traps and held overnight in aerated laboratory holding tanks. A tether of thin monofilament fishing line (2.7 kg test, 0.3 mm diameter, 1.0 m long) tied to a small split ring was attached to the lower jaw of each fish. I tethered fish at least 2 m apart and 2 m from shore by sliding the split ring over heavy monofilament line (9.1 kg test, 0.5 mm diameter) held vertically in the water column by a 111 g pyramid sinker and a fishing float attached to opposite ends. This procedure allowed fish to swim freely in any direction, constrained only by the length of the tether. Fish were tethered for approximately 2 hours on ebbing tides beginning shortly after the marsh surface had drained. Experiments were conducted in two study canals on two occasions in July 1991 by tethering fish in three segments of a canal and three nearby natural channels of similar width.

STATISTICAL ANALYSES

Because each subject (marsh or shallow water site) was sampled under all treatments and sampled repeatedly over time, I used a multivariate approach to repeated measures analysis of variance to test for differences in salinity and catches (number of individuals) among habitats (O'Brien and Kaiser 1985; Norusis 1990). Salinity data were pooled within each sampling period (summer-fall 1990 and winter-spring 1991) and analyzed separately by period. I analyzed catch data for the six numerically dominant species separately by period and sampling method (flume or trawl). When significant results were found among treatments, the data were analyzed with a posteriori contrasts (Norusis 1990). To correct for the error introduced by making multiple statistical comparisons, the significance levels (0.10 for a posteriori contrasts and 0.05 for all other analyses) were adjusted using the method described by Rice (1989). Catch data were $\ln(x+1)$-transformed prior to analyses in order to meet the MANOVA assumption of homogeneity of variances (Green 1979). I used a paired t-test to compare predator encounter rates (i.e., number of missing killifish) in canals and natural channels.

RESULTS

Average water temperatures ranged from a high of 31.3°C in August to a low of 13.5°C in January (Figure 10.2). Salinities generally increased from north to south across the study area, and one could usually observe a salinity gradient of 2-5 $^\circ/_{\circ\circ}$ between the trench and deep canal. Mean salinities during the study ranged from 1.6 $^\circ/_{\circ\circ}$ at the trench in February to 21.4 o/oo in the shallow canal in November (Figure 10.2). Differences in salinities among habitats were statistically significant during both sampling periods ($p<0.0005$).

A total of 236,508 organisms having a preserved wet weight of 114.7 kg was collected during the study (300 flume and 303 trawl samples). Forty-one species (22 families) of fishes and four species (3 families) of decapod crustaceans were identified from these samples (Table 10.1). Grass shrimp, blue crabs (*Callinectes sapidus* Rathbun), Gulf killifish, diamond killifish (*Adinia xenica* Jordan and Gilbert), brown shrimp (*Penaeus aztecus* Ives), and sheepshead minnows (*Cyprinodon variegatus* Lacepede) numerically dominated catches (Table 10.1) and accounted for over 95 percent of both flume and trawl samples. These species dominated catches in terms of biomass as well, representing > 92 percent of the total biomass. Striped mullet (*Mugil cephalus* Linnaeus) was the only other species that contributed substantially to total biomass (Table 10.1).

Average catches of several abundant species differed with respect to habitat, sampling method, and study period (Table 10.2). The mean number of Gulf killifish and brown shrimp collected was significantly different among habitats sampled during summer-fall 1990 (Table 10.3). Greatest catches of Gulf killifish were taken in tributary creeks, and fewer brown shrimp were collected on marshes adjacent to tributaries than in other marsh habitats. Although not statistically significant, catches of diamond killifish and sheepshead minnows also exhibited a strong trend toward greatest numbers in tributary creeks.

In the winter-spring period, catches of grass shrimp, Gulf killifish, diamond killifish, and sheepshead minnows were significantly different among habitats sampled (Table 10.4). Sheepshead minnows were collected in greatest numbers on marshes adjacent to the trench. Gulf and diamond killifishes were most abundant in trawl samples from tributary creeks. The average catch of sheepshead minnows was significantly less in the large canal than in the tidal creek, its tributaries, or the trench, but was not statistically different than that from the small canal. Grass shrimp were most abundant in trawl samples from the large canal.

Although average water depth along the marsh edge was greater in canals than in nearby natural channels (deep canal = 69 cm, shallow canal = 54 cm, natural channels = 38 cm), predator encounter rates in the two habitats were similar ($T=0.20$, $p\leq0.425$). Percentages of fish missing at the end of experiments were 0-50 percent, 60-100 percent, and 20-100 percent in shallow canal, deep canal, and natural channels, respectively.

DISCUSSION

Nekton assemblages and densities of dominant species in channel-edge and adjacent marsh habitats of canals and natural channels were remarkably similar. Although there were differences in densities of some species among the various sites sampled, no clear differences emerged between natural habitats and those associated with canals. Nekton occupied narrow strips of marsh along canals at high tide in densities similar to that found on natural marshes.

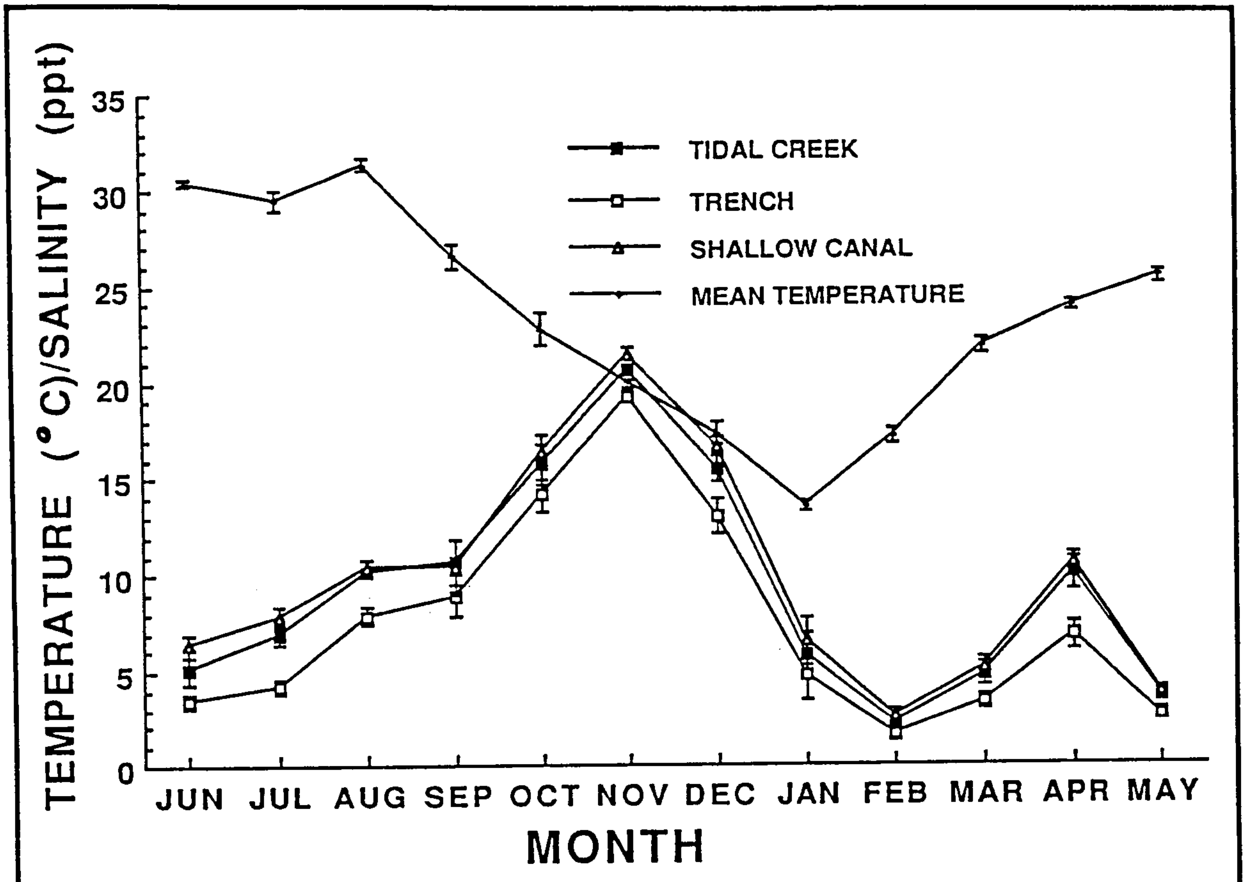

Figure 10.2. Average monthly temperature (all sample sites combined) and mean monthly salinity for sites on tidal creek, trench, and shallow canal from June 1990 through May 1991. (Error bars equal one standard error.)

However, canals with continuous levees are not equivalent to natural channels in terms of the amount of marsh habitat they provide. Using aerial photography, I estimated the length of marsh-water interface (edge) along five natural channels and their tributaries in my study area. Estimates of tributary lengths were conservative, because small creeks are not always visible on photographs. Nonetheless, the average length of edge along natural channels was about half that found bordering their tributaries. Because marshes fringing canals are not continuous, the amount of edge associated with canals is even less than that along natural channels of equal length. Therefore, natural channel systems contained more than three times as much marsh edge habitat as canals of equal length. Backfilled pipeline trenches, on the other hand, do not have levees that block access to small tributaries and adjacent marshes; small waterbodies that are intersected only add to the edge associated with these features. Therefore, from a fisheries habitat standpoint, the push method and backfilling is preferable to using the flotation method for installing pipelines. In wetlands where the push method cannot be used, gaps should be placed in levees, canals should be backfilled, or innovative dredging techniques that do not create levees (e.g., high-pressure spray dredging) should be encouraged (Cahoon and Cowan 1988).

The impact of existing canals on fisheries habitat could also be mitigated. Levees of existing canals probably have their greatest direct impact on fisheries habitat by blocking access to adjacent marshes and aquatic habitats. Levees also contribute to habitat loss by enhancing marsh waterlogging and the rate of marsh erosion (Turner *et al.* 1982; Turner and Cahoon 1987). Breaching levees at various locations, especially at sites where natural channels were blocked by levee construction,

Table 10.1. List of Fishes and Decapod Crustaceans Collected on the Marsh Surface and in Adjacent Water Bodies using Flumes and Trawls, respectively. (The total catch [number of individuals] and total biomass [g preserved wet weight] are given for each species. Relative abundance [RA = % total number] and relative biomass [RB = % total biomass] are given only when they are equal to at least 1%.)

Scientific and common name	flume catch	trawl catch	flume RA	trawl biom.	biom.	RB
Palaemonetes pugio Holthuis grass shrimp	49,307	144,187	81.8	8,754.3	20,968.2	25.9
Callinectes sapidus Rathbun blue crab	4,582	3,462	3.4	33,585.4	14,918.9	42.3
Fundulus grandis Baird and Girard Gulf killifish	3,532	5,231	3.7	8859.2	6568.1	13.5
Adinia xenica (Jordan & Gilbert) diamond killifish	2,119	6,539	3.7	678.5	2495.7	2.8
Penaeus aztecus Ives brown shrimp	1,626	1,931	1.5	1484.3	1579.9	2.7
Cyprinodon variegatus Lacepede sheepshead minnow	969	2,605	1.5	1096.7	4705.6	5.1
Gobiosoma bosci (Lacepede) naked goby	401	695	--	168.6	210.8	--
Penaeus setiferus (Linnaeus) white shrimp	278	1,416	--	224.4	576.8	--
Menidia beryllina (Cope) inland silverside	244	1,097	--	162.3	820.9	--
Brevoortia patronus Goode Gulf menhaden	226	841	--	25.4	76.7	--
Bairdiella chrysoura (Lacepede) silver perch	197	250	--	65.9	67.7	--
Fundulus pulvereus (Evermann) bayou killifish	196	172	--	119.3	97.7	--
Poecilia latipinna (Lesueur) sailfin molly	192	325	--	168.0	236.6	--
Mugil cephalus Linnaeus striped mullet	184	1,108	--	3029.5	497.5	3.1
Fundulus jenkinsi (Evermann) saltmarsh topminnow	158	164	--	80.4	75.2	--
Anchoa mitchilli (Valenciennes) bay anchovy	120	1,230	--	38.6	190.5	--
Cynoscion nebulosus (Cuvier) spotted seatrout	89	80	--	290.1	58.2	--
Lagadon rhomboides (Linnaeus) pinfish	84	126	--	118.9	112.9	--
Dormitator maculatus (Bloch) fat sleeper	57	4	--	253.7	63.2	--
Fundulus similis (Baird & Girard) longnose killifish	31	36	--	87.3	66.1	--

Table 10.1. List of Fishes and Decapod Crustaceans Collected on the Marsh Surface and in Adjacent Water Bodies using Flumes and Trawls, respectively. (The total catch [number of individuals] and total biomass [g preserved wet weight] are given for each species. Relative abundance [RA=% total number] and relative biomass [RB=% total biomass] are given only when they are equal to at least 1%.) (continued).

Scientific and common name	flume catch	trawl catch	flume RA	trawl biom.	biom.	RB
Lucania parva (Baird) rainwater killifish	28	16	--	11.4	7.4	--
Gobionellus shufeldti (Jordan & Eigenmann) freshwater goby	22	26	--	10.4	4.4	--
Paralichthys lethostigma Jordan & Gilbert southern flounder	10	5	--	230.6	33.3	--
Leiostomus xanthurus Lacepede spot	7	97	--	32.8	194.2	--
Sciaenops ocellatus (Linnaeus) red drum	7	66	--	233.6	18.9	--
Archosargus probatocephalus (Walbaum) sheepshead	7	4	--	3.2	1.4	--
Myrophis punctatus Lutken speckled worm eel	7	1	--	49.4	5.3	--
Symphurus plagiusa (Linnaeus) blackcheek tonguefish	6	12	--	36.5	10.5	--
Citharichthys spilopterus Gunther bay whiff	6	10	--	18.7	14.4	--
Achirus lineatus (Linnaeus) lined sole	4	34	--	6.3	28.4	--
Evorthodus lyricus (Girard) lyre goby	4	0	--	16.8	0.0	--
Syngnathus scovelli (Evermann & Kendall) Gulf pipefish	2	11	--	0.9	6.4	--
Micropogonias undulatus (Linnaeus) Atlantic croaker	2	1	--	0.8	0.3	--
Pogonias cromis (Linnaeus) black drum	2	0	--	0.1	0.0	--
Syngnathus louisianae Gunther chain pipefish	1	3	--	0.9	1.6	--
Elops saurus Linnaeus ladyfish	1	2	--	0.1	0.3	--
Opsanus beta (Goode and Bean) Gulf toadfish	1	0	--	<0.1	0.0	--
Eleotris pisonis (Gmelin) spinycheek sleeper	1	0	--	7.7	0.0	--

Table 10.1. List of Fishes and Decapod Crustaceans Collected on the Marsh Surface and in Adjacent Water Bodies using Flumes and Trawls, respectively. (The total catch [number of individuals] and total biomass [g preserved wet weight] are given for each species. Relative abundance [RA = % total number] and relative biomass [RB = % total biomass] are given only when they are equal to at least 1%.) (continued).

Scientific and common name	flume catch	trawl catch	flume RA	trawl biom.	biom.	RB
Cynoscion arenarius Ginsburg sand seatrout	0	2	--	0.0	2.1	--
Pomatomus saltatrix (Linnaeus) bluefish	0	2	--	0.0	0.5	--
Sphoeroides parvus Shipp & Yerger least puffer	0	2	--	0.0	2.1	--
Strongylura marina (Walbaum) Atlantic needlefish	0	2	--	0.0	1.8	--
Eucinostomus argenteus Baird spotfin mojarre	0	1	--	0.0	0.1	--
Gambusia affinis (Baird & Girard) mosquitofish	0	1	--	0.0	<0.1	--
Synodus foetens (Linnaeus) inshore lizardfish	0	1	--	0.0	0.2	--
Totals	64,710	171,798	95.6	59,951.0	54,720.7	95.4

Table 10.2. Comparisons of Average Catches (number of individuals) of Numerically Dominant Species Among Different Habitats. (Means ± standard errors are listed for both flume and trawl collections and two sampling periods [Summer-Fall = June-December, Winter-Spring = January-May]. TC = tidal creek, CT = creek tributaries, T = pipeline trench, SC = small pipeline canal, LC = large pipeline canal. --- = value <0.05.)

		Summer-Fall 1990				Winter-Spring 1991				
Species	Sampling Device	TC	CT	T	SC	TC	CT	T	SC	LC
Grass shrimp	Flume	81.8 ±13.4	53.0 ±10.0	113.1 ±19.0	193.4 ±24.9	167.0 ±28.6	n.d.	142.5 ±16.3	207.1 ±35.3	465.0 ±70.1
	Trawl	336.4 ±65.6	1,021.5 ±295.6	225.1 ±93.9	565.2 ±121.7	134.7 ±26.5	205.0 ±76.9	166.3 ±42.8	353.1 ±70.2	1,156.4 ±166.3
Blue crab	Flume	15.6 ±1.41	8.2 ±1.0	12.5 ±1.3	18.4 ±1.4	19.8 ±2.3	n.d.	15.3 ±3.1	17.0 ±1.7	18.2 ±2.3
	Trawl	17.6 ±2.8	15.4 ±2.0	14.9 ±2.2	14.4 ±2.5	6.2 ±1.5	3.9 ± 0.9	4.6 ±1.0	4.9 ±0.9	11.6 ±3.5
Gulf killifish	Flume	12.3 ±1.8	16.3 ±1.6	23.6 ±2.3	11.9 ±2.3	4.2 ±0.8	n.d.	7.1 ±1.2	7.3 ±2.6	2.9 ±0.8
	Trawl	22.9 ±7.1	62.9 ±16.2	15.2 ±3.4	4.0 ±2.1	3.6 ±0.9	19.7 ±6.1	2.6 ±0.7	4.0 ±0.9	2.8 ±0.8
Diamond killifish	Flume	2.5 ±0.9	7.7 ±2.5	5.9 ±1.5	26.1 ±10.6	0.8 ±0.2	n.d.	1.3 ±0.3	3.6 ±1.3	1.7 ±0.7
	Trawl	3.0 ±1.0	39.9 ±18.7	1.8 ±0.7	12.6 ±9.8	7.5 ±1.8	107.5 ±41.5	11.1 ±3.3	19.5 ±11.3	8.3 ±3.2
Brown shrimp	Flume	1.1 ±0.2	0.4 ±0.2	1.9 ±0.6	2.7 ±0.5	12.4 ±4.6	n.d.	11.0 ±4.0	9.5 ±2.6	12.2 ±3.8
	Trawl	10.5 ±2.0	2.4 ±0.6	5.1 ±1.0	7.4 ±0.7	8.4 ±3.2	3.5 ±1.7	8.1 ±2.9	5.2 ±2.0	6.5 ±2.5
Sheepshead minnow	Flume	0.6 ±0.2	8.5 ±2.4	5.4 ±1.5	1.6 ±1.3	1.2 ±0.3	n.d.	5.9 ±1.0	0.6 ±0.2	0.2 ±0.1
	Trawl	1.0 ±0.4	28.3 ±6.9	9.4 ±3.1	1.1 ±0.7	3.9 ±1.7	20.7 ±7.1	9.5 ±2.2	1.6 ±0.6	0.1 ±0.1
Naked goby	Flume	1.2 ±0.4	—	—	2.1 ±0.5	1.2 ±0.5	n.d.	0.4 ±0.3	0.8 ±0.3	5.9 ±1.3
	Trawl	3.0 ±0.9	0.1 ±0.1	—	3.3 ±1.0	1.2 ±0.6	—	—	1.5 ±0.8	12.7 ±4.0
White shrimp	Flume	0.8 ±0.3	1.3 ±0.7	1.2 ±0.6	2.8 ±0.8	0.0	n.d.	0.0	0.0	0.0
	Trawl	4.0 ±0.8	8.0 ±2.9	15.0 ±3.6	6.7 ±1.6	0.0	0.0	0.0	0.0	—
Inland silverside	Flume	0.5 ±0.3	0.8 ±0.3	2.4 ±0.6	0.3 ±0.3	0.4 ±0.3	n.d.	1.2 ±0.5	0.2 ±0.1	0.2 ±0.2
	Trawl	5.5 ±2.8	9.6 ±4.3	5.9 ±1.4	2.7 ±1.0	0.8 ±0.4	1.7 ±1.0	0.7 ±0.2	0.2 ±0.1	0.6 ±0.2
Gulf menhaden	Flume	0.0	0.0	0.0	0.0	0.1 ±0.1	n.d.	5.4 ±4.0	0.0	2.0 ±1.9
	Trawl	—	0.0	0.5 ±0.2	1.4 ±1.0	1.5 ±0.8	3.4 ±1.9	8.1 ±3.0	2.6 ±0.6	12.6 ±7.2
Silver perch	Flume	0.2 ±0.2	0.0	0.0	0.9 ±0.6	0.3 ±0.1	n.d.	0.8 ±0.3	1.9 ±0.8	2.0 ±0.8
	Trawl	0.5 ±0.2	0.1 ±0.1	—	1.0 ±0.5	2.1 ±1.8	2.1 ±1.9	0.2 ±0.1	0.9 ±0.5	1.6 ±1.0
Bayou killifish	Flume	0.2 ±0.1	0.5 ±0.2	0.6 ±0.2	2.8 ±1.2	0.1 ±0.1	n.d.	—	0.3 ±0.1	—
	Trawl	0.1 ±0.1	0.6 ±0.3	0.1 ± —	—	0.2 ±0.1	1.1 ±0.5	0.0	3.8 ±3.6	—
Sailfin molly	Flume	0.1 ±0.1	0.7 ±0.3	0.3 ±0.1	0.9 ±0.3	0.1 ± —	n.d.	0.0	0.2 ±0.1	3.1 ±1.2
	Trawl	0.2 ±0.1	1.7 ±0.6	—	1.7 ±1.1	0.1 ±0.1	0.6 ±0.3	—	1.0 ±0.6	4.8 ±1.7
Striped mullet	Flume	—	0.6 ±0.2	1.0 ±0.4	0.2 ±0.1	0.1 ±0.1	n.d.	3.0 ±1.0	0.3 ±0.1	0.1 ±0.1
	Trawl	0.1 ±0.1	0.3 ±0.2	—	0.0	0.9 ±0.5	32.6 ±15.2	5.8 ±2.5	1.0 ±0.7	0.1 ±0.1

Table 10.3. Results of the MANOVA Tests of Differences in Catch Among Habitats for the Summer-Fall 1990 Sampling Period. (* = significant result [adjusted $p < 0.05$].)

Species	Sampling Device	d.f.	F	P
Grass Shrimp	Flume	3,6	3.14	.108
	Trawl	3,6	6.50	.026
Blue Crab	Flume	3,6	6.33	.027
	Trawl	3,6	0.21	.885
Gulf Killifish	Flume	3,6	6.27	.028
	Trawl	3,6	11.32	.007*
Diamond Killifish	Flume	3,6	4.18	.065
	Trawl	3,6	9.25	.011
Brown Shrimp	Flume	3,6	14.82	.004*
	Trawl	3,6	2.75	.135
Sheepshead Minnow	Flume	3,6	2.55	.152
	Trawl	3,6	7.67	.018

Table 10.4. Results of the MANOVA Tests of Differences in Catch Among Habitats for the Winter-Spring 1991 Sampling Period. (* = significant result [adjusted $p < 0.05$].)

Species	Sampling Device	d.f.	F	P
Grass Shrimp	Flume	3,6	8.50	.014
	Trawl	4,8	14.63	.001*
Blue Crab	Flume	3,6	4.03	.069
	Trawl	4,8	0.21	.885
Gulf Killifish	Flume	3,6	2.91	.123
	Trawl	4,8	6.50	.012*
Diamond Killifish	Flume	3,6	1.18	.392
	Trawl	4,8	6.50	.012*
Brown Shrimp	Flume	3,6	0.63	.625
	Trawl	4,8	1.57	.272
Sheepshead Minnow	Flume	3,6	60.28	.000*
	Trawl	4,8	15.42	.001*

would reopen areas of marsh for use by nekton and reduce ponding behind levees. Openings in levees would also allow tidal exchange in canals that are impounded by plugs and levees, and would permit their use by transient organisms (Neill and Turner 1987a).

Because pipeline canals are designed with steep banks (Wicker *et al.* 1989), I expected higher predation rates there than in natural channels (McIvor and Odum 1988). However, predator encounter rates in canals were similar to those in nearby natural channels. This result may be due to changes that take place after canal construction. Where canals are dredged in marshes with soft substrates, canal banks usually slump after construction, reducing bank steepness and depth (Adkins and Bowman 1976). Although bottom profiles of both study canals were steeper than those of the tidal creek (slopes: shallow canal = 0.12, deep canal = 0.25, tidal creek = 0.09) (Figure 10.3), bottom profiles of canals had slopes much less than one, the slope called for in design specifications for flotation canals (Wicker *et al.* 1989). As a result of this slumping process, bottom profiles of canals may approach that of natural channels, and habitat value probably increases over time.

Differences in the distribution of nekton across the study area were probably not related to the differences in salinity among habitats. Although salinities increased from north to south across the study area, most species collected are euryhaline, and salinities were well within the tolerance of these species. The most striking difference among habitats was that of significantly higher densities of several species (Gulf killifish, diamond killifish, and sheepshead minnows) found in creek tributaries. This relationship of increasing densities of nekton with decreasing stream-order has been observed elsewhere (Weinstein 1979). Rozas *et al.* (1988) also found high densities of nekton in small tributaries (rivulets) in a tidal freshwater marsh. However, high densities of these species in tributaries at low tide did not translate into significantly higher densities on the adjacent marsh surface at high tide as observed in other studies (Rozas and Odum 1987; Hettler 1989), and in 1990 brown shrimp were collected in significantly lower numbers on marshes adjacent to tributaries than other habitats (Table 10.3). This result may have been influenced by the location of tributary flumes. Nekton swim up tributaries as the tide rises, and most organisms probably enter marshes near the heads of tributaries where marsh flooding occurs first. My flumes were within 15-20 m of tributary mouths and, therefore, may have been bypassed by most organisms.

Densities of several organisms collected on marshes also varied seasonally. For example, Gulf killifish and diamond killifish were most abundant in summer-fall 1990; grass shrimp and brown shrimp were most numerous on marshes in winter-spring 1991 (Table 10.2). Seasonal variability in the use of marshes by these species is probably related to their reproductive cycles. Greatest densities on marshes were observed during periods of highest reproduction or peak recruitment to the estuary. For example, brown shrimp were an order of magnitude more abundant in flumes during winter-spring 1991 than in summer-fall 1990, although average trawl catches during the two periods were similar (Table 10.2). This apparent increase in the use of the marsh surface during 1991 coincided with the brown shrimp's (February-April) period of peak recruitment into Louisiana estuaries (Gaidry and White 1973). Brown shrimp collected in my flumes averaged 54 mm in summer-fall 1990 and 40 mm in winter-spring 1991. Zimmerman and Minello (1984) also found that small, newly recruited brown shrimp showed an affinity for marsh vegetation, and that their use of the marsh surface decreased as they increased in size; brown shrimp exited Galveston Bay marshes when they reached a total length of 50-60 mm.

SUMMARY

Although narrow fringing marshes within canals open to tidal flow represent a very small portion of the total canal area, they are undoubtedly important habitat for nekton at high tide. In canals where fringing marshes have been eroded back to levees by boat traffic or where marshes are otherwise unavailable to nekton, fisheries habitat is likely diminished in quality even when the canals are open to tidal exchange and use by transient species. The value of habitat in canals may increase over time as slumping decreases depth and steepness of bottom profiles. The push method and backfilling should be used to install pipelines in coastal wetlands when possible, because access to adjacent habitats by aquatic organisms is not blocked by levees as is the

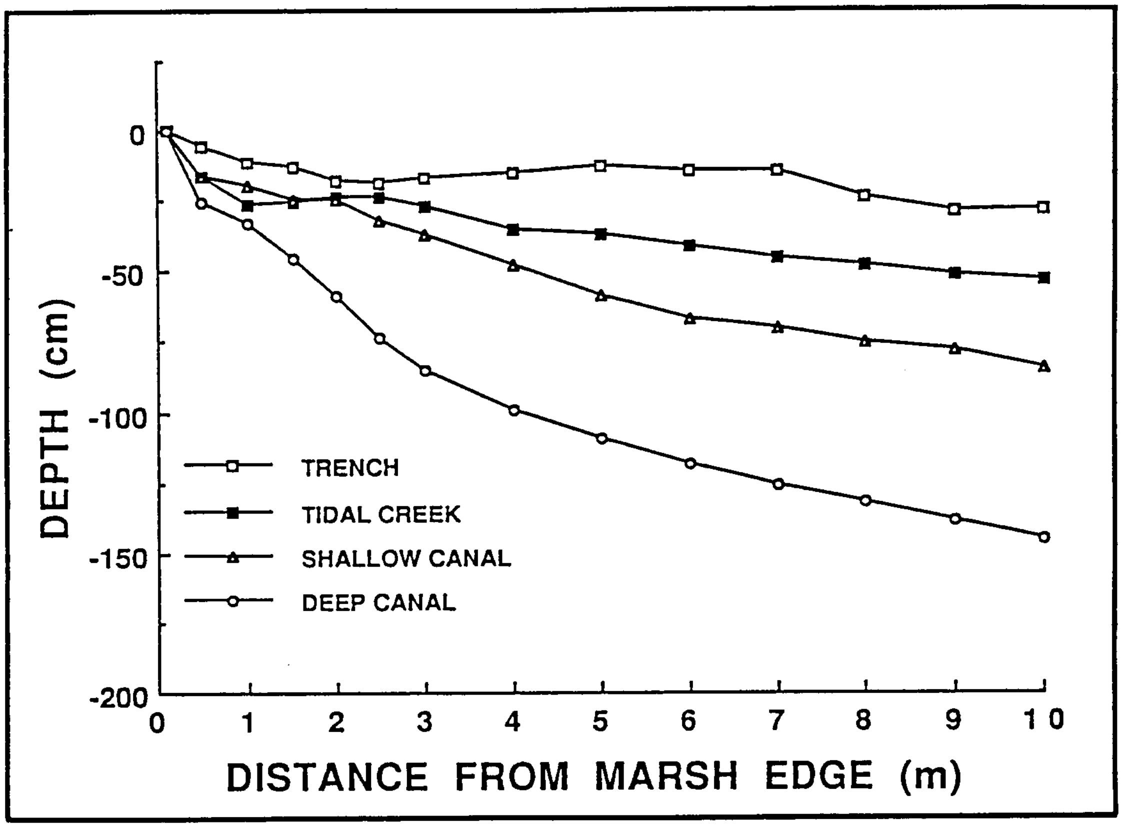

Figure 10.3. Average depth of subtidal area (subtidal profiles) in front of flumes out to a distance of 10 m from the marsh/channel interface.

case when the flotation method is used. Negative impacts on fisheries habitat of existing flotation canals could be lessened by (1) opening canals to tidal exchange and (2) breaching or totally removing levees to allow nekton access to habitats behind levees.

ACKNOWLEDGEMENTS

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INFLUENCE OF HYPOXIA ON THE INTERPRETATION OF EFFECTS OF PETROLEUM PRODUCTION ACTIVITIES

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INTRODUCTION

The continental shelf of the southeastern Louisiana coast is the site of extensive oil and gas production activities as well as the largest area of seasonal near-bottom hypoxic waters in the coastal United States. Studies of the environmental effects of offshore oil and gas development on the Louisiana shelf have been confounded by the effects of the Mississippi River as a source of turbid, nutrient-rich fresh water and anthropogenic pollutants, seasonally intense and widespread hypoxic bottom waters, and storm events. The influence of hypoxia was important in interpretation of benthic data collected as part of several studies of the fate and effects of offshore petroleum activities (e.g., OEI-GURC, Ward *et al.* 1979; Central Gulf Platform study, Bedinger 1981; API produced water study, Neff *et al.* 1989). Still, within this area, differences in hydrocarbon contamination of sediments are evident, particularly where there are large amounts of operational discharges, i.e., produced waters. We hypothesized that the effects of offshore development could be identified and placed in the context of natural, temporal variability, in this case as caused by hypoxic bottom waters.

STUDY AREAS

Several study areas on the southeastern Louisiana continental shelf where bottom water hypoxia occurs and oil and gas production platforms with significant production discharges were located and identified. These were narrowed to a set of four potential platforms. An initial reconnaissance of potential study sites was conducted during April 1990 to determine the general patterns of variance in faunal, chemical, and environmental parameters. The platforms targeted as potential study areas are listed in Table 10.5 and shown in Figure 10.4.

In spite of the seeming plethora of study sites on the southeastern shelf, each of the above sites was complicated in several ways. Unocal's South Timbalier (ST) 53A complex and Chevron's South Timbalier 52A complex were in close proximity to an instrument mooring with a near-bottom oxygen meter at South Timbalier 53B. One of the two (ST53A) had a much larger produced water discharge. The Shell West Delta (WD) 32E platform, while significant in produced water discharged, was in a different sedimentary regime than those of the South Timbalier 52 and 53 blocks. Thus, a dilemma was posed in a tradeoff between a large discharge that may provide more of an environmental signal in sediments of smaller size fraction (Shell's West Delta 32E) versus a large discharge (Chevron's ST52A complex) or a smaller discharge (Unocal's ST53A) in a sedimentary environment that would be less likely to record chemical contaminants but that was located close to an existing instrument mooring. Another dilemma was posed with the information that the ST53A platform was scheduled for exploratory drilling in the area in 1990, and that the ST53B inactive platform was scheduled for removal in 1990. An additional problem was the necessity of confining transect configurations at Chevron's ST52A complex in order to avoid pipelines; shell materials placed at the base of ST52A also complicated the sample design for this platform. Sampling around the Shell WD32E platform was complicated by sandblasting activity on the platform.

The instrument mooring with current meters, particle traps, and near-bottom continuously recording oxygen meter as part of the Rabalais *et al.* hypoxia studies was deployed in March 1990 at ST53B. Recovery of the oxygen meter in mid-May indicated a problem with the instrument and loss of the first 2-month's record. Data were recovered from mid-May through mid-October, when the mooring was removed. The second oxygen meter was deployed at the Shell WD32E platform in mid-June. Data were recovered from mid-June through mid-October, when the mooring was removed.

PRELIMINARY FINDINGS

We are in the third year of study of a 3-year project. Without a complete set of benthic community data and chemical analyses, it would be premature to draw conclusions. Some observations, however, can be made.

Hypoxia in 1990

The 1990 season of hypoxia, as monitored off Terrebonne/Timbalier Bays and at ST53B in the hypoxia studies of various scientists, was unusual from the previous five years in that hypoxia occurred earlier and more persistently in the spring, hypoxia was more severe through the summer months, hypoxic bottom waters occurred farther offshore and in deeper waters, anoxic conditions were documented for long periods of the record, and the generation of hydrogen sulfide in the bottom waters was recorded more often. The flow of the Mississippi River was high for 1990, with crests in March and another in June. The long-term average period of high flow is usually in April. On the other hand, hypoxia was not as severe nor as persistent at the WD32E platform.

Hydrocarbons

Results of sediment analyses indicate no clear progression of analyte concentrations with proximity to the platform at a given site and no clear temporal patterns in the summer of 1990. The analytes detected in all samples were likely from pyrogenic and petrogenic sources. The April samples from Chevron's ST52A complex showed no analyte concentrations above 35 parts per billion (ppb); and the June ST52A sampled showed highest

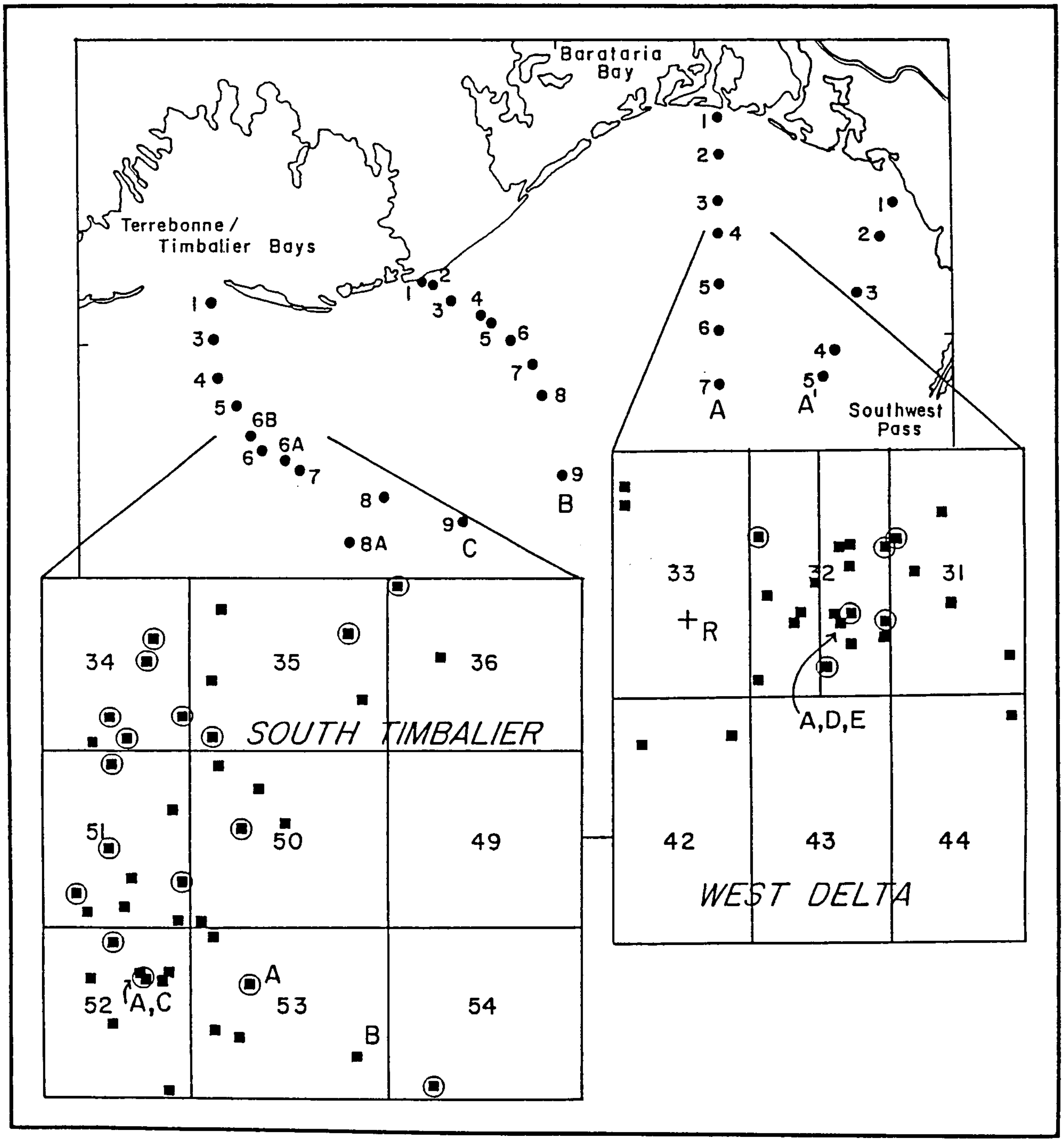

Figure 10.4. Location of Shell's West Delta 32A&D complex with platform E, a reference station (R) in WD33 block, Unocal's South Timbalier 53A complex and ST53B, and Chevron's South Timbalier 52A complex with platform C. (Station C6A on Transect C off Terrebonne/Timbalier Bays [=Unocal ST53B] was the location of a permanent instrument mooring with a near-bottom oxygen meter; an additional near-bottom oxygen meter was deployed at WD32E. Circled platforms indicate those with produced water discharges.)

Table 10.5. Potential Study Areas.

Company	Lease Block	Water Depth	Volume Discharged	Sediment Type
Shell Offshore	West Delta 32E Oxygen Meter	19 m	19,000 bbl/d	silt
Unocal	South Timbalier 53A and A-Aux.	19 m	5,550 bbl/d	sandy silt
Unocal	South Timbalier 53B Oxygen Meter	19 m	inactive	silty sand
Chevron USA	South Timbalier 52 A and C complex	19 m	20,000 bbl/d	sandy silt

analyte concentrations at 50 m (5-300 ppb) and 250 m (10-100 ppb). [N.B., the relocation of the transect at ST52A complex between April and June, but the subsequent dropping of this site from the study.] The analyte concentrations in sediments from Shell's WD32E platform showed no pattern of temporal variations, but the June samples at 50 and 100 m had somewhat higher concentrations of higher molecular weight compounds (i.e., fluoranthenes, pyrene at levels of approximately 20 ppb). The Unocal ST53A site sediment samples had concentrations of analyte compounds below 50 ppb (dibenzothiophene) and showed no clear temporal pattern and no pattern of distance from the platform. Concentrations of analytes in the Unocal ST53B sediments were similar to or lower than those in sampled from ST53A.

Other Analytes

Analyses for trace metals are not complete, but preliminary data indicate no strong trends for changing concentrations in metals with distance from the platforms nor levels elevated above expected background. Lead 210, radium 226, and radium 228 concentrations were mostly at background levels, with the exception of one sample from near the ST52A complex (20 m).

Benthic Communities

Initial results from benthic infaunal analyses indicate healthy macroinfaunal communities at all sites in April 1990. There were very different communities and community responses to hypoxia between the Shell WD32E platform and the other platforms analyzed. The benthic community at WD32E was more diverse in number of species and groups of taxa than ST53A and ST53B during all months (April, June - September), but especially during the peak of hypoxia in July-August. Hypoxic conditions, however, were not as persistent nor as severe at WD32E. The abundance of organisms differed by site, by month, and by response to hypoxic stress. Mean number of individuals were similar at WD32E for the months April-August, then showed a seasonal decline in number. Abundance peaked at ST53A and ST53B in April and June prior to the onset of severe hypoxia, after which the benthic fauna were dramatically reduced and showed no recovery until September or October and then only slightly.

Consistent trends in benthic community parameters were evident at all three sites with distance from the platform for April-September. These trends were not always correlated with increasing distance from a discharge, however, and were confounded by sediment texture differences. Until a complete data set for benthic infaunal samples can be coupled with the sediment texture and sediment contaminant data in a multivariate analysis, it would be premature to draw conclusions about the effects of hypoxia and/or production-related contaminants on benthic communities. The consistency of trends with time indicates a signal that supersedes the one produced by hypoxia. These initial observations, however, may not survive a rigid statistical test.

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FATE AND TRANSPORT OF PARTICLE-REACTIVE NORMAL, ALKYLATED AND HETEROCYCLIC AROMATIC HYDROCARBONS

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The goal of this phase of our research was to develop a microcosm system which could be used to study the desorption of alkylated polynuclear aromatic compounds (PAH) from contaminated sediments under a variety of conditions. As suggested by the scientific advisory board, we wanted to be able to use the microcosms for studies involving benthic organisms as well as abiotic conditions. Figure 10.5 shows the microcosm design which was developed and which has been used to study desorption of alkylated PAH from contaminated sediments over time courses up to 120 days.

We also embarked upon an extensive methods development effort which was directed at the trace determination of a number of specific positional isomers of alkylated naphthalenes, phenanthrenes, and dibenzothiophenes. The mean detection limits achieved for water samples (100 ml) and sediment samples (<2 g) using selected ion monitoring gas chromatography/mass spectrometry (GC/MS) are 0.05 ppb and 0.5 parts per billion (ppb), respectively. These methods have been applied to analysis of surface sediments and cores from the field, core sections from microcosm desorption experiments, pore water samples, and dynamic desorption experiments.

METHOD DEVELOPMENT

A Hewlett-Packard 5890 Gas Chromatograph directly interfaced to a Hewlett-Packard 5970B Mass Selective Detector was operated using the parameters presented in Table 10.6. A series of linear temperature ramps was necessary for the maximal separation of isomers of alkylated PAHs

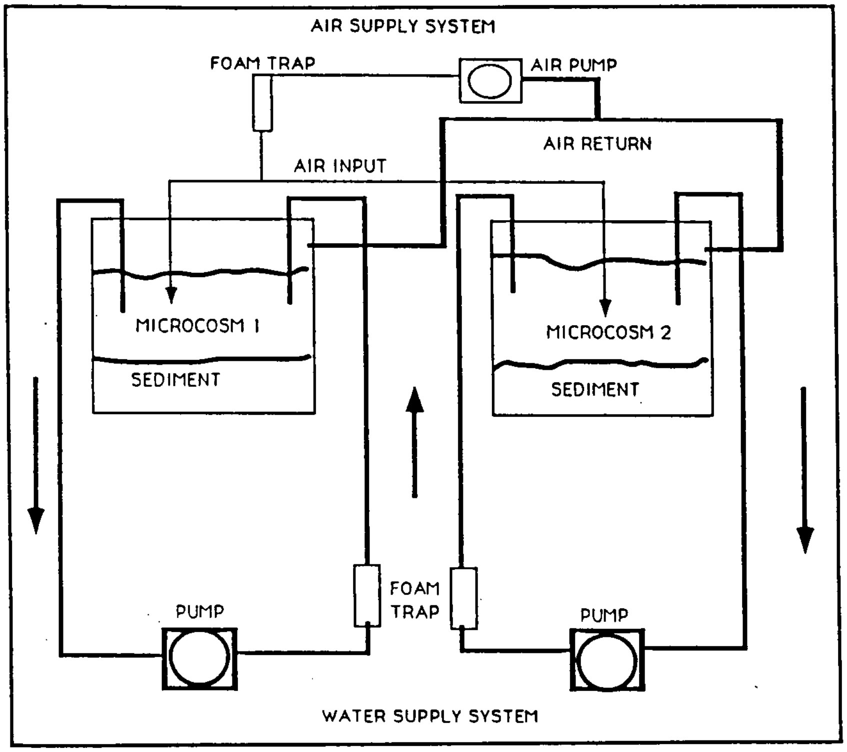

Figure 10.5. Microcosm design for sediment desorption studies.

Table 10.6. Instrumental Parameters.

A. Heated Zones
Splitless Injection Port Temperature: 235°C
Purge Time: 0.5 min.
GC/MS Transfer line temperature: 280°C

B. Gas Chromatography Column
Column: DB-5, 30 m, 0.25 film thickness, 0.25 mm I.D. J&W Scientific,Inc.
Carrier Gas: Helium
Linear velocity: 40 cm/sec (butane injection at 100C)

C. Gas Chromatograph Temperature Program
Initial Column Temperature: 50°C
Time at Initial Temperature: 3 min.
Temperature Ramp #1: 6°C/min to 120°C
Temperature Ramp #2: 3°C/min to 190°C
Temperature Ramp #3: 12°C/min to 283°C
Time at Final Temperature: 14.5 min.

D. Mass Spectrometer Data Acquisition
Scan Range: 45-450 amu.
Scan Rate: 1.06 scans/sec

and for separation of parent PAH compounds from alkylated PAHs with interfering ions, while keeping analysis time (60 minutes) and band-broadening to a minimum.

Table 10.7 lists the target analytes and deuterated reference standards, their abbreviations, and the mass fragments used for quantitative evaluation ("primary ion") and for confirmation of identity ("confirming ion"). Alkylated PAH standards were purchased from Chiron Laboratories A.S. (Norway). The standards represent the two isomers of methylnaphthalene, all 10 of the dimethylnaphthalene isomers, isopropylnaphthalene and 1,6,7-trimethylnaphthalene for the class "C3" (three substituted carbon groups) naphthalenes, all four possible isomers of methyldibenzothiophene, 1,2-dimethyldibenzothiophene for the class "C2" dibenzothiophenes, five of five possible methylphenanthrenes, 16 of 25 isomers of dimethyl phenanthrene, and 1,2,8-trimethylphenanthrene for the class of "C3" phenanthrenes. Retention order of the alkylated PAH isomers was determined by preparing 10 parts per million (ppm) dilutions in hexane containing one of each type of isomer, ie., a methylnaphthalene, a dimethylnaphthalene, a methylphenanthrene, a dimethylphenanthrene, etc. A final standard, containing all parent PAH compounds (Ultra Sci., US-106), alkylated PAH, and deuterated surrogate standards was prepared at 5 ppm by dilution with dichloromethane and was analyzed with hexamethylbenzene (HMB) as an internal standard. The HMB was also coinjected into the GC/MS with each sample aliquot to monitor performance of the instrument and injection technique, but was not used in the calculations of analyte final concentrations. Quantifications are made using the internal standard (I.S.) method based on the corresponding deuterated surrogate standard for each analyte, as shown in Table 10.8.

Chromatographic data (Table 10.8) for parent and alkylated PAH were obtained from 20 daily calibration analyses of the standard mixture. In addition to the analytes listed, C4- and C5-naphthalenes, C3-dibenzothiophenes, and C3-phenanthrenes can be estimated using relative response factors generated from similar class analytes represented by the standard mixture. For example, the C3-dibenzothiophenes are estimated using the relative response factor for C2-dibenzothiophenes, 1,2-dimethyldibenzothiophene. In this way, we are able to quantitate additional compound classes without the considerable expense of these additional standards. The C1-C3-fluorenes are estimated using the response factor from the parent compound.

FIELD APPLICATIONS

An extensive body of information has been acquired for surface and depth sections of cores collected seasonally at various distances from produced water discharges located at Pass Fourchon, Bayou Rigaud, and Eugene Island (OCS) in South Louisiana. Figures 10.6-10.9 show examples of data for alkylated PAH homologs in samples collected at Pass Fourchon during two seasons. Variations in the relative concentrations of alkylated and heterocyclic PAH can be seen at various distances from the discharge site, however, similarities in pattern are apparent between the two seasons shown. These figures illustrate the complexity of processes impacting the sediments, such as discharge parameters and weather patterns. Figure 10.10 shows depth profile data for cores taken at a single site over four seasons, and illustrate again the dynamic nature of processes affecting these sediments. Note the similarity between cores from three seasons (one season had no detectable concentrations of any PAH except phenanthrene). The pattern of a subsurface decrease followed by an increase in concentrations lower in the core is often seen, and may indicate that chemical processes have more effect on PAH distributions than discharge parameters or sedimentation rates. We are applying ratioing of analytes in order to further examine this data to determine if there are selective mobilization/removal processes which may be active in the field for various members of the class of alkylated and heterocyclic PAH. These field data are also being compared to microcosm data to compare and further elucidate transport processes.

MICROCOSM STUDIES

Design of the Sediment Microcosm

The microcosm test apparatus was designed with the intent to limit possible complicating variability while retaining a necessary amount of flexibility. The test apparatus (Figure 10.10) consists of two 5-gallon aquaria in which are situated 28 clear,

Table 10.7. Target Analytes.

Peak No.	Analyte	Abbreviation	Primary Ion	Confirming ion
1	Naphthalene	Naphthalene	128	129
2	2-Methylnaphthalene	2-MN	142	141
3	1-Methylnaphthalene	1-MN	142	141
4	2-Ethylnaphthalene	2-EN	156	141
5	1-Ethylnaphthalene	1-EN	156	141
6	2,6/2,7-Dimethylnaphthalene	2,6/2,7-DMN	156	141
7	1,3/1,7-Dimethylnaphthalene	1,3/1,7-DMN	156	141
8	1,6-Dimethylnaphthalene	1,6-DMN	156	141
9	1,4/2,3-Dimethylnaphthalene	1,4/2,3-DMN	156	141
10	1,5-Dimethylnaphthalene	1,5-DMN	156	141
11	Acenaphthylene	Acenaphthylene	152	153
12	1,2-Dimethylnaphthalene	1,2-DMN	156	141
13	2-Isopropylnaphthalene	2-IPN	170	155
14	1,8-Dimethylnaphthalene	1,8-DMN	156	141
15	Acenaphthene	Acenaphthene	153	154
16	Fluorene	Fluorene	166	165
17	Dibenzothiophene	Dibenzothiophene	184	185
18	Phenanthrene	Phenanthrene	178	179
19	Anthracene	Anthracene	178	179
20	4-Methyldibenzothiophene	4-MDBT	198	197
21	2/3-Methyldibenzothiophene	2/3-MDBT	198	197
22	1-Methyldibenzothiophene	1-MDBT	198	197
23	3-Methylphenanthrene	3-MP	192	191
24	2-Methylphenanthrene	2-MP	192	191
25	4/9-Methylphenanthrene	4/9-MP	192	191
26	1-Methylphenanthrene	1-MP	192	191
27	4,5-Dimethylphenanthrene	4,5-DMP	206	191
28	3,6-Dimethylphenanthrene	3,6-DMP	206	191
29	3,5-Dimethylphenanthrene	3,5-DMP	206	191
29	2,6-Dimethylphenanthrene	2,6-DMP	206	191
30	2,7-Dimethylphenanthrene	2,7-DMP	206	191
31	3,9-Dimethylphenanthrene	3,9-DMP	206	191
32	1,6/2,5/2,9-Dimethylphenanthrene	1,6/2,5/2,9-DMP	206	191
33	1,7-Dimethylphenanthrene	1,7-DMP	206	191
34	1,9/4,9-Dimethylphenanthrene	1,9/4,9-DMP	206	191
35	Fluoranthene	Fluoranthene	202	101
36	1,5-Dimethylphenanthrene	1,5-DMP	206	191
37	1,8-Dimethylphenanthrene	1,8-DMP	206	191
38	1,2-Dimethylphenanthrene	1,2-DMP	206	191
39	9,10-Dimethylphenanthrene	9,10-DMP	206	191
40	Pyrene	Pyrene	202	101
41	Benzo(a)anthracene	Benzanthracene	228	226
42	Chrysene	Chrysene	228	226
43	Benzo(b)fluoranthene	Benzo(b)fluor	252	253
44	Benzo(k)fluoranthene	Benzo(k)fluor	252	253
45	Benzo(a)pyrene	Benzo(a)pyrene	252	253
46	Indeno(1,2,3-cd)pyrene	Indenopyrene	276	278
47	Dibenz(a,h)anthracene	Dibenzanthracene	278	276
48	Benzo(g,h,i)perylene	Benzoperylene	276	278
Deuterated Internal/Surrogate Standards				
	d8-Naphthalene	d8-Naph	136	
	d10-Acenaphthene	d10-Ace	164	
	d10-Phenanthrene	d10-Phen	188	
	d12-Chrysene	d12-Chrys	240	
	d12-Perylene	d12-Peryl	264	

Table 10.8. Chromatographic Data for Target Analytes.

ANALYTE	I.S.	MEAN R.R.T*	RSD R.R.T. %	MEAN RRF	RSD RRF %	Ave. Est. DL ng
Naphthalene	d8-Naph	1.005	0.012%	0.80	2.2%	0.1
2-MN	"	1.223	0.019%	1.02	2.9%	0.3
1-MN	"	1.259	0.018%	1.12	3.2%	0.3
2-EN	d10-Ace	0.878	0.025%	1.29	3.6%	0.7
1-EN	"	0.883	0.012%	1.45	4.1%	0.8
2,6/2,7-DMN	"	0.894	0.018%	0.80	3.4%	0.4
1,3/1,7-DMN	"	0.915	0.010%	0.67	2.3%	0.3
1,6-DMN	"	0.920	0.012%	0.74	3.9%	0.4
1,4/2,3-DMN	"	0.943	0.010%	0.87	2.9%	0.5
1,5-DMN	"	0.948	0.013%	0.87	3.9%	0.3
Acenaphthylene	"	0.956	0.009%	0.49	2.4%	0.1
1,2-DMN/2-IPN	"	0.966	0.039%	1.29	4.2%	0.2
2-IPN	"	0.969	0.012%	1.80	3.6%	1.0
1,8-DMN	"	0.996	0.012%	0.88	3.2%	0.4
Acenaphthene	"	1.008	0.013%	0.71	2.3%	0.2
Fluorene	"	1.155	0.023%	0.64	4.6%	0.2
Dibenzothiophene	d10-Phen	0.976	0.016%	0.80	1.6%	0.2
Phenanthrene	"	1.005	0.009%	0.92	2.1%	0.1
Anthracene	"	1.015	0.009%	0.93	2.2%	0.1
4-MDBT	"	1.081	0.014%	1.26	3.4%	0.3
2/3-MDBT	"	1.101	0.012%	1.23	3.3%	0.3
3-MP	"	1.124	0.010%	1.24	4.5%	0.3
1-MDBT	"	1.125	0.010%	1.49	3.8%	0.4
2-MP	"	1.129	0.013%	1.06	3.5%	0.3
4/9-MP	"	1.149	0.010%	1.31	4.5%	0.3
1-MP	"	1.153	0.012%	1.07	7.1%	0.2
4,5-DMP	"	1.178	0.032%	2.46	27.9%	0.2
3,6-DMP	"	1.220	0.040%	1.56	7.3%	0.4
3,5-DMP	"	1.223	0.040%	1.98	8.3%	0.3
2,6-DMP	"	1.225	0.039%	0.92	7.1%	0.3
2,7-DMP	"	1.228	0.042%	1.08	6.5%	0.2
3,9-DMP	"	1.236	0.042%	1.16	7.6%	0.3
1,6/2,5/2,9-DMP	"	1.240	0.041%	1.44	5.7%	0.3
1,7-DMP	"	1.243	0.044%	1.06	7.2%	0.2
1,9/4,9-DMP	"	1.249	0.042%	1.47	6.5%	0.3
Fluoranthene	"	1.250	0.042%	0.77	7.1%	0.1
1,5-DMP	"	1.252	0.043%	1.69	7.6%	0.3
1,8-DMP	"	1.256	0.046%	1.11	8.0%	0.3
1,2-DMP	"	1.264	0.048%	1.49	8.1%	0.2
9,10-DMP	"	1.275	0.050%	1.56	9.0%	0.3
Pyrene	"	1.276	0.047%	0.79	10.7%	0.1
Benzanthracene	d12-Chrys	0.999	0.005%	0.82	2.9%	0.1
Chrysene	"	1.001	0.032%	0.89	2.6%	0.1
Benzo(b)fluor	d12-Peryl	0.972	0.017%	0.62	9.7%	0.2
Benzo(k)fluor	"	0.974	0.020%	0.58	9.2%	0.2
Benzo(a)pyrene	"	0.995	0.009%	0.79	3.7%	0.3
Indenopyrene	"	1.107	0.051%	1.14	25.7%	1.3
Dibenzanthracene	"	1.112	0.043%	1.16	24.8%	3.5
Benzoperylene	"	1.138	0.073%	1.17	33.3%	1.0

IS = Internal Standard Reference Compound
R.R.T. = Relative retention time = R.T. x/R.T. IS
R.R.F. = Relative response factor = (Conc. x/Area x)/(Conc. IS/Area IS)
* n=20, data from daily calibrations over a 2-month period.

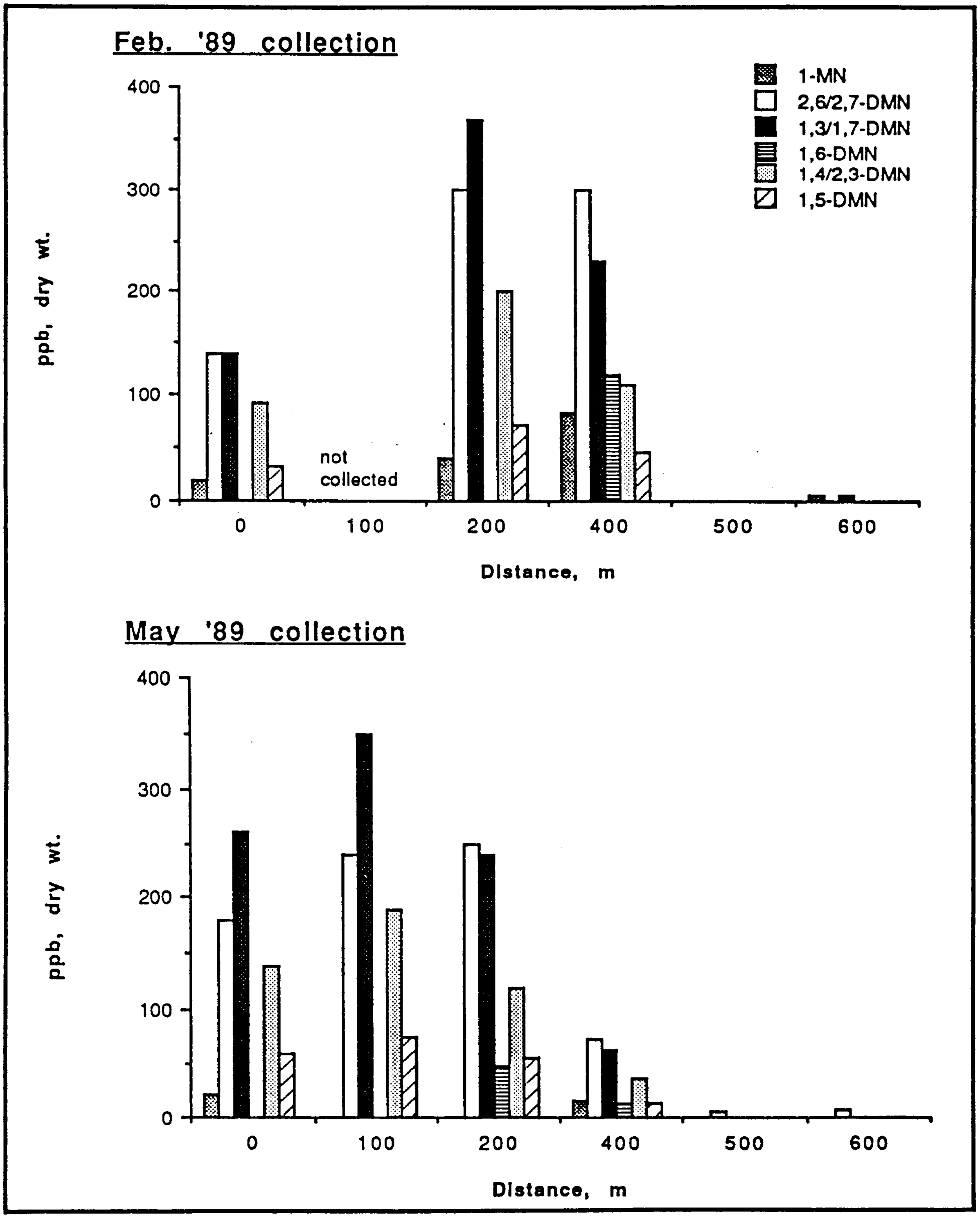

Figure 10.6. Selected alkylated naphthalenes concentrations in surface sediments collected at Pass Fourchon, Louisiana, at 2 time periods.

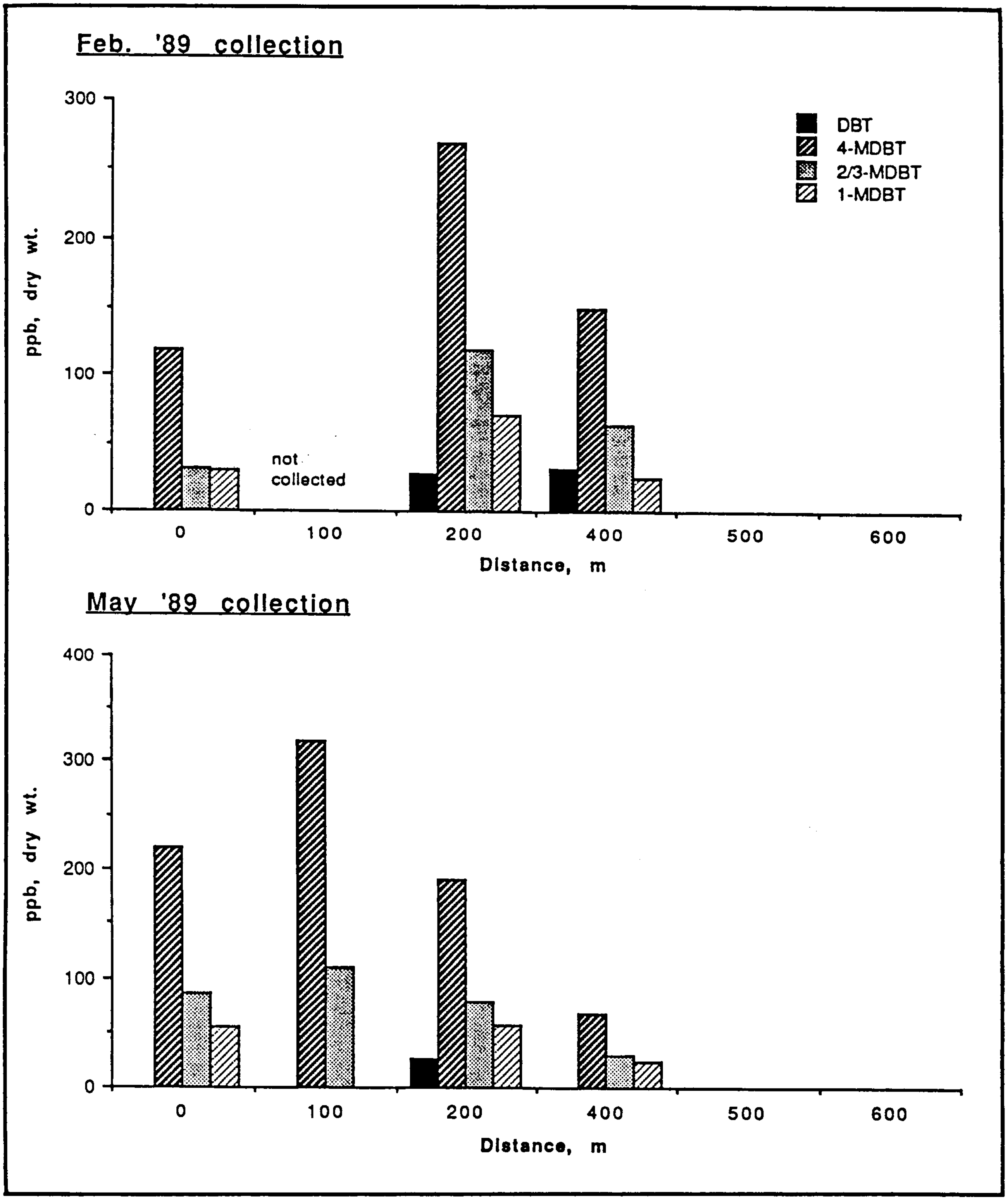

Figure 10.7. Methyldibenzothiophenes concentrations in surface sediments collected at Pass Fourchon, Louisiana, at 2 time periods.

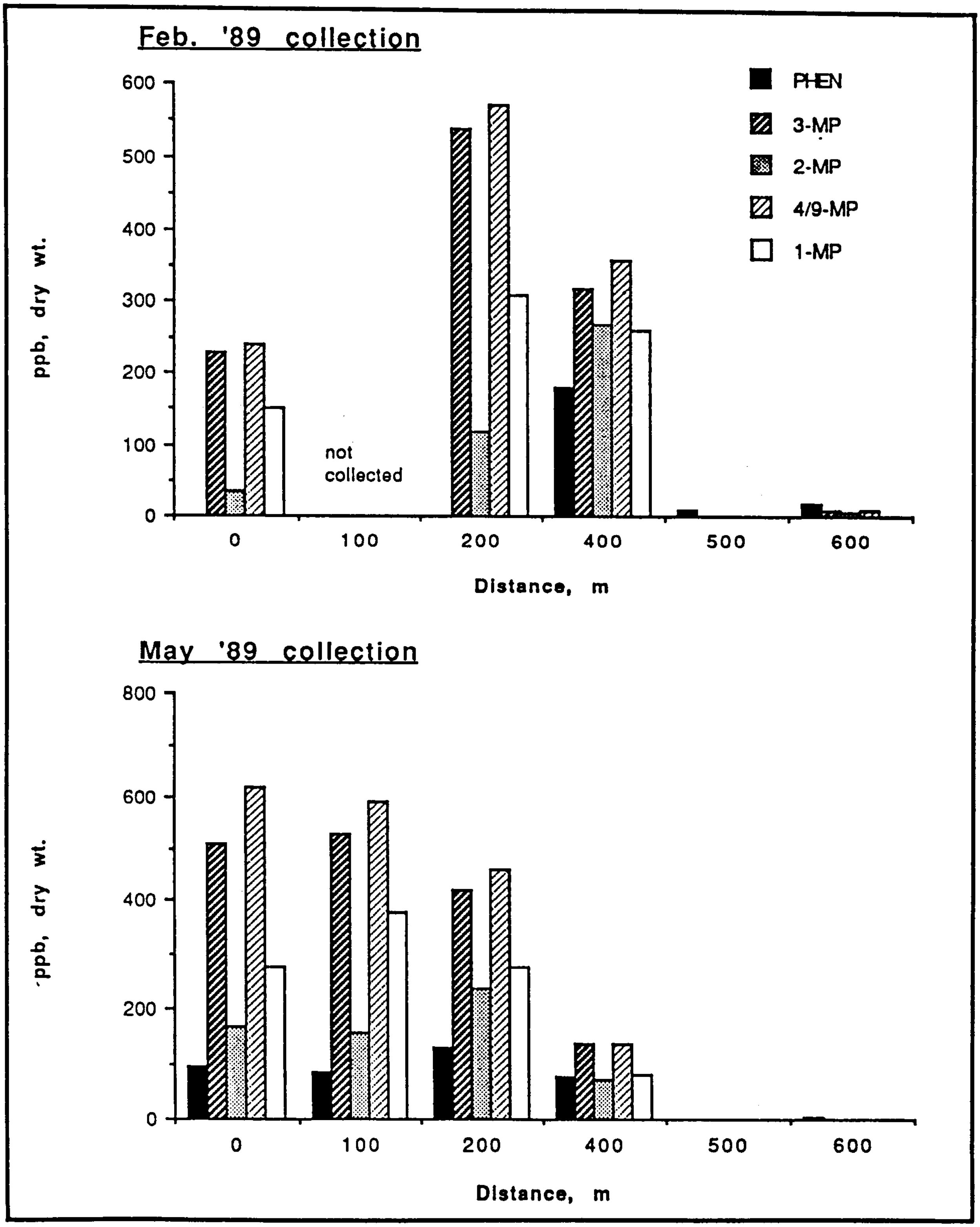

Figure 10.8. Methylphenanthrenes concentrations in surface sediments collected at Pass Fourchon, Louisiana, at 2 time periods.

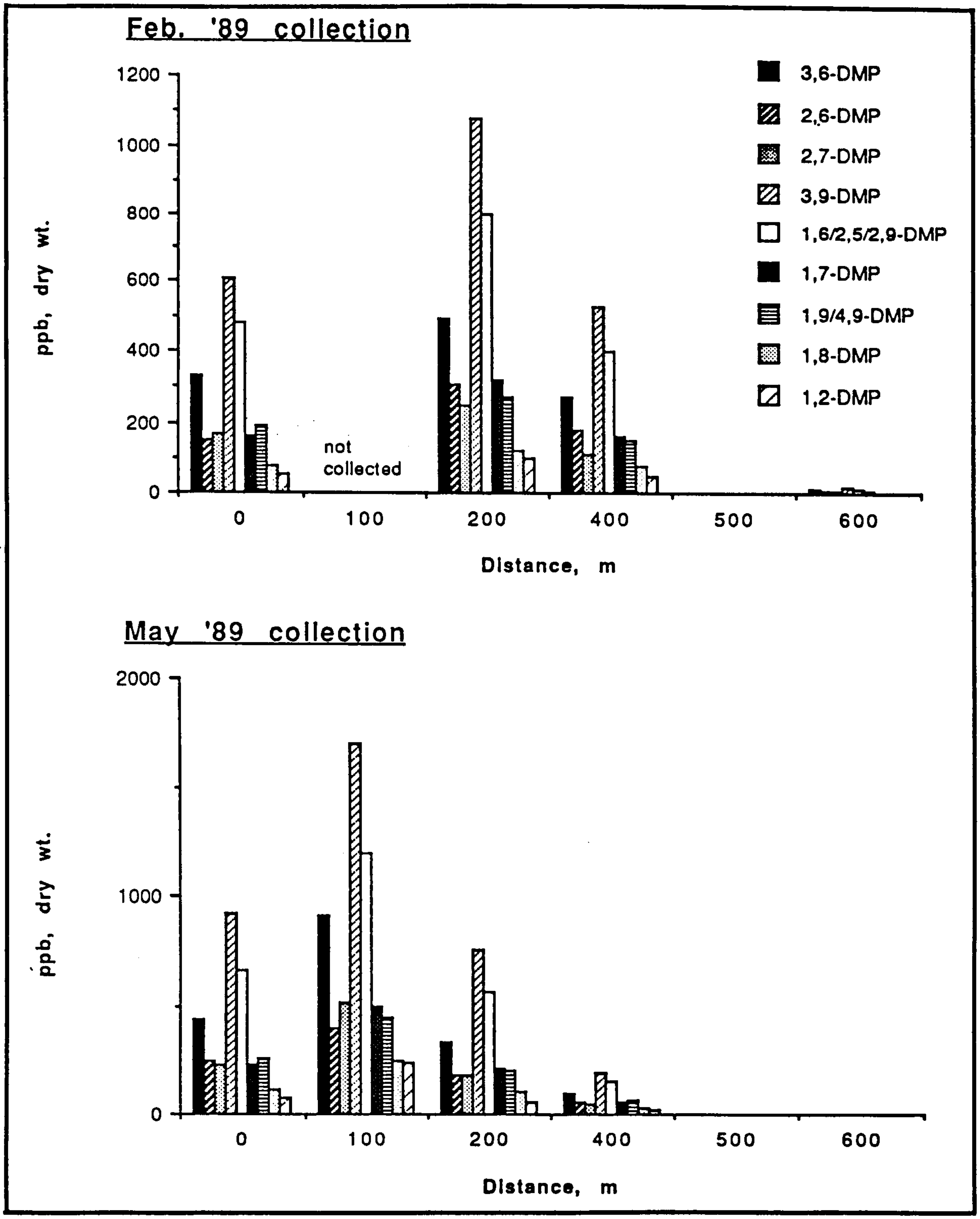

Figure 10.9. Dimethylphenanthrenes concentrations in surface sediments collected at Pass Fourchon, Louisiana, at 2 time periods.

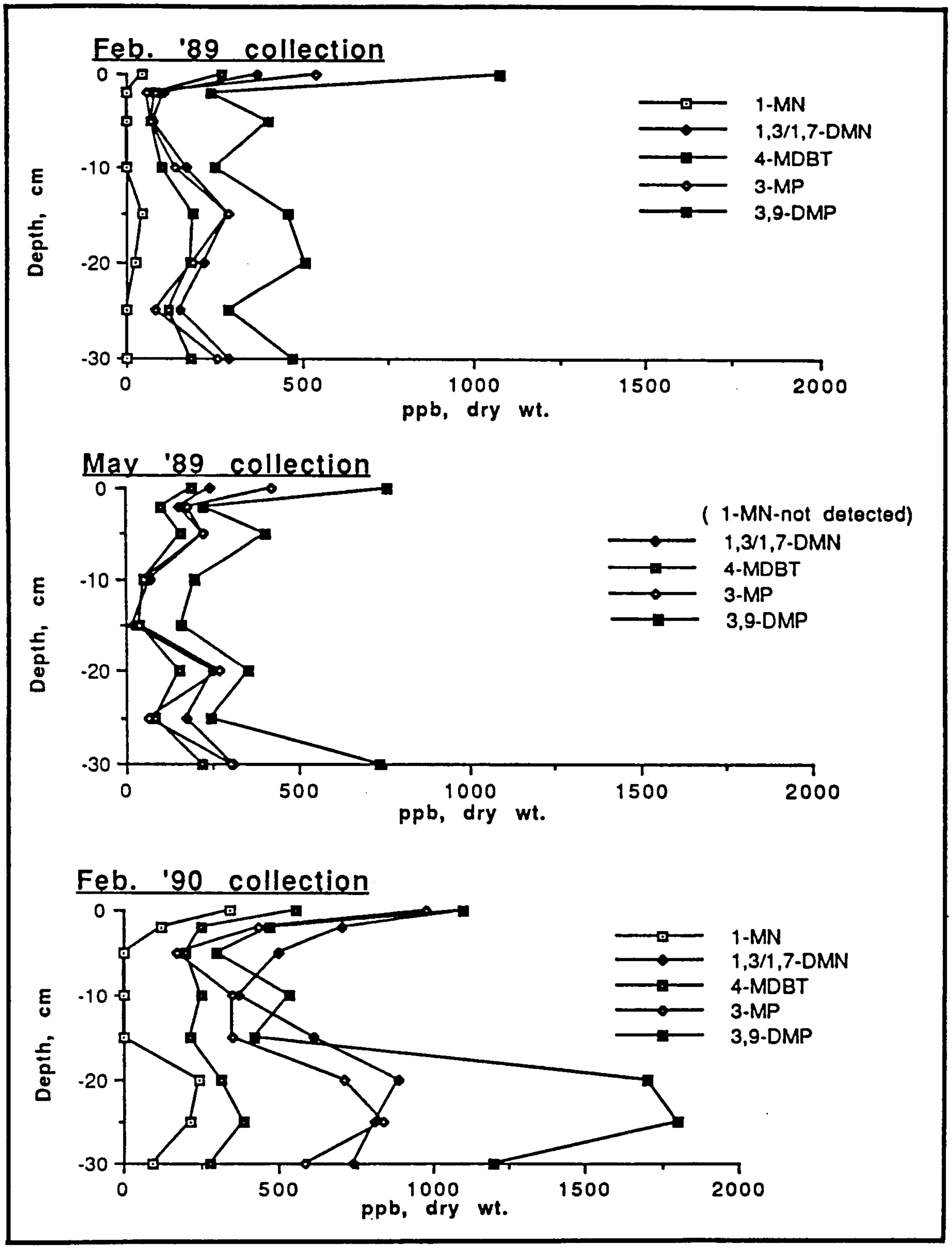

Figure 10.10. Depth profiles for selected alkylated naphthalenes concentrations in cores taken at a single Pass Fourchon site over three seasons.

graduated glass sample jars of 110 ml volume, 24 of which have been filled with 100 ml of the test sediment. The jars have been arranged in four rows of seven with the four corner sample jars not filled with sediment but filled with cleaned glass spheres. Other sub-microcosms may also be used or a single bed of sediment can be used in the system. The pumping system can accommodate up to 6 additional microcosms.

The remaining volume of the tanks is filled, except for a two cm depth air space below the lids, with water having a salinity of 14 parts-per-thousand prepared from deionized water and Instant Ocean in this particular experiment. This water is circulated in such a manner to affect five water exchanges (volume of aquarium) in a 24 hour period. This exchange rate is satisfactory for biological experiments as well. The water enters and exits from opposite ends of the tanks via four nozzles which are situated 1 cm above the sample jar tops and are aligned with the four columns of sample jars that run the length of the aquaria. The nozzles are manifolded to a common carrier line that feeds or accepts flow from the nozzles evenly.

Upon exiting the tanks, the water passes through a foam plug trap which removes the hydrocarbons that may have desorbed into solution. The water is then introduced to the other tank than that from which it was removed by the action of a peristaltic pump and the manifold/nozzle system previously discussed. The process of mixing the waters between tanks should prevent any variability in the waters flowing over the samples. The water volume of the system as well as the arrangement of the sample jars is preserved in the tanks after sampling events by replacing the samples taken with jars filled with clear glass spheres.

The potential for flow variation over the samples necessitated two design features. The first, already mentioned, is that the corner sample jars in the aquaria were not used due to poor water flow characteristics in these areas. Secondly, the flow and mixing within the tanks is enhanced by the use of an air-bubbling system. The 2,200 ml of air per minute that are pumped into each tank via a submerged airstone create mixing and flows throughout the tank. The air from both tanks is recirculated constantly as the air that is pumped into the water is drawn from the air space above the water and passed through a urethane foam plug trap to remove any volatilized hydrocarbons.

The entire microcosm test apparatus is operated in a compartmentalized enclosure to exclude light and to provide thermal stability. The enclosure is only opened for brief periods for sampling and maintenance procedures which are performed under low light conditions.

Modifications of Analytical Methods for Sediment Desorption Experiments

- Extraction of microcosm soil cores: Three core jars were removed from each microcosm tank at sampling times of 0, 1, 3, 7, 14, 28, 60, and 120 days, for a total of 48 samples. The jars were capped and refrigerated until the day before extraction, when the overlying water was removed and the capped jar frozen overnight at -20C. Two methods of extraction were evaluated for preparation of sediment core samples. The method chosen for use is as follows: For extraction, the jar was broken and the frozen core placed in a coring device designed for these experiments. The device consisted of a longform beaker, with the same diameter as the core jars, to which a caliper was attached. The frozen core was placed into the device top side down and a glass plunger pushed through from the opposite end to force the core against a scraper while aligned with the caliper. The core was scraped against Stanley Sureform scrapers, a separate scraper for each 2-mm section, and which were sonicated in DCM and baked at 200°C overnight prior to each use. The scrapers were supported over 500 ml tared jars and the soil allowed to fall into the jar for each section. Residual soil on the scrapers was removed by tapping the scrapers against the lip of the jars. A subsample of ~0.5 gm was removed for dry-weight determination and the jar reweighed to obtain the wet weight of the sample. Wet weights were typically 2-3 g and moisture content averaged 60 percent, and was generally 1-2 percent higher in the top sections. Dichloromethane was added to each jar, then an aliquot of the deuterated surrogate standards, and finally 30 gm of sodium sulfate was mixed in thoroughly using a stainless steel spatula. The jars were sonicated for 10 minutes in an ice-cooled bath, and the solvent decanted through sodium sulfate. This procedure was repeated three times. The resulting extract was concentrated as described previously and sulfur removed by activated copper.

- The GC/MS analysis of microcosm extracts and determination of desorption rates for alkylated PAH: Extracts were analyzed by GC/MS operated in the selected ion monitoring mode for enhanced sensitivity of the target analytes, utilizing the same temperature program as previously described for the GC. The standard mixture was diluted to 1 ppm for calibration of the instrument. Injections into the GC were made by autosampler, and hexamethylbenzene was added to each extract to monitor instrument performance. Figure 10.11 shows an example of data obtained for cores representing a "0-day" sample, (ie., cores were capped and stored immediately after the sediments were bedded), a day-28 core, and a day-60 core taken from the microcosm tanks. In spite of the lack of treatment of the "0-day" samples, concentrations of analytes were significantly lower in the top segment of the core. This may be the result of freezing the core, or due to rapid desorption into overlying water that separated from the sediment during the bedding process. The data for the day-28 core shows that desorption of some PAHs is occurring from the top sections of the core while some other compounds such as 1-ethylnaphthalene (1-EN) appear to be unchanged with depth. By day 60, several of the dimethylnaphthalenes are greatly depleted in the core while 1-EN is still found at very similar concentrations with depth. Figure 10.12 shows the ratios of several dimethylnaphthalenes to 1-EN as a function of depth and core age in the desorption microcosm. These data suggest that while the ratios of these alkylated species remain relatively constant with depth, they are increasing with time.

From these data and other data obtained on these and other cores, we are developing estimates of the desorption rate constants of alkylated and heterocyclic PAHs from sediments under different conditions of salinity, OC, and colloid enrichments. Further, because of the new analytical methodology which we have developed and employed, we are able to make several independent estimates of these rates for several positional isomers of the same compound (i.e., 10 dimethylnaphthalenes) having similar sorption constants and aqueous solubility.

Dr. Jay C. Means, Professor of Environmental Chemistry and Aquatic Toxicology at Louisiana State University (LSU) School of Veterinary Medicine, is recognized nationally for his work on the fate and transport of hydrocarbons and other hydrophobic contaminants such as polychlorinated biphenols and chlorinated hydrocarbons in aquatic environments, including estuarine and coastal marine systems. His laboratory group pioneered the research on the predictive modelling of sorption/desorption processes on sediments and also on estuarine colloids. He was the principal investigator responsible for pollutant chemistry and bioavailability of a Cooperative Agreement entitled "Fates and Effects of Nearshore Discharges of OCS Produced Formation Waters", as well as a principal investigator of two other projects related to impacts of produced waters in coastal Louisiana. He is also co-principal investigator of a three-year grant under the Minerals Management Service University Research program entitled Biochemical Indicators and Genotoxicity of Produced Waters.

Ms. Debra J. McMillin is a Research Associate for the Aquatic Toxicology Laboratory, Department of Physiology and Toxicology, LSU School of Veterinary Medicine. She holds a master's degree and has seven years of experience in environmental analytical chemistry, specializing in chromatography and mass spectrometry. She has been responsible for GC/MS and HPLC methods development, sediment analyses, and data interpretation for four projects assessing the impacts of produced waters.

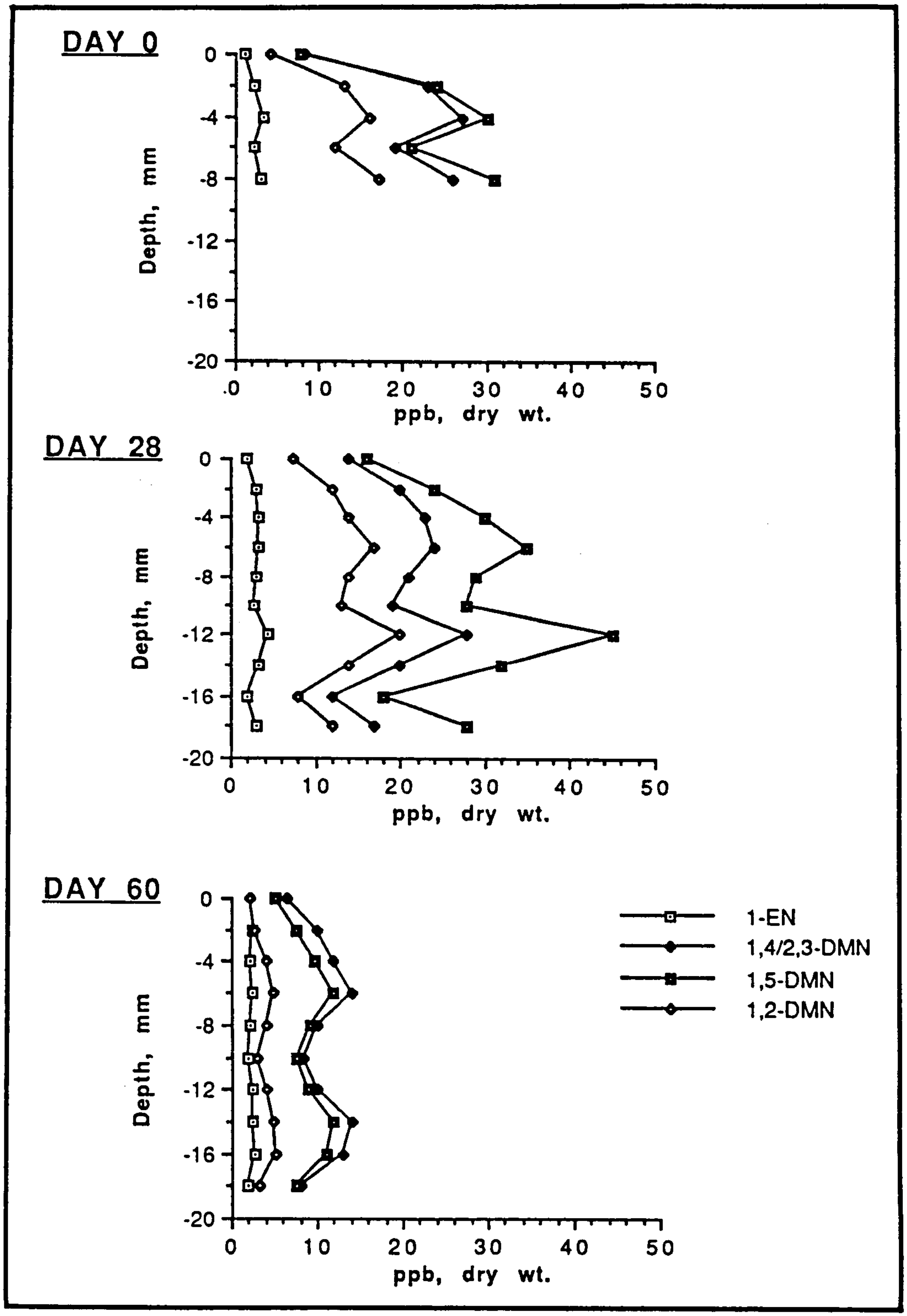

Figure 10.11. Depth profiles for selected alkylated naphthalenes concentrations in microcosm cores representing three sampling periods.

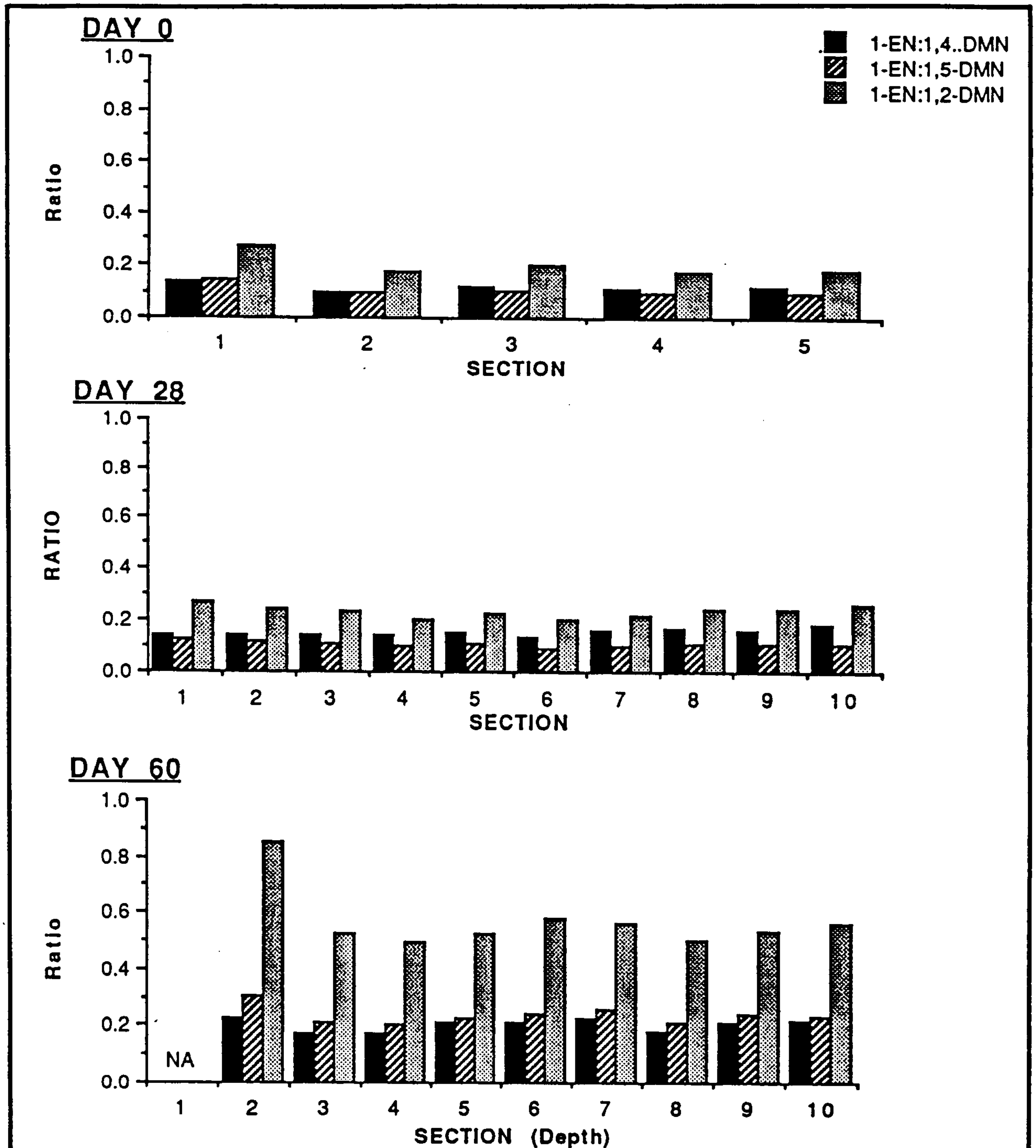

Figure 10.12. Ratios of selected alkylated naphthalenes concentrations (1-ethylnaphthalene: 1, 4/2, 3 dimethylnaphthalene, 1,5-dimethylnaphthalene, and 1,2-dimethylnaphthalene) in microcosm cores representing three sampling periods.

EFFECT OF SHORELINE AND SHALLOW HABITAT CONTAMINATION AND LOSS ON DOMINANT INFAUNAL INVERTEBRATES

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Thalassinoid shrimp are among the most common macrofaunal burrowing organisms of estuarine and marine soft sediment environments. Despite their diversity and abundance along the east and west coasts of North America, relatively little is known regarding effects of these prodigious burrowers on sediment turnover, nutrient flux, and benthic microbial assemblages. Studies of the ghost shrimp, *Lepidophthalmus louisianensis* and *Callichirus islagrande* (both previously *Callianassa*), in the northern Gulf of Mexico indicate that high densities of these species significantly increase the productive aerobic-anaerobic interface by constructing extensive subsurface burrows. The density of burrows varies with season, habitat type, and recruitment patterns. Burrows of *L. louisianensis* may seasonally exceed $400/m^2$ in estuarine intertidal and shallow subtidal mudflats. Resin castings of these burrows reveal that they are long, multibranched, and (at times) interconnected structures which occasionally extend to >2.5 m depth. Burrows of *Callichirus islagrande* also vary in number seasonally and with sediment type, ranging from 80 to $140/m^2$. Calculation of the aerobic-anaerobic interface along burrow walls indicates that these animals may increase the surface area of this sediment-water boundary by up to eight times. Present data, together with those from previously published studies, suggest that burrowing shrimp are primary determinants of abiotic and biotic characteristics in many estuarine and marine intertidal environments.

INTRODUCTION

Callianassid ghost shrimp often dominate the infaunal macroinvertebrate assemblage of marine intertidal and shallow subtidal environments. Except for a brief pelagic phase, most ghost shrimp spend their entire lives in self-constructed, complex burrow systems used for shelter, feeding, and reproduction. Construction and maintenance of the burrows mobilize a large quantity of sediment that is expelled from burrow openings onto the sediment surface. This active processing of sediments or bioturbation results in "turning over" of sediments at rapid rates. The process serves as a two-way conveyer of materials to and from the sediment surface, and thus has a dramatic effect on local sediment characteristics (Suchanek 1983, 1985; Branch and Pringle 1987).

In addition to moving sediments, ghost shrimp maintain an aerobic environment within the burrow by pumping large amounts of water through the burrow from the overlying water column. Estimates of the overall pumping rates of entire populations indicate that some shrimp may move as much water through their burrows each day as is exchanged daily through normal tidal fluxes (Dworschak 1981). This flow of oxygenated water keeps the burrow and immediately surrounding sediments aerated, and extends the sediment-water (aerobic-anaerobic) interface from the sediment surface to depth; it also appears to move nutrients from the burrow - sediment interface back into the water column (Waslenchuk *et al.* 1983; Aller *et al.* 1983). In general, these nitrogen-rich, oxygenated burrow conditions appear to be ideal for high microbial production (Koike and Mukai 1983; Griffis and Chavez 1988; Dobbs and Guckert 1988).

In expansive intertidal and shallow subtidal habitats of the northern Gulf of Mexico, the callianassid ghost shrimp, *Lepidophthalmus louisianensis*, has extensively colonized a variety of substrates in coastal estuaries; abbreviated larval stages, extreme tolerance of low oxygen, and excellent osmoregulatory ability have favored widespread and abundant colonization of low-salinity mudflats (Felder 1978; Felder *et al.* 1986). By contrast, another species, *Callichirus islagrande*, has extensively colonized sandy intertidal and subtidal beaches and flats of barrier islands. Populations of both species are deemed highly vulnerable to local mass mortalities from oil spills and activities related to clean-up of such spills. Current studies have been undertaken in order to more fully predict the scope of ecological impacts stemming from such mass mortalities.

METHODS

Primary study sites were estuarine mudflats of Bay St. Louis, Mississippi, and barrier island beaches of Isle Dernieres, Louisiana. In addition, comparative studies were conducted (under private support) in near Cartagena, Colombia, where *Lepidophthalmus sinuensis* (an ecological equivalent of *L. louisianensis*) has established dense populations in penaeid shrimp culture ponds. Field efforts to date have included monitoring of populations by quadrate counts at and immediately below the sediment surface. For analyses of biomass, animals were jetted from the substrate with a gasoline-driven pump. Resin casts of burrows were also jetted from the substrate to determine burrow morphology. Redox measurements were taken in the field at the time that burrow and pore waters were taken for nutrient analyses. Sediment traps were constructed to capture material expelled from individual burrow openings over a single tidal cycle.

RESULTS AND CONCLUSIONS

- The ghost shrimp, *Lepidophthalmus louisianensis* and *Callichirus islagrande*, occur in high densities (200-300 burrows/m^2) in intertidal sandflats of the Gulf of Mexico. The habitats occupied are such that these populations would experience expansive massive mortality with landfall of coastal and marine oil spills. *Lepidophthalmus sinuensis*, a South American counterpart to *L. louisianensis*, reaches even greater densities in estuarine mudflats of Colombia, South America (> 500 burrows/m^2).

- All three species construct burrows connected to the sediment surface through a narrow shaft called a "chimney" that widens into a main burrow shaft with depth. Maximum burrow depth ranged from 0.6 m (*Callichirus islagrande*) to over 2.5 m (*Lepidophthalmus louisianensis*).

- Ghost shrimp burrows increase the surface area of the productive sediment-water interface by adding burrow wall area beneath the sediment surface. Calculations of burrow surface areas from resin casts indicate that at maximum population densities, ghost shrimp add 4 to 8 m^2 of burrow wall surface area beneath every m^2 of sediment. Previous work on the composition of the burrow wall suggests that this is a highly productive region. Dobbs and Guckert (1988) found that microbial biomass of *Callianassa trilobata* burrow lining was five times greater than that of the sediment surface. Branch and Pringle (1987) found similar results for *Callianassa kraussi* burrow walls. These data suggest that ghost shrimp may increase the density of benthic microbial populations in addition to increasing the surface area of the sediment-water interface.

- Ghost shrimp burrows increase the volume of water beneath the sediment surface. At maximum densities, ghost shrimp populations add 13 to 16 liters of burrow volume beneath each m^2 of sediment surface.

- The pumping of water through these burrows may flush nutrients from sediments. Preliminary data on the nutrient composition of water from the burrows of *Callichirus islagrande* suggest that the movement of burrow water may contribute ammonia and silicate to the overlying water. Further study is required to measure the rates of water movement through burrows.

- Sediment bioturbation ranged from 2.2 kg (wet) m-2 day-l (*Lepidophthalmus sinuensis*) to over 25 kg (wet) m-2 day-l (*Callichirus islagrande*). High levels of bioturbation in these and other thalassinoid species results in the rapid turnover of sediments to depth.

- A review of previous work on ghost shrimp burrows and bioturbation indicates that other thalassinoid species also have large impacts on sediment movement and surface area of the sediment-water interface.

- Further study is needed to quantify the effects of thalassinoid burrows and burrowing on benthic microalgae and nutrient fluxes. Future work in the field and laboratory will also focus on (1) the microbial populations associated with burrow walls, and (2) the feeding biology of ghost shrimp. An ideal setting for further study of these processes has been found in Colombian penaeid shrimp ponds, where effects of dense ghost shrimp populations are magnified and where ponds can be manipulated as experimental mesocosms.

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Dr. Darryl L. Felder has been with the University of Southwestern Louisiana for 16 years. He is presently a Professor and the Chairman of the Department of Biology, and serves as Director of the Center for Crustacean Research. He also has long served as a representative to the Louisiana Universities Marine Consortium Council and presently chairs that body. His research interests center on biology of crustacea and span physiology, development, ecology, functional morphology, and development of this group, with particular emphasis on adaptations of coastal burrowing forms. Dr. Felder received his B.S. and M.S. in biology from Texas A&I University and his Ph.D. in zoology and physiology from Louisiana State University.

EFFECT OF OIL SPILLS ON RECOVERY OF COASTAL WETLANDS

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Mr. Mark W. Hester
Wetland Biogeochemistry Institute
Center for Wetland Resources
Louisiana State University,
Mr. Wayne Grip
Aero-Data Corporation,
and
Dr. John M. Hill
Houston Advanced Research Center

INTRODUCTION

On April 23, 1985 a break in an oil pipeline near Nairn, Louisiana resulted in the release of approximately 300 barrels of Louisiana crude oil into a brackish/saline marsh. An assessment of the impact of the spill to the marsh vegetation was conducted approximately three months after the spill. Vegetation response to the spill was determined in 68 permanent plots randomly selected within (1) the visually oil-contaminated marsh; (2) the marshes, which may have received some oiling, located immediately north and south of the oil-contaminated marsh; and (3) reference marshes located further north and south of the oil-contaminated marsh. Assessment of the oil impact within these permanent plots in conjunction with soil petroleum hydrocarbon determinations resulted in the conclusion that impact to the vegetation was primarily confined to the marsh immediately surrounding the pipeline rupture. The capability of this type of marsh to recover from an oil spill is unknown.

Thus, the primary goals of the present study were to determine the degree of marsh recovery since the spill and evaluate marsh degradation at this site relative to natural and man-induced causes. The specific objectives are as follows: (1) document pre-spill land loss rates using historical aerial photography, (2) document post-spill rates of marsh recovery using recent aerial photography and vegetation monitoring, (3) determine the effect of the oil spill, if any, on the study area's rate of deterioration, and (4) determine the growth response of transplanted marsh grasses in impacted areas for remediation strategy considerations.

METHODS

Historical photography was acquired and photomosaics constructed to visually assess regional land loss rates. The historical imagery has been used to generate detailed maps of the original study site (impacted and control marshes). Approximately 8-10 year intervals have been mapped. Comparison of these maps will establish pre-spill marsh deterioration rates. Color infrared imagery has been acquired of the study site every other year and used to determine post-spill recovery rates. The mosaics have been photointerpreted and land cover categories assigned and digitized. Acreage estimates are being acquired for both pre- and post-spill conditions. By comparing these data, an estimate of the impact of the spill on background rates of marsh deterioration will be established.

The ground-truth research consists of reanalyzing the vegetative status in the 68 permanent plots established after the spill in 1985. In addition, sites that were delineated as oil-stressed in 1985 were randomly chosen and plant carbon assimilation determined and compared to immediately adjacent non-stressed sites to determine if any residual oil impact is apparent.

We have also assessed the potential of mitigating oil impacts by determining if vegetative transplants can be used to re-establish vegetation at sites that have deteriorated due to the oil impact. The purpose of this transplantation study is to test a number of hypotheses concerning why vegetation is not recolonizing some of the previously oil-affected sites. Elevation has been manipulated to test whether this factor is primarily responsible for the negligible plant recolonization at certain sites. This experiment is on-going.

RESULTS

Field Acquired Analyses

Data for the 1985 and 1989 plant cover categories and oil impact index are summarized in Table 10.9 by marsh area. Significant time differences ($P<.05$) were detected for total plant cover (live plus dead percent cover), adjusted live percent cover (normalizing for absolute differences in plant cover), adjusted dead percent cover, and oil impact index (Table 10.9). In general, these significant time effects can be attributed to increases in total and adjusted live percent cover (Figures 10.13 and 10.14) and decreases in adjusted dead percent cover and oil impact index from 1985 to 1989 (Table 10.9). It is important to note that in 1989 there were no longer any significant main effects due to marsh area, whereas the 1985 data consistently showed an oil effect and reduction in plant cover in the impacted area (transects 5 through 11) compared to the intermediate and control areas (Table 10.9). In 1989 there were no longer any visual signs of oil on the vegetation or the marsh surface (Figure 10.15).

The recovery of the vegetation in the impacted area is clearly evident from (1) the significant increase in adjusted live percent cover between 1985 and 1989 in the impacted marsh (Figure 10.14) and (2) the fact that the adjusted live cover did not significantly differ between the impacted marsh and the control marshes in 1989 (Table 10.9). However, an a priori single-degree-of-freedom contrast showed a significantly lower total percent cover in the impacted marsh compared to all control marshes in 1989. Thus, the total cover still appeared lower in the impacted marsh compared to the control areas four years after the spill. However, the proportion of live healthy vegetation in the impacted area is comparable to the other areas, and is indicative of recovery.

Although the impacted area doubled in total percent cover from 1985 to 1989, the other marsh areas also showed an increase in total percent cover (Table 10.9; Figure 10.13). This increase in total percent cover in the intermediate and control areas may be a seasonal effect, since the 1985 data were collected earlier in the growing season (July) than the 1989 data, which were collected at the end of the growing season (November) when total cover would be expected to be near the yearly maximum.

Overall trends in species cover values in 1989 were similar to those in 1985. The same three species (*Spartina alterniflora, Spartina patens,* and *Distichlis spicata*) were present in the plots, but *Spartina alterniflora* displayed the greatest increase in live adjusted percent cover in the 1989 impacted area transects. *Spartina patens* and *Distichlis spicata* also

Table 10.9. Total Percent Cover (TPC), Adjusted Live Percent Cover (ALPC), Adjusted Dead Percent Cover (ADPC), and Oil Impact Index (OII) by Marsh Area for 1985 and 1989.

		Variable							
		TPC		ALPC		ADPC		OII	
	n	1985	1989	1985	1989	1985	1989	1985	1989
North Control	10	53 ab[1]	82 a	63 a	84 a	37 b	16 a	0.00 b	0.00 a
North Intermediate	10	53 ab	90 a	83 a	85 a	17 b	15 a	0.00 b	0.00 a
Impacted	28	32 c	64 a	28 b	80 a	72 a	16 a	2.27 a	0.00 a
South Intermediate	10	61 a	84 a	77 a	83 a	23 b	17 a	0.05 b	0.00 a
South Control	10	40 bc	76 a	88 a	85 a	12 b	15 a	0.10 b	0.00 a

[1]Column means followed by the same letter are not significantly different (P > .05) based on a Duncan's Multiple Range Test.

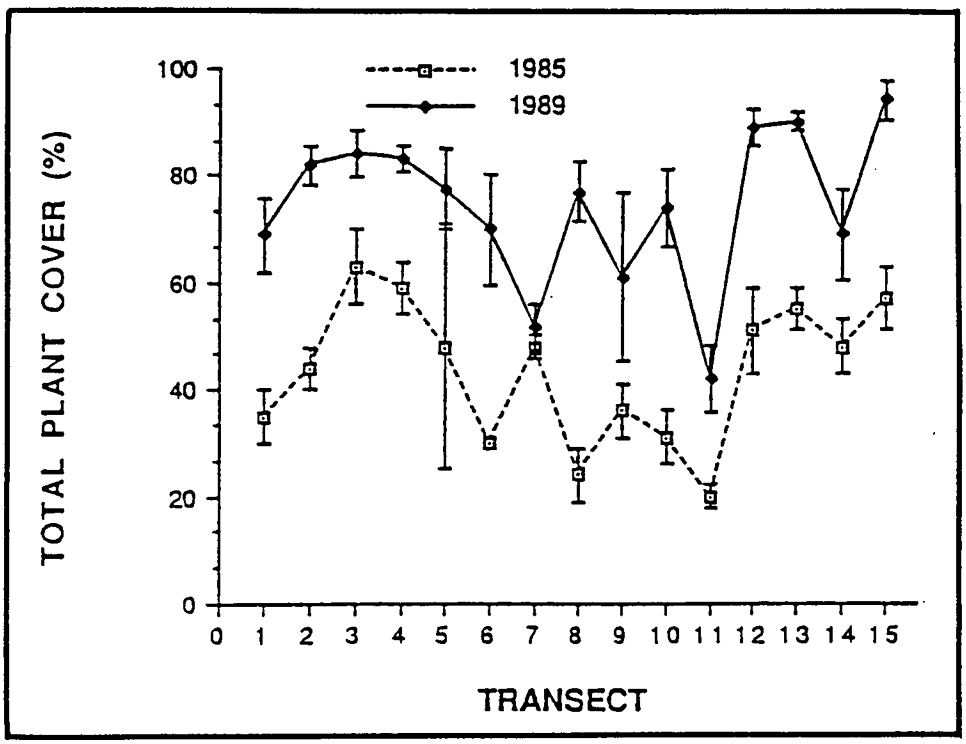

Figure 10.13. Total plant cover (live cover plus dead cover) by transect for the 1985 and 1989 sampling dates.

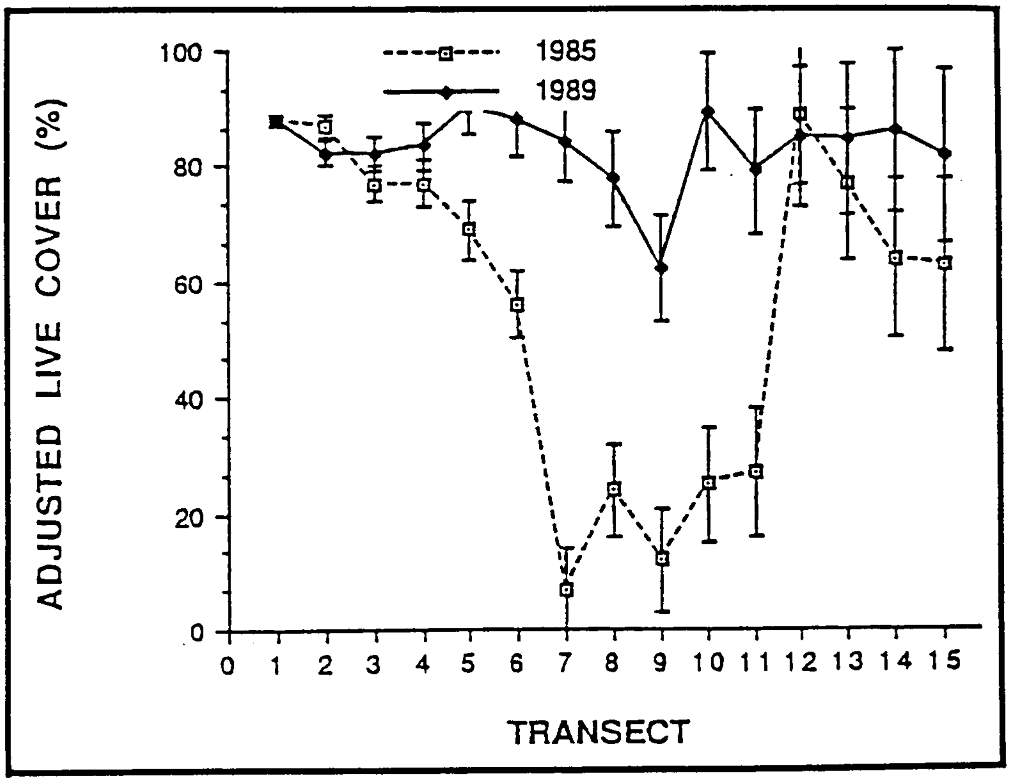

Figure 10.14. Adjusted live plant cover (100% x live cover/total cover) by transect for the 1985 and 1989 sampling dates.

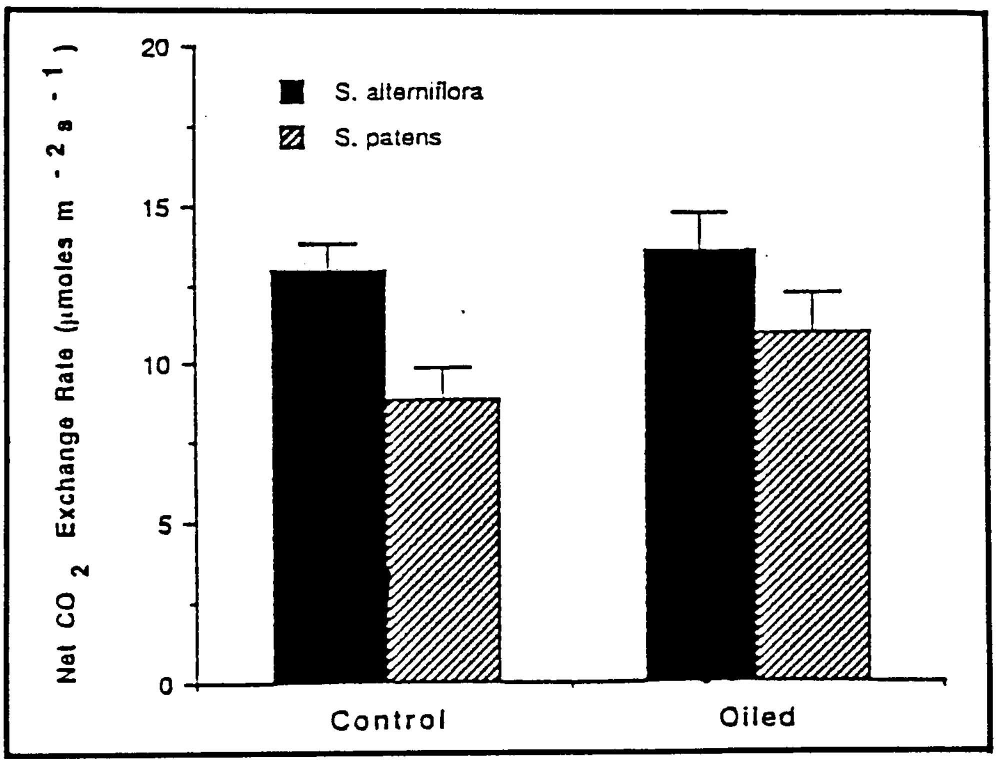

Figure 10.15. Plant photosynthetic response (mean net CO_2 exchange rate with standard error) of *Spartina alterniflora* and *Spartina patens* in control and oiled plots (August 1990; n=12).

showed some increase in live adjusted percent cover in the 1989 impacted area transects.

Plant photosynthetic response (net CO_2 exchange rate) showed no significant differences between oiled and control plots for either *Spartina alterniflora* or *Spartina patens* (Figure 10.15). Unadjusted live percentage cover was significantly greater in the control plots (Table 10.9). However, all other plant cover values (total cover, dead cover, adjusted live cover) were not significantly different between oiled and control plots. Similarity of plant covers between oiled and control plots was desirable to ensure that our comparison of photosynthetic response was not affected by differences in plot vegetation composition, and, therefore, was a valid test of any residual oil effect.

Hydrocarbon analysis of the subsample of soil cores collected in November 1989 showed that of the three cores collected from oil-impacted plots, 11-C and 10-A had higher levels of total saturated hydrocarbons (134,000 to 160,000 ppb) than the control cores from 2-C and 14-C (20,000 to 42,000 ppb; Table 10.10). However, the total saturated hydrocarbons of 9-C (54,000), also an oil impacted plot, did not show as much of increase over the control levels (Table 10.10). Interestingly, plots 9-C and 11-C both showed trace amounts of C1, C2, and C3-dibenzothiophene (characteristic substitution products of parent dibenzothiophene in weathered oil) whereas 14-C did not have detectable levels of these compounds, despite the fact that it had the greatest total saturated hydrocarbon value. We plan to have more of these cores analyzed over the next year.

Photointerpretive Analyses

The following represent the initial visual findings resulting from the detailed photointerpretation and mapping of historical and recent aerial imagery of the study area.

- Shoreline erosion at the site is rather constant from 1950 to the present (1990), averaging approximately 50 feet during the 40 year project period. The actual amount varies on a site-specific basis.
- Internal marsh breakup was almost nonexistent through 1970. By 1978, a significant amount of marsh loss had occurred. Therefore, the historical imagery revealed that portions of the impacted marsh and surrounding area appeared to have been in various stages of deterioration before the spill occurred.
- The oil spill had caused a significant amount of marsh dieback by 1986, one year after the spill. Marsh dieback was apparent from the first aerial imagery acquired after the oil spill on June 13, 1985 until 1986. However, by October 20, 1990 a significant amount of plant recovery had occurred in the areas where water depth tended to be shallow (as indicated by mud flats in imagery acquired at low tide).
- Background internal marsh loss (except for that caused by canal dredging) and shoreline erosion appeared to have slowed considerably since 1982.

Thus, the historical imagery analysis supports the ground truth data demonstrating significant vegetative recovery 4-5 years after the spill.

Dr. Irving A. Mendelssohn is Professor in the Department of Oceanography and Coastal Sciences and in the Wetland Biogeochemistry Institute at Louisiana State University. Dr. Mendelssohn received his Ph.D. in 1978 from North Carolina State University. He is a coastal plant ecologist who has specialized in studying the response of coastal marsh vegetation to various stresses and in the use of vegetation to restore and preserve eroded and eroding coastal areas.

Mr. Mark W. Hester is a Research Associate IV at the Center for Wetland Resources, Louisiana State University, Baton Rouge, Louisiana. Mr. Hester received his B.A. in biology from Indiana University in 1980 and an M.S. in marine sciences from Louisiana State University with a minor in experimental statistics in 1985. Mr. Hester is a coastal plant ecologist/ecophysiologist with research interests that include factors controlling wetland plant species distributions, plant stress physiology, barrier island vegetation dynamics, and wetland restoration/stabilization projects.

Table 10.10. Total Saturated Hydrocarbons (11/89), Initial Plot Oil Impact Index (7/85), and Initial Total and Dead Percentage Vegetative Cover (7/85) from a Subsample of Five Representative Plots.

Plot	Total Saturated Hydrocarbons (ppb)	Initial Oil Impact Index	Initial Total Vegetative Cover (%)	Initial Dead Vegetative Cover (%)
2-C	42,000	0.0	55	5
14-C	20,000	0.0	35	10
11-C	134,000	2.0	15	10
9-C	54,000	3.0	35	32
10-A	160,000	3.0	50	50

Mr. Wayne Grip is President of Aero-Data, Inc. which conducts remote sensing, photo interpretation, and historical mapping for environmental issues. Mr. Grip has a B.S. in geology and soils from University of Wisconsin, Madison, Wisconsin.

Dr. John Hill received his Ph.D. in biology from Texas A&M University. Dr. Hill is presently head of Remote Sensing GIS Laboratory at the Houston Advanced Research Center. Dr. Hill has specialized in the acquisition, processing, and interpretation of photographic and digital remotely sensed data for the monitoring and analysis of environmental and ecological conditions. Dr. Hill is an active member of numerous professional societies and has authored over 50 technical publications.

MONITORING, ASSESSMENT, AND PREVENTION OF MARINE DEBRIS ON GULF BEACHES — POST MARPOL V

Session:	MONITORING, ASSESSMENT, AND PREVENTION OF MARINE DEBRIS ON GULF BEACHES - POST MARPOL V
Co-Chairs:	Mr. Villere C. Reggio, Jr. Dr. Robert M. Rogers
Date:	November 6, 1991

Presentation	Author/Affiliation
Monitoring, Assessment, and Prevention of Marine Debris on Gulf Beaches - Post Marpol V: Session Introduction	Mr. Villere C. Reggio, Jr. and Dr. Robert M. Rogers Minerals Management Service Gulf of Mexico OCS Region
Take Pride Gulf-Wide Beach Cleanups - The Use of Volunteer Data in Marine Debris Monitoring	Ms. Linda Maraniss Center for Marine Conservation
Marine Debris Monitoring at Gulf Islands National Seashore	Ms. Gail Bishop National Park Service Gulf Islands National Seashore
Marine Debris Monitoring on Padre Island National Seashore	Mr. John E. Miller National Park Service Padre Island National Seashore
Marine Debris Monitoring on Mustang Island, Texas	Mr. Anthony F. Amos The University of Texas at Austin Marine Science Institute
Industry's Waste Management and Monitoring Program	Mr. Bernie Herbert Amoco Production Company and Mr. Rodney Foreman ARCO Oil and Gas Company
Use of MARPOL Annex V Reception Facilities and Disposal Systems at Selected Gulf of Mexico Ports, Private Terminals, and Recreational Boating Facilities	Mr. Dewayne Hollin Sea Grant College Program Texas A&M University and Mr. Michael Liffmann Louisiana Sea Grant College Program Louisiana State University
One Company's Response to Offshore Waste Management	Mr. Dexter A. Babin Texaco E&P Inc. and Mr. Beau Toll Innotec, Inc.

MONITORING, ASSESSMENT, AND PREVENTION OF MARINE DEBRIS ON GULF OF MEXICO BEACHES POST MARPOL V: SESSION INTRODUCTION

Mr. Villere C. Reggio, Jr.
and
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Gulf of Mexico OCS Region

Beginning in 1988 it became international and U.S. policy to prohibit the disposal of plastic waste anywhere in the marine environment, and to eliminate the disposal of metal, paper, glass, wood, cloth, and rubber items within 25 miles of the Gulf of Mexico shoreline. A major purpose of the newly adopted policy was to protect living marine resources and the Gulf of Mexico's recreational beaches from the adverse effects of maritime trash and garbage. Increasing public and private concern for the integrity of coastal and marine resources threatened by marine debris has led to gulf-wide educational and stewardship initiatives, changes in waste management practices by marine industries, and even resulted in new institutional compacts specifically designed to address the issue (i.e., Gulf of Mexico Program).

With telltale evidence of the more than 37,000 workers directly employed in the Gulf of Mexico's offshore petroleum operations being routinely removed during Texas and Louisiana beach cleanups, it became incumbent on Minerals Management Service (MMS) to address this issue as part of its environmental assessment program. Although trash and debris have been identified as an impacting factor in lease sale environmental impact statements for over 15 years, the effectiveness of existing and developing mitigation is poorly understood. Hence MMS invited the principal investigators of all recent and ongoing Gulf of Mexico marine debris survey and monitoring programs to review their project scope and objectives, and to share their findings. As noted in the following reports, the data would indicate it is premature to draw any firm conclusions on significant progress in reducing plastic pollution on Gulf of Mexico beaches. There is reason to believe, however, from the data presented, as well as from commitments being made by several oil companies, that certain items reflective of the oil and gas industry's presence in the Gulf of Mexico are decreasing, and that decline should continue.

Mr. Villere C. Reggio, Jr., is an Outdoor Recreation Planner with the MMS, Gulf of Mexico OCS Region. His responsibilities include research, assessment, and reporting on the interrelationship of the OCS oil and gas program with the natural resources and recreational elements of the marine and coastal environment throughout the Gulf of Mexico region.

Dr. Robert M. Rogers has served as Contracting Officer's Technical Representative on numerous marine studies, including the University of Texas MARPOL V marine debris monitoring and evaluation project. His graduate work in trophic interrelationships among Gulf of Mexico marine fishes led to a Ph.D. from Texas A&M University. He has been with the OCS Environmental Studies Program since 1977.

TAKE PRIDE GULF-WIDE BEACH CLEANUPS – THE USE OF VOLUNTEER DATA IN MARINE DEBRIS MONITORING

Ms. Linda Maraniss
Center for Marine Conservation

In 1986, The Center for Marine Conservation (CMC) organized the first statewide beach cleanup ever held in Texas. That summer the CMC also created a 65 item data card for volunteers to record the kinds and amounts of trash found along the beach.

During the summer of 1986 the CMC also formed a steering committee made up of people who lived and worked at sea, or who had factories or ports near the Gulf of Mexico (Gulf). Representatives from ports, shipping companies, oil companies, the plastic industry, the U.S. Coast Guard, and state and federal governments were also represented.

Members of the steering committee shared information on how shipboard trash was handled, sources of some specific debris items, and ways to identify sources of marine debris.

Since September 1986, the CMC has analyzed the data collected by volunteers and published the results. In 1988, the CMC created the National Marine Debris Data Base, expanding the data collection program to include all coastal states. National reports published by the CMC on marine debris include a state by state look at the sources of debris, the "Dirty Dozen" which is a listing of the top 12 trash items found in each state, and a breakdown of the composition of trash found.

Our marine debris reports have proven useful to the average citizen, teachers, students, policy makers, and legislators on the state, local, and national levels. The information has been used by the media to report on the kinds and sources of marine debris littering our beaches and oceans. Data collected each September is one way to monitor the effectiveness of MARPOL Annex V legislation.

Beach cleanup and data collection programs have expanded to other countries including Canada, Guatemala, Costa Rica, Japan, and Mexico. Cleanups were also held in the Virgin Islands and Puerto Rico.

The CMC has educated volunteers about marine debris so that they would be good data collectors. We printed a Guide to Good Data Collection, wrote a book on how to organize a beach cleanup, translated the data card and guide into Spanish, and we publish a Coastal Connection newsletter mailed to thousands of people who have completed data cards at the beach cleanup.

Data collected nationally in 1988 told the pre-MARPOL marine debris situation. The law took effect on December 31, 1988. At that time is was legal to dump all shipboard trash at sea.

Data collected in September 1989 reflected trash found 9 months after Annex V came into force. Dumping plastic and other kinds of trash was now illegal.

Data collected in September 1990 occurred after the first full year of MARPOL Annex V legislation.

In the fall of 1988, 1,000 tons of trash were removed from America's beaches with the help of 47,000 volunteers.

In the fall of 1989, 65,600 volunteers cleaned 2,946 miles of beach, and removed 861 tons of debris.

In the fall of 1990, 107,260 volunteers worked along 3,656 miles of coastline and collected 1,323 tons of trash from United States and international beaches.

The CMC's data card has grown from 65 items to 81 items under the categories of plastic, styrofoam, glass, rubber, metal, paper, and wood. The data card includes a section to list foreign labels, cruise line names, military identification or fishing company names. This information helps to identify sources of trash. During the past year, the CMC's marine debris office has written more than 150 friendly letters to the CEO's of companies whose products were found during a beach cleanup. We all know that just because a lunch meat wrapper from Oscar Mayer was found on a beach in Virginia it was not put there by that company. The CMC has found it useful to send letters to alert companies such as Morton Salt and Pizza Hut that their trash was found. This has been useful in Florida, where trash from several cruise liners was found during cleanups. Letters have been sent to several cruise lines, and the U.S. Navy when their trash has been found at a coastal cleanup.

Letters to oil companies include Chevron, Mobil, Phillips, Shell, Penrod, Parker Oil, Oil Field Protectors Supply Company, Conoco, Citco, Esso/Exxon International, Marathon Oil/Suntrand Sun, Texaco Incorporated, Exxon Corporation, British Petroleum Company, and Arco Oil and Gas Company.

In 1990, 85,070 data cards were distributed. Volunteers returned 18,872 cards. In many cases cards were completed by several volunteers working together with one card. Alabama had the highest return rate of data cards with 59.8 percent. Florida's return rate was also good with 43.2 percent.

The CMC uses 28 of the 81 items on the data card as indicator items to identify sources of marine debris.

The totals from the September 1991 cleanup are being analyzed now. The report will be published in May and the results announced at a press conference in Washington, D.C.

The information to follow will be from the September 1990 cleanup (CMC 1991). Categories and percent of 1990 totals using only the 28 indicator items include:

- Recreational Boating and Fishing Wastes = 1.06% (1990)
- Commercial Fishing Wastes = 3.62% (1990)
- Operational Wastes = 1.41% (1990)
- Galley Wastes = 3.33% (1990)
- Sewage-Associated Wastes = 0.49% (1990)
- Medical Wastes = 0.09% (1990)

For our purposes today, I will not discuss sewage waste, medical waste, or commercial fishing wastes. Anyone interested in all the totals should contact the CMC for our national reports on marine debris.

Bottles and Associated Goods

We look at a category of trash associated with bottles and associated goods. Indicator items for bottles and associated goods include:

- plastic beverage bottles
- glass beverage bottles
- metal beverage cans
- plastic 6-pack rings
- metal bottle caps
- metal pull tabs

Nationwide, bottles and associated goods accounted for 14.32 percent of all the trash recorded in 1990. Three of the five Gulf states ranked higher than the national average with this kind of trash.

Alabama	18.44%
Florida	18.65%
Louisiana	13.92%
Mississippi	20.82%
Texas	11.00%

Recreational Fishing and Boating Wastes

Indicator items for recreational fishing and boating wastes include:

- plastic monofilament fishing Line
- plastic floats and lures

Nationwide the total was 1.06 percent (1990). Three of the five Gulf states ranked higher.

Alabama	0.97%
Florida	1.14%
Louisiana	1.34%
Mississippi	0.88%
Texas	1.50%

The MARPOL Annex V regulates the discharge of wastes from all ships at sea. An offshore oil platform falls under the MARPOL definition of a ship and so must comply with the no-dumping restrictions.

Operational Wastes

The category designated as operational wastes includes trash generated by offshore operations such as petroleum exploration and drilling in addition to equipment used on cargo vessels. Indicator items for operational wastes include:

- plastic hard hats
- plastic strapping bands
- plastic sheeting
- plastic pipe thread protectors
- glass light bulbs
- write-protection rings
- fluorescent light tubes
- wooden pallets
- wooden crates

Nationwide these wastes accounted for 1.41 percent of all trash items reported. Unfortunately, many of these items are particularly harmful in the marine environment. For example, the 20,889 strapping bands and 21,409 pieces of plastic sheeting reported are known to pose entanglement and ingestion problems for marine animals.

Plastic sheeting can foul boat motors, and glass light bulbs, of which 12,790 were found nationwide, are a potential safety hazard for beach visitors.

Operational wastes were both prevalent and above the national figure in four of the five Gulf states.

Strapping bands and plastic sheeting were the predominate items in the operational wastes category. Other states that were above the national percentage were Alaska, Oregon, Maine, Rhode Island, and Maryland.

Comparing data from September 1988, 1989, and 1990, the percent of operational waste nationally has decreased.

2.03% in 1988
1.60% in 1989
1.41% in 1990

Nationwide the total was 1.41 percent (1990). But in 1990, four of the five Gulf states ranked higher than the national.

Alabama	1.53%
Florida	1.34%
Louisiana	3.42%
Mississippi	1.83%
Texas	2.82%

Galley Wastes

Galley waste indicator items include:

- plastic trash bags
- plastic milk or water jugs
- bleach bottles
- vegetable sacks
- egg cartons
- foamed meat trays

The percent of galley wastes decreased from 7.83 percent in 1988 to 3.33 percent in 1990. Nationwide in 1990 the total for galley waste was 3.33 percent. All of the Gulf states except Florida reported percentages at least two to three times above the national figure.

Alabama	6.13%
Florida	3.14%
Louisiana	9.39%
Mississippi	6.69%
Texas	6.66%

Each of the Gulf states does show a decrease in percent of galley waste over a three year period.

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Ms. Linda Maraniss has worked for the CMC since 1982. She was the education director in the Washington, D.C., headquarters until moving with her family to Texas. She established the CMC's first regional office in 1986. In the summer of 1986, Ms. Maraniss created the first Texas Coastal Cleanup program. Ms. Maraniss has just completed writing the CMC's newest publication, *The Gulf of Mexico, A Special Place*, an activity book for third and fourth grade students. Due to generous funding by several companies and foundations, including Shell Oil, Amoco Production, Texaco Marine, and Conoco, 7,000 books have been distributed to coastal schools for free in all five Gulf of Mexico states since July 1991.

MARINE DEBRIS MONITORING AT GULF ISLANDS NATIONAL SEASHORE

Ms. Gail Bishop
National Park Service
Gulf Islands National Seashore

INTRODUCTION

The amount of marine debris found on beaches and in the oceans is becoming an international concern as shown by the thousands of volunteers cleaning beaches in countries around the world. Most of the marine debris is composed of plastic which is persistent in the marine environment and poses serious threats to marine life which can be entangled or killed.

Gulf Islands National Seashore (GUIS), the largest National Seashore in the United States, was selected for one of eight National Park study areas in a joint

National Park Service/National Marine Fisheries Service (NMFS) Marine Debris Monitoring Program in 1989. The objective of this five-year study is to provide a scientific assessment of national, regional, and seasonal trends in marine debris abundance, composition, and accumulation.

STUDY SITES

The GUIS stretches 150 miles from West Ship Island, Mississippi, to Santa Rosa Islands, Florida, in the north-central area of the Gulf of Mexico. The seashore incorporates six offshore islands including two federally designated wilderness islands and comprises 16,446 onshore acres and 122,416 offshore acres. There are 170.43 km (105 miles) of seashore shoreline.

Three Mississippi (West Ship Island, Horn Island North, and Horn Island South) and two Florida (Perdido Key and Fort Pickens) beach sites were selected for marine debris monitoring. Of these sites four are located on the Gulf of Mexico side and one on the Mississippi Sound side. All study sites are 1 km in length and in varying widths depending on the distance from the waters edge to the seaward extent of vegetation.

METHODOLOGY

Surveys were conducted quarterly in December (fall), March (winter), June (spring), and September (summer). Debris seen from walking height was counted and removed when possible. Large objects such as refrigerators too big to be removed were marked with spray paint or tags. Counted debris was recorded on standard data forms which were adapted from NMFS data forms used in Alaska debris monitoring programs. Categories on the forms included plastic fishing gear, plastic packaging material, plastic personal effects, miscellaneous plastics, glass, metal, paper, and cloth. In addition, sections of rope or fishing line greater than one meter, netting, and floats were measured. Items that were less than one half of their original size were considered fragments. All data forms for the quarterly surveys were analyzed and graphed by the North Carolina State University Department of Recreational Resources.

DISCUSSION

Many factors influence the dispersion and amount of marine debris such as weather patterns, currents, shoreline growth or erosion, offshore and onshore activities. These include fisheries, dredging, shipping, oil and gas, recreation, defense, and industry. In addition land generated debris is flushed via river systems flowing into the central Gulf of Mexico region.

This monitoring program is ongoing and conclusive trends are not known. However, preliminary results indicate that approximately 16,131 items were removed in Fiscal Year (FY) 1989, 10,805 in FY 1990, and 17,331 in FY 1991. Seventy-five percent of the items removed in FY 1989 were made of plastic and this increased by 10 percent in FY 1990. In FY 1989 the plastic debris by category was composed of 46 percent packaging, 38 percent miscellaneous, 19 percent fishing, and 7 percent personal. The composition of plastic debris changed in FY 1990: 42 percent miscellaneous, 39 percent packaging, 10 percent personal, and 9 percent fishing.

The three top plastic items in FY 1989 were hard fragments, caps and lids, and foam fragments. In FY 1990 the top three plastic items were foam fragments, hard fragments, and caps and lids. In 1989 the mean number of foam fragments per km was 68.2. These small fragments are of particular concern since they can easily be ingested by marine life.

Other types of debris which are harmful to wildlife are ropes, nets, and fishing line. The mean number of ropes greater than 1 m was 10.4 per km. The total number of items per km for GUIS was 674 in 1989, 512 in 1990, and 864 in 1991.

Although the Marine Debris Monitoring Program is focused on marine debris related to fishing activities, information about oil and gas activities is noted. For example, the presence or absence of petroleum such as tar balls, slicks, tar pancakes, or asphalt is marked on the data forms. During the three years of monitoring, the presence of petroleum has been found usually in the form of tar balls. In addition, obvious debris related to oil and gas industry, such as write protectors, is recorded under the heading "offshore oil industry." Although over a thousand pieces of oil blotter paper washed ashore in one survey site, there has been a moderate amount of plastic items directly related to the oil and gas industry when compared to the fishing industry.

The Marine Debris Monitoring Program is funded through FY 1993 when a comprehensive report will be published.

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Ms. Gail Bishop received her M.S. in science education at the University of Southern Mississippi. She has worked for the National Park Service since 1977. In 1986 she joined the staff as supervisory park ranger at GUIS where she became active in organizing volunteer beach cleanups. Because of her interest and expertise she was asked to coordinate the Marine Debris Survey at GUIS.

MARINE DEBRIS MONITORING ON PADRE ISLAND NATIONAL SEASHORE

Mr. John E. Miller
National Park Service
Padre Island National Seashore

Marine debris has become an increasing concern to the general public as well as the scientific community. It is estimated that 6.4 million tons of debris are discarded annually into the world's oceans, mostly in the northern hemisphere (National Academy of Sciences 1975). Marine debris can threaten wildlife, both in the water and on the beach. Additionally, once washed ashore, this debris impacts upon beach aesthetics and can pose health problems.

MARINE DEBRIS SURVEY

In 1989, National Marine Fisheries Service (NMFS) and National Park Service (NPS) undertook a cooperative project to quantify the types and amounts of debris littering our beaches and the long-term trends in ocean pollution. Monitoring is being conducted at eight units of the National Park System located along the Atlantic, Pacific, and Gulf of Mexico coasts, during this five year study.

Padre Island National Seashore (PAIS) is one of the parks selected to participate in this program. The PAIS is located on Padre Island, Texas, the longest undeveloped barrier island in the United States (Figure 11.1). Over 112 km (70 miles) Gulf of Mexico beach is contained within the boundaries of PAIS. Wind and current patterns vary throughout the year. However, longshore currents consistently converge offshore from Padre Island and deposit considerable quantities of marine debris on local beaches. Unfortunately, much of the debris deposited into the Gulf of Mexico, from river outflow and direct dumping offshore, eventually washes ashore on Padre Island.

The National Park Marine Debris Monitoring Program was initiated in 1989. Marine debris was enumerated quarterly at six locations within PAIS. However, during 1991, survey methods, site locations, and site sizes were altered to improve the accuracy and scientific validity of data collection. In March 1991, two 50-m long transects were permanently established at 3 sites randomly located over a 20 km stretch of beach (Figure 11.1). The two northernmost transects were established in an area closed to vehicular traffic and hence were less likely to be littered by beach visitors. Survey site widths varied at different beach locations, dependent upon the distance from the water's edge to the seaward limit of vegetation or base of the foredune ridge. All marine debris found within the transects was removed so that the results from future surveys could be used to quantify seasonal differences in debris accumulation. Quarterly surveys of marine debris, utilizing the revised protocol, began in June 1991 and continued during September 1991.

During each survey, flags were used to mark the transect boundaries. The entire transect was then divided into rows, approximately 2 m wide, to aid in

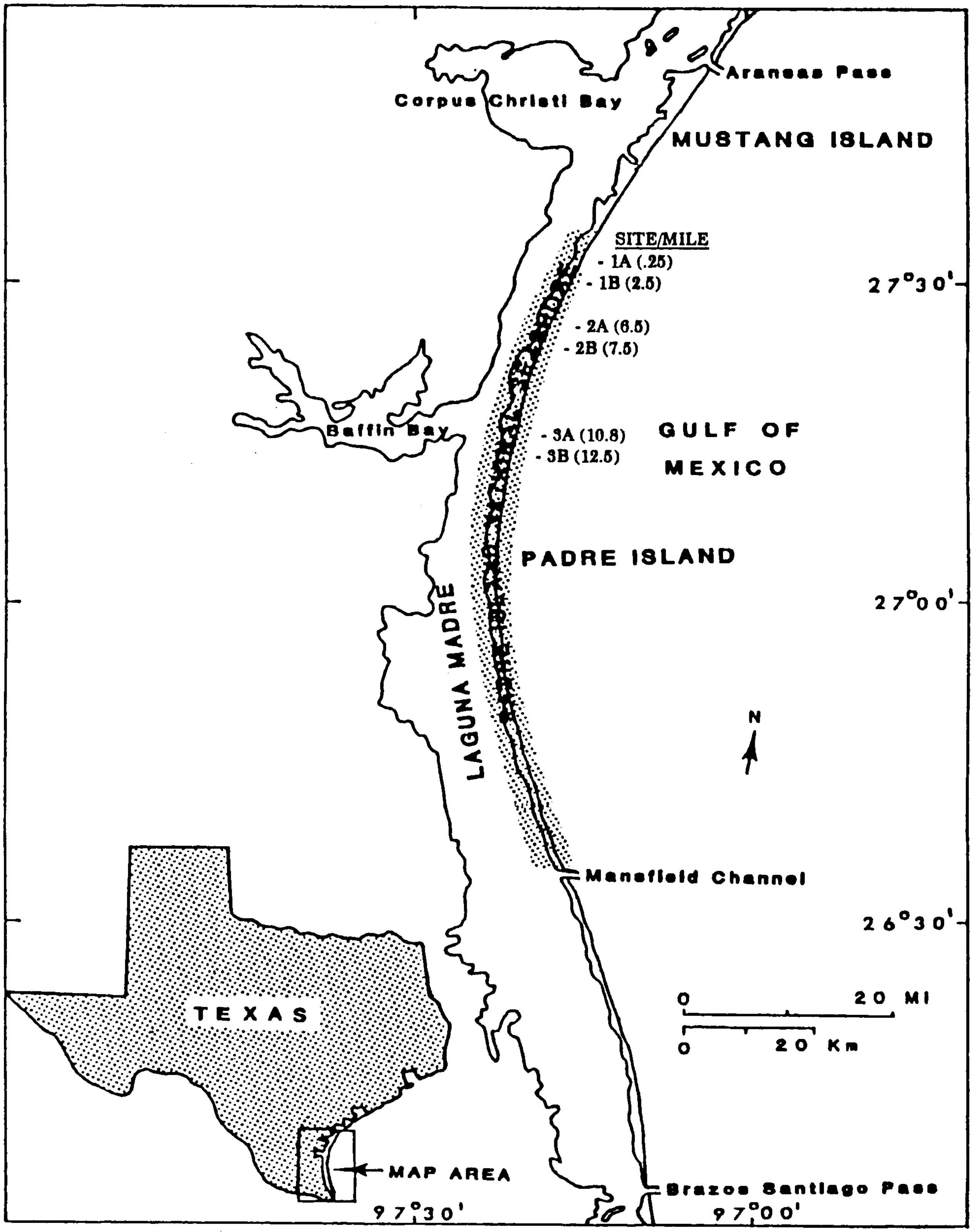

Figure 11.1. The PAIS Marine Debris Project survey sites.

debris detection, enumeration, and removal. Monitoring teams consisted of two persons per team, 1 person responsible for physically picking up the debris and the other person for recording the type of debris. All debris greater than 5 mm in size and visible from a walking height was recorded on data sheets and placed into a plastic bag so that it would not be counted again during that or subsequent surveys. Enumerated debris items were only left within the transect if their removal was impossible or would result in harm to the vegetation. Debris items that could not be removed were counted and marked with fluorescent paint, to prevent mistakenly recounting the same item during another survey quarter. Weights were obtained for bags containing debris that were recorded and removed from each transect. However, wood products, such as plywood and planking, were counted and removed, but not weighed or measured.

Florescent paint was used to mark debris items outside the transect to determine the extent of lateral debris movement into and out of the transect. To prevent mistaking lateral movement directions, debris items on each side of the transect were painted with two different colors. If a piece of painted "lateral movement" debris was encountered during a survey, it was counted as debris within the transect, but the paint color and the type of debris were recorded for future reference.

A noteworthy episode of debris influx occurred in July 1991. Approximately 10,000 pounds of medical waste were removed from a 20 km stretch of beach. Because of the increased summer visitation and a potential health hazard, the medical debris was removed at the northern two transect sites prior to being surveyed. This particular event did impact data results, for the summer survey, because of the dramatic increase in the amount of debris found in the associated categories.

The amount of debris recorded for each survey site per quarter was entered into a computerized database. A total of 11,238 debris items were recorded in 1991. Plastics comprised the majority (92%) of the items collected with glass, wood, metal, and other categories comprising the remaining 8 percent of the total debris collected.

The results of the third year of monitoring are vastly different than the previous years. Unfortunately, only a minimal amount of the data collected during previous years can be utilized for comparisons. Although data have not been collected for a full year utilizing the new methodology, some general trends have been elucidated so far. The debris removed from the survey sites has reduced in mass from when the sites were originally cleaned. The majority of all debris found is comprised of plastic and it is generally found as fragments, rather than as a whole object. Little medical debris is found, with the exception of the single influx in July 1991. There is also an increased amount of debris found at the transect sites to the south. Surveys indicated a very minimal amount of lateral debris movement.

While there is occasionally some evidence of debris origin, such as labels having Spanish writing, suggesting a Mexican or Central American origin or debris items such as salt bags and onion sacks that suggest a commercial fishing source, it would be somewhat irresponsible to blame a specific individual or country without irrefutable knowledge that they were the known offenders. Similarly, some debris items such as bags with company names on them, hard hats, and, oil drums suggest petroleum industry sources. However, except for a very few specific types or items of debris, the origin of the debris is extremely difficult to competently determine.

HAZARDOUS MATERIALS MONITORING

The PAIS has been actively involved in attempting to quantify the numbers of discarded drums containing unknown, potentially toxic waste since 1984. These drums, typically containing petroleum based products, were removed and disposed by the U.S. Coast Guard from 1984-1990. This year, by Congressional Mandate, the park has assumed removal and disposal responsibilities.

Data have been accumulated since 1984 regarding the size and contents of discarded containers. This year (January-September), park staff have removed 766 containers. Of these containers, 134 were 55-gallon drums, while the remaining 632 were smaller in size. Only 12 of the 55-gallon drums had contents, while 85 of the smaller containers held unknown liquid products.

After extensive review of available recorded data, and in an attempt to obtain comparisons as to yearly trends, numerous inaccuracies and inconsistencies were discovered. Hence, any interpretation of these data must be made in a guarded fashion. However, some generalized comparisons of data can be made. There is an indication that the number of discarded 55-gallon drums, both with and without contents, has decreased sharply from 1985 to 1991. At the same time, the number of smaller containers has dramatically increased.

REFERENCE

National Academy of Sciences. 1975. Marine litter, pp. 405-433. *In* Assessing Potential Ocean Pollutants. A report of the study on assessing potential ocean pollutants to the Ocean Affairs Board. Commission on Natural Resources. National Research Council, National Academy of Sciences, Washington, D.C.

Mr. John E. Miller was born in Charleston, West Virginia, and joined the U.S. Army in 1967 and served in Viet Nam. Upon his military discharge in 1970, Mr. Miller attended Stephen F. Austin State University in Texas and graduated with a B.S. degree in 1973 and a Masters of Forestry degree in 1975.

After several years of working as a Recreational Planner and school teacher, in 1978, Mr. Miller joined the U.S. Peace Corps as an Assistant Professor, College of Forestry, University of the Philippines. Mr. Miller joined the NPS in 1980 as a Resources Management Specialist and has since worked in six National Park Service field areas. Mr. Miller is currently stationed at Padre Island National Seashore, Texas, and is designated the NPS's representative for the Minerals Management Service Technical Working Group and is the Park's marine debris coordinator.

MARINE DEBRIS MONITORING ON MUSTANG ISLAND, TEXAS

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INTRODUCTION

In 1987 a marine debris monitoring program was begun on Mustang Island, Texas. The idea was to quantify and classify the amount of marine debris on a 12 km (7.5 miles) stretch of Mustang Island's Gulf of Mexico beach. Since 1978, I have been making a comprehensive study of a 12-km stretch of Mustang Island (Texas) Gulf beach to record the long term trend in bird population, the impact of human usage of the beach on the birds, and the physical changes in the beach, dunes, and adjacent Gulf of Mexico. The survey is called BEACHobs, and to-date I have completed 2,000 separate surveys done on alternate days (with gaps). Initially my recording of the beach debris and litter was anecdotal in the form of notes. In 1983, I began to estimate the abundance of 40 categories of natural and anthropogenic debris. While I still continue those estimates, I realized that a more numerical study was needed to answer the question of whether the quantity of litter was increasing as the public perceived it to be.

In April 1987 I started a separate survey of the same beach to count the litter and some items of natural debris using the same techniques as the BEACHobs surveys. I called this survey GARBGobs. This is a continuing survey effort. GARBGobs assesses the "macro-trash" (items easily seen by eye from the survey vehicle). Simultaneously with GARBGobs, three sites were cleaned of debris which was later examined at the laboratory. This revealed the "micro-trash" often hidden from casual observation. These are the debris Collections. After a full year of GARBGobs, I added five items of commonly found litter to the BEACHobs survey counts (count of five). Finally in June 1991 we started a survey of all containers on San Jose Island, an adjacent, isolated beach to the north of the other survey sites (Figure 11.2). A summary of the various surveys is given in Table 11.1. The BEACHobs is an unfunded project of the

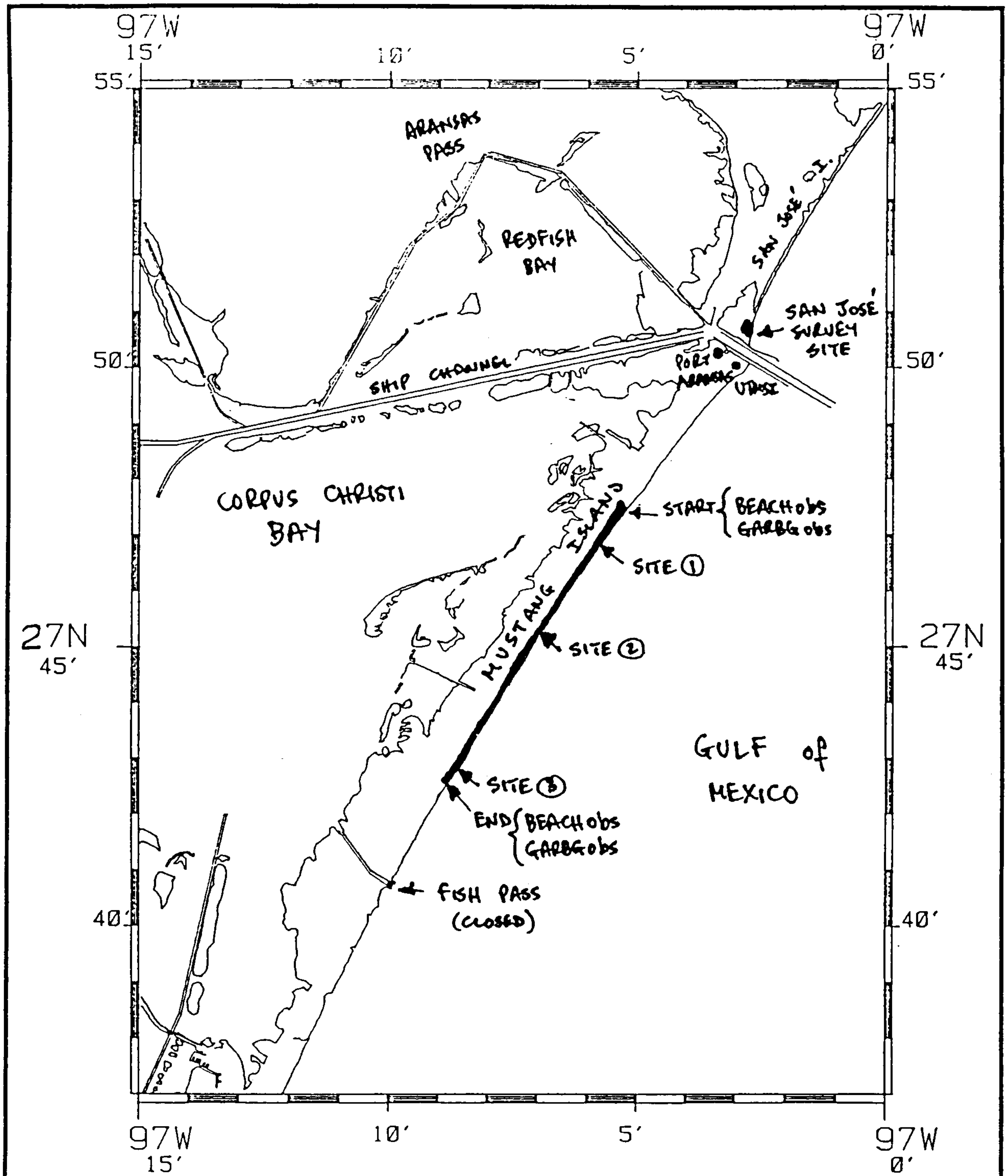

Figure 11.2. Marine debris survey sites on Mustang and San Jose Islands.

Table 11.1. History of Mustang Island Beach Surveys.

Survey Name	Start	End	No. of Observations	Frequency (Days)
BEACHobs	04/14/78	---	1993	2
GARBGobs	04/09/87	---	162	8
Collections	03/19/87	04/01/88	49	8
	01/02/91	---	45	8
Count of Five	04/29/88	---	439	2
Containers	06/19/91	---	6	30

author's. The GARBGobs was helped by a grant from Texas A&M University Sea Grant College Program. Because the GARBGobs study was done prior to the implementation of MARPOL Annex V and continued after 1989 (with a hiatus in 1990), the Minerals Management Service has funded a two-year repeat of the surveys starting after MARPOL had been in effect for two years. The hope is to see what trends have taken place since MARPOL. The MMS project started in January 1991. The field work will continue for 18 months with six months to analyze the results. This report is a preliminary analysis of the results to November 1991.

METHODS

GARBGobs: Debris Counts

The beach is driven from north to south shoreward of the debris line left by the previous high tide. The driver, who is also the data recorder, can view debris from the strand line to the shoreline. A course of 11.8 km is driven and all man-made litter of a dimension large enough to be seen from the slowly moving vehicle is recorded. While no exact criterion has been established for this dimension, the survey is best suited for such items as plastic bottles, bags, cans, and other readily identified items. Some of the more numerous litter (styrofoam pieces and the ubiquitous "miscellaneous pieces of plastic") are more difficult to count accurately. Countable natural items include the Portuguese Man O' War (*Physalia physalis*), cabbagehead jellyfish (*Stomolophus*), and driftwood, which are counted in an attempt to record the relationship between beaching of natural and man-made items.

Data are recorded on an HP-75 hand-held computer with the keyboard reconfigured to permit single-keystroke entry of commonly encountered items. A specially-designed template aids the observer in entering the items, accomplished with one hand while steering with the other. A program written in HP Basic called GARBGobs handles the sorting and storage of data. Because the debris is not evenly distributed along the beach, an interface connects the computer to a NuMetrics electronic distance processor. At 30-second intervals the distance travelled in meters from the starting point is imbedded in the data stream. Thus the distribution of items along the beach front is recorded. The keyboard can be de-configured so that notes may be entered into memory. Notes are coded to allow later sorting into like categories. This anecdotal information adds to the numerical data by describing beach conditions and noting the author's general impressions which can be compared with similar notes made during bi-daily beach surveys made since 1978.

BEACHobs: (Count of Five)

After the first year of GARBGobs was completed in April 1988, four (eventually five) types of litter were counted every other day during the author's BEACHobs surveys. Methods are the same as with GARBGobs. Items counted are 1-gallon plastic milk jugs, egg cartons, chemical drums (55- and 5-

gallon), Mexican bleach bottles (green bottles), and beverage cans.

Debris Collections

Simultaneous with GARBGobs, collections are made of all debris and litter at three sites along the same stretch of beach. At each site, a swath of beach 10-m wide is scraped clean of all debris from the shoreline to the high tide line. The debris is bagged, labelled, and returned to the laboratory where it is sorted, classified, and weighed. Sites are always the same, located at 1, 3, and 7 miles from the starting point. Sites were chosen because of their isolation in relationship to condominiums where "beachgoer" litter is prevalent. Forty-one categories of "micro-trash" and natural debris have been identified.

Container Collections

All containers found from shoreline to dune line along a 250-m stretch of San Jose Island are collected and brought back to the laboratory. Collections are made once per month. San Jose Island is inaccessible except by boat and the beach there is not cleaned. Containers are classified by material or type (plastic, glass, cardboard, beverage cans, and other cans). They are also classified by country of origin, volume, and color. Data on large containers (5-gal or greater) are recorded on the beach to avoid transporting these. After the tallies are done, many of the containers are recycled through a local (Port Aransas) recycling effort.

PRELIMINARY RESULTS

For a preliminary look at the results, I have tabulated pre- and post- MARPOL Annex V data from each of the types of survey (except the BEACHobs estimates). In general, pre-MARPOL data were collected from April 1987 through December 1988, and post-MARPOL data in the first 10 months of 1991. Post-MARPOL data show a reduction in most classes of anthropogenic debris on the beach compared to pre-MARPOL data. Table 11.2 is a partial listing of the results from the GARBGobs debris counts. Items have been roughly grouped into categories indicating the probable origin of the material. There are many items which fit into more than one category. The heading "many sources" includes the most numerous of litter types which could come from several sources.

With the exception of beach usage, all categories show reductions in numbers between 24 and 58 percent. Beach usage, as indicated by "people" counts, is up by 59 percent. Offshore oil-industry items, with the exception of pallets, hard hats, and plastic strapping, are less common on beaches in the post-MARPOL era. Fishing industry materials, with some notable exceptions are also down, as are typical "beachgoing" items, despite the increase in beach usage. Of the three natural debris items counted, the trend is down, but driftwood (much of which is of anthropogenic origin) is considerably greater, as is the major natural item, *Sargassum* weed, which is uncountable. It must be noted that in calculating trends for these groups, no consideration is made for the vastly different weights and volumes of the varied items. Huge standard deviations indicate the greatly varying quantities of all items as a function of time. On an eight-day interval, debris is usually cleaned from the study beach, nonetheless, recounting occurs. No attempt is made to compensate for this. Despite this, some noteworthy changes are apparent: greatly reduced are write-protect rings, large plastic sheeting, and styrofoam. A large increase in Mexican green bleach bottles (probably used by the shrimping industry of that country). Galley waste from shrimpboats also appears to be down. No attempt has been made here to record trends in the activities of the various industries with the exception of a count of beachgoers and shrimpboats visible while the surveys are in progress.

Results of the debris collections (Table 11.3), which were done only from March 1987 through March 1988, and from January 1991 to the present, give a different picture. The "microtrash" has almost universally increased, as has natural debris of all kinds, sometimes dramatically. Tarballs have decreased. The microtrash increase is hidden from the casual observer, but the public has noticed the increase in wood and weed and the decrease in tar. The category "Either" shows that wood and tar on Texas beaches could be either anthropogenically "generated", or of natural origin. Numbers given are in $kg.km^{-1}$ (or $g.m^{-1}$). To assess the actual quantity of material collected and weighed from our total of 30-m of beach, multiply by 30 for grams. The values range from 1312 kg of post-MARPOL

Table 11.2. Results of Pre- and Post-MARPOL Annex V GARBGobs Counts.

Item	Total Counted		Freq. (%)		Items/km		%Chng	High(/km)	
	Pre n=74	Post n=32	Pre n=74	Post n=32	Pre n=74	Post n=32		Pre n=74	Post n=32
NATURAL							-54.0		
Cabbageheads	5537	2724	62.2	58.1	7.84	7.68	-2.5	136.01	55.9
Physalia	32540	748	71.6	74.2	51.35	2.68	-94.8	1399.7	39.8
Driftwood	11151	8582	98.6	100.0	15.43	23.93	+55.1	353.5	145.7
OIL INDUSTRY							-58.4		
Pallets	26	45	20.3	51.6	0.04	0.13	+225.0	0.4	0.8
W-P rings	98	8	44.6	16.1	0.21	0.03	-85.7	3.0	0.3
Plastic sheet	3389	237	100.0	90.3	4.43	0.70	-84.2	21.3	3.4
Pails	284	101	66.2	74.2	0.50	0.28	-44.0	7.0	1.2
Hardhats	21	19	21.6	35.5	0.04	0.06	+50.0	0.7	0.3
55-gal drums	19	2	17.6	3.2	0.03	0.01	-74.2	0.5	0.2
Strapping	307	331	29.7	80.6	0.69	0.95	+37.7	8.6	6.3
Light bulbs	892	304	87.8	77.4	1.47	0.92	-37.4	6.6	4.3
MANY SOURCES							-47.3		
Plastic bottles	7450	3988	100.0	100.0	12.00	11.47	-4.4	43.0	47.5
Glass bottles	3634	1372	94.6	96.8	5.91	3.90	-34.0	34.7	23.1
Misc. plastic	9672	7979	98.6	100.0	16.30	23.65	+45.1	149.9	153.4
Styrofoam	55217	8933	100.0	100.0	86.08	25.05	-70.9	993.4	247.6
Plastic bags	28730	9518	98.6	100.0	51.64	26.47	-48.7	1179.9	91.6
FISHING							-23.7		
Shrimpboats	67	7	24.3	6.5	0.10	0.02	-80.0	1.4	0.5
Outboard oil	207	188	44.6	67.7	0.34	0.56	+64.7	7.0	3.9
Milk jugs	2017	576	94.6	90.3	3.33	1.67	-49.9	50.5	8.2
Egg cartons	2065	487	95.9	87.1	2.99	1.44	-51.8	15.7	6.1
Gloves	1195	574	93.2	93.5	1.79	1.61	-10.1	10.1	13.2
Floats	258	125	77.0	77.4	0.43	0.37	-14.0	2.8	1.8
Nets	52	39	40.5	54.8	0.08	0.11	+37.5	0.7	0.4
Rope	3723	1783	95.9	93.5	6.36	5.29	-16.9	37.7	22.7
Produce sacks	363	247	83.8	93.5	0.54	0.69	+27.8	1.9	2.2
Light sticks	1049	193	71.6	61.3	2.19	0.54	-75.3	36.8	6.2
Green bottles	1105	998	85.1	80.6	1.73	2.87	+65.9	13.8	27.8
BEACHGOING							-30.3		
Beverage cans	2994	1539	100.0	100.0	4.22	4.35	+3.1	25.3	17.6
Drink cups	4419	999	100.0	100.0	7.04	2.84	-59.7	104.8	8.3
Lids	3961	2075	97.3	93.5	6.89	5.93	-13.9	35.5	30.2
6-Pack rings	1469	312	90.5	77.4	2.51	0.92	-63.3	26.1	3.8
Balloons	262	112	62.2	67.7	0.51	0.32	-37.3	3.5	1.6
Toys	99	100	45.9	58.1	0.16	0.29	+81.3	2.0	1.9
Shoes	620	312	82.4	90.3	0.97	0.89	-8.2	10.4	5.3
BEACH USAGE							+58.8		
Cars	1413	709	97.3	96.8	2.08	2.03	+2.4	11.0	11.6
People	4881	4319	97.3	100.0	6.80	12.18	+79.1	29.3	75.9
Camped cars	193	194	71.6	83.9	0.35	0.54	+54.3	2.3	2.3
Camped people	343	346	70.3	83.9	0.63	0.97	+54.0	4.5	5.0
Dogs	89	67	56.8	74.2	0.15	0.19	+26.7	1.3	0.8
Horses	129	96	24.3	32.3	0.15	0.26	+73.3	1.4	2.0

Table 11.3. Results of Pre- and Post-MARPOL Annex V Debris Collections.

Item	Total (kg/km) Pre n=49	Total (kg/km) Post n=38	Freq. (%) Pre n=49	Freq. (%) Post n=38	Mean (kg/km) Pre n=49	Mean (kg/km) Post n=38	%Chng	High(kg/km) Pre n=49	High(kg/km) Post n=38
NATURAL VEGETATION							+320.4		
Seagrass	851.0	3635.7	83.7	73.7	17.37	95.68	+450.1	150.56	3427.60
Vegetation	278.3	1414.4	51.0	42.1	5.68	37.22	+555.3	144.20	1153.03
Sargassum	15836.6	43742.7	81.6	71.1	323.20	1151.12	+256.2	2640.10	8151.51
Hyacinth	423.1	7913.6	51.0	57.9	8.63	208.25	+2313.1	123.25	3757.17
ANIMAL							+422.7		
Physalia	108.4	78.1	16.3	21.1	2.21	2.05	-7.2	55.53	37.43
Cabbageheads	164.6	1136.8	8.2	42.1	3.36	29.91	+790.0	143.63	586.67
Mollusks	705.4	2752.3	81.6	86.8	14.40	72.43	+403.0	136.20	1314.40
MINERAL							+1024.0		
Rocks	122.0	1064.4	34.7	86.8	2.49	28.01	+1024.0	52.33	871.20
ANTHROPOGENIC							+132.8		
Plastic	838.2	682.4	98.0	89.5	17.11	17.96	+5.0	131.87	190.81
Styrofoam	69.4	55.1	81.6	23.7	1.42	1.45	+2.1	15.50	32.86
Aluminum	72.5	38.5	40.8	57.9	1.48	1.01	-31.8	23.93	14.40
Cig. butts	5.46	6.6	53.1	57.0	0.11	0.17	+54.5	1.10	1.70
Glass	58.4	140.7	26.5	44.7	1.19	3.70	+210.9	25.43	74.10
Cloth	10.3	45.1	4.1	13.2	0.21	1.19	+466.7	5.60	43.07
Paper	15.9	8.3	24.5	39.5	0.32	0.22	-31.2	5.40	1.80
Rope	63.2	206.3	49.0	60.5	1.29	5.43	+320.9	14.83	91.21
EITHER							+463.7		
Wood	1657.6	14631.7	81.6	52.6	33.83	385.04	+1038.2	929.47	5995.45
Tarballs	2000.2	1351.2	91.8	89.5	40.82	35.56	-12.9	722.43	588.63

Sargassum, to 25.1 kg of pre-MARPOL plastic pieces, to 200 g of cigarette butts.

Table 11.4 gives results of the bi-daily "Count of Five." Here the results support the 8-daily GARBGobs counts showing a decrease in milk jugs, egg cartons, and chemical containers, and an increase in green bottles. The beverage can index was not started until after MARPOL. Two things should be noted: (1) the overall result is an increase (Table 11.4A) in these items as a category, brought about by the post-MARPOL invasion of the green bottles; (2) when all 429 "Count of Five" observations are used (Table 11.4B), both decreases and the increase are less dramatic. This shows that if these changes can be directly attributed to MARPOL, the change in habits of those dumping materials overboard has been a slow one. In Table 11.2, except for the total counted column, the data are normalized to number.km^{-1}.

Finally, the newly initiated container survey results for plastic, glass, and aluminum (beverage cans only) are given in Table 11.5. There was an expected initial decline in numbers of containers collected (San Jose Island beach is not cleaned). The initial total volume was approximately 2,400 1.km^{-1} with plastic by far the largest container

Table 11.4. Results of Pre- and Post-MARPOL Annex V Count of Five Litter Counts.

(A) 1988 vs 1991 (Post-MARPOL years 1989 & 1990 omitted)

Item	Total Counted		Freq. (%)		Number/km		%Chng	High(#/km)	
	Pre n=90	Post n=92	Pre n=90	Post n=92	Pre n=90	Post n=92		Pre n=90	Post n=92
ANTHROPOGENIC							+6.1%		
Milk jugs	2417	1301	98.9	98.9	2.17	1.15	-45.2	23.68	20.35
Egg cartons	1286	586	95.6	76.1	1.15	0.52	-54.8	9.81	3.61
Green bottles	735	3275	87.8	75.0	0.66	2.88	+336.4	5.38	50.82
Pails	498	178	73.3	52.2	0.45	0.15	-66.7	6.24	1.67
Beverage cans	----	2455	----	97.8	----	2.18	-----	-----	9.96

(B) 1988 vs 1989 through 1991 (Includes all Post-MARPOL years)

Item	Total Counted		Freq. (%)		Number/km		%Chng	High(#/km)	
	Pre n=90	Post n=339	Pre n=90	Post n=339	Pre n=90	Post n=339		Pre n=90	Post n=339
ANTHROPOGENIC							+0.2%		
Milk jugs	2417	8340	98.9	94.7	2.17	1.99	-8.3	23.68	39.20
Egg cartons	1286	3171	95.6	83.8	1.15	0.76	-33.9	9.81	6.79
Green bottles	735	6255	87.8	79.1	0.66	1.49	+125.8	5.38	50.82
Pails	498	1030	73.3	56.3	0.45	0.25	-44.4	6.24	6.71
Beverage cans	----	6681	----	97.2	----	1.59	-----	-----	28.62

Table 11.5. Container Study by Volume and by Country.

	Containers by Volume (liters)			Containers by Country (Percent by number)								
				USA			Mexico			Foreign		
Month	PLAS	GLAS	ALUM	P	G	A	P	G	A	P	G	A
June	504	23	66	45	61	100	20	4	0	35	35	0
July	109	10	43	63	58	98	19	0	0	18	42	2
August	51	4	30	42	100	100	37	0	0	21	0	0
Sep	300	4	27	47	74	100	38	16	0	15	10	0
MEAN	241	10	42	49	73	100	29	3	0	22	22	1

material found. By country, the United States accounts for 49 percent of the plastic, 73 percent of the glass, and essentially 100 percent of the aluminum cans (including imported beverages of United States origin). For Mexico, the numbers are 29 percent, 3 percent, and 0 percent, and foreign countries they are 22 percent, 22 percent, and 1 percent. Many of the plastic containers have sea-turtle bites in them. Analysis of these and other data is in progress.

CONCLUSIONS

The initial conclusion of this survey is one of cautious optimism in the reductions observed in many of the anthropogenic items which have marred Texas beaches for many years. The degree that this improvement is due to the implementation of MARPOL Annex V cannot yet be determined. The final analysis of the data at the end of the project will hopefully shed more light on this.

ACKNOWLEDGEMENTS

Thanks are due to those who have assisted in the thankless task of counting, collecting, examining, and measuring beach debris; Pam Plotkin, Andi Wickham, Chuck Rowe, Cecilia Zankas, Paul Trefsa, and Judy Roberson. Acknowledgement is also due to Texas A&M University Sea Grant College Program, Interagency Contract IAC (86-87)1607 for support in the pre-MARPOL phase of this project. The present work is supported by U.S. Department of the Interior, Minerals Management Service, Contract #14-35-0001-30546. This is Contribution #91-003 of The University of Texas at Austin, Marine Science Institute.

Mr. Anthony F. Amos was born and educated in England. He has training and experience in electronics research and oceanic circulation with special interest in polar oceanography. He is presently a Research Associate at the University of Texas' Marine Science Institute at Port Aransas (UTMSI).

Mr. Amos is the local observer for the National Stranded Marine Mammal and Turtle Networks, official cooperative observer for the U.S. Weather Service, and he maintains the tide gauge at Aransas Pass. He has an interest in photography and ornithology. Mr. Amos writes a regular column on the beach environment for a local newspaper and is editor of UTMSI's Newsletter and the institution's brochure.

Mr. Amos has been studying marine debris along a 7 mile stretch of Mustang Island for 14 years and is currently under contract with Minerals Management Service to evaluate the effect of MARPOL on Mustang Island Beach.

INDUSTRY'S WASTE MANAGEMENT AND MONITORING PROGRAM

Mr. Bernie Herbert
Amoco Production Company
and
Mr. Rodney Foreman
ARCO Oil and Gas Company

INTRODUCTION

The Offshore Operators Committee (OOC) was formed over 40 years ago and is an organization representing over 70 companies who conduct all of the oil and gas exploration and production activities in the Gulf of Mexico. The OOC interacts with the various governmental agencies in implementing their respective functions.

Within the OOC is an ad hoc committee called the Environmental Waste Handling-Recycling Committee. Among its functions are:

- Review existing beach litter data and prepare an OOC report on the current status. Establish industry waste reduction goals which are based on historical data.
- Identify industry areas of improvement for waste reduction and apply recycling where it's feasible. The types of waste targeted are domestic garbage, chemical drums, packaging, and shipping materials.
- Provide industry-wide educational tools and support for the established policies.

- Become involved in the local communities by establishing recycling programs, preferably for oil company domestic recyclables such as motor oil, grease, and plastics.

HISTORICAL BEACH LITTER DATA REVIEW

Gulf of Mexico currents sweep marine debris away from the Florida coast and towards the Texas coast. South Padre Island recovers a large portion of the Gulf of Mexico's debris. Arco has performed several surveys from platforms located at West Cameron 205 and High Island 24L which show the western movement of marine debris with these sweeping Gulf of Mexico currents. These surveys show the eventual beach landing location is typically western, but it is also different depending on the time of the year. Figures 11.3 and 11.4 show the test results. This factor impacts the amount and source of beach litter deposited on a specific beach.

The only current published source of beach litter data is the Center for Marine Conservation (CMC). The CMC's historical records show that "Industry" contributes less than 5 percent of the volume recovered on the beach. The OOC believes their culpability is greater, and estimates it could have been 10-12 percent of historical beach trash loads. The CMC obtains its estimates from the annual National Beachsweep Day record cards. This event usually occurs in late September of each year. These data cards are completed by inexperienced participants, but the data is the best available to date. The weather, access to the beach, and the experience of the beachsweep participants can affect the data, making it difficult to use CMC'S historical records to quantitatively determine the impact of a specific industry on the beach litter problem. However, CMC's data is very useful in educating the public on the magnitude of the marine debris problem facing coastal communities.

There are several Federally funded routine sweeps in addition to two industry-routine sweeps which should begin improving the available data. These are typically performed by the same trained personnel, over a specified section of beach, and are performed frequently. These locations are shown on Figure 11.5. A thorough review of these Federal and industry routine beachsweeps should provide industry a more accurate benchmark. The initial results from these studies should be available in the near future.

The review of available data has provided insight into initiating an industry marine debris baseline. The OOC has identified several distinguishable oil and gas industry marine debris items which will assist in setting a historical benchmark. These items are buoys, shrink wrap, drums, pallets, spools, tires, seismic rings, pipe thread protectors, and hard hats. In addition to monitoring the source and number of industry items accumulating on beaches, a review of current OOC waste management policies provided insight into a second means of establishing an industry baseline. The results of this review showed that offshore waste management practices have received significant attention by offshore oil and gas operators.

- Three-fourths of the survey respondents reported using some form of advanced waste management practices such as recycling, sorting, or waste minimization.

- Transportation of materials in bulk is widespread.

- A majority utilize covered baskets for transporting solid waste.

- One-half have implemented a "no styrofoam" policy offshore.

- Over three-fourths stated they would be willing to accept a small increase in costs if reusable shipping materials replaced disposable containers.

Therefore, the OOC's solid nonhazardous waste reduction goals will be based on quantitative beach debris counts for the industry items listed above. The CMC data will continue to be a good qualitative source of the industry's marine debris impact. The data which soon will be available from the Federal and industry routine beachsweeps should provide a more quantitative estimate for benchmark purposes. The marine debris reduction goals will also be based on improving the percent of offshore operators adhering to waste management practices such as recycling, purchasing materials in bulk reusable containers, minimizing packaging, and "no styrofoam" policies.

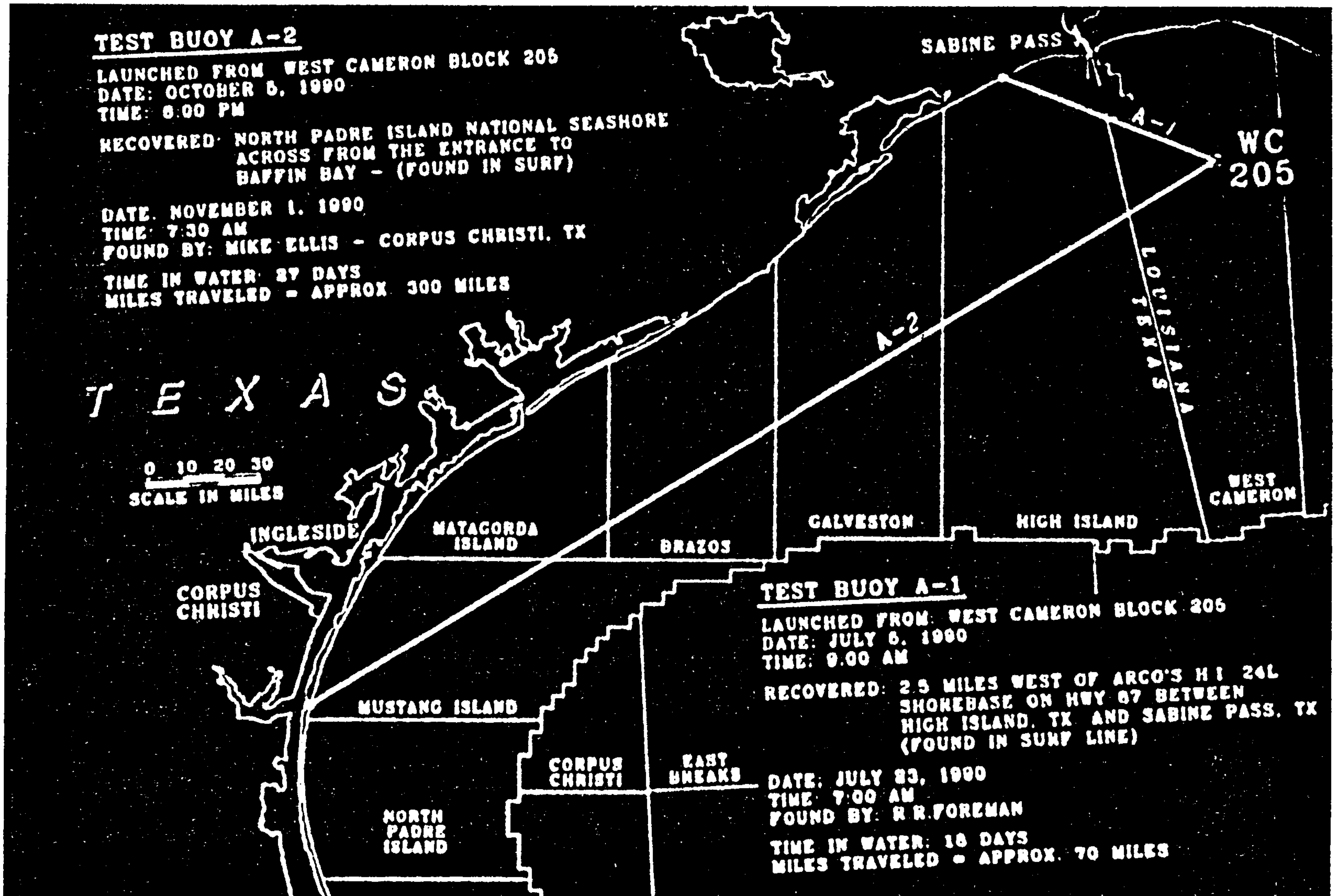

Figure 11.3. Drift buoy test from Federal Lease Block, West Cameron 205.

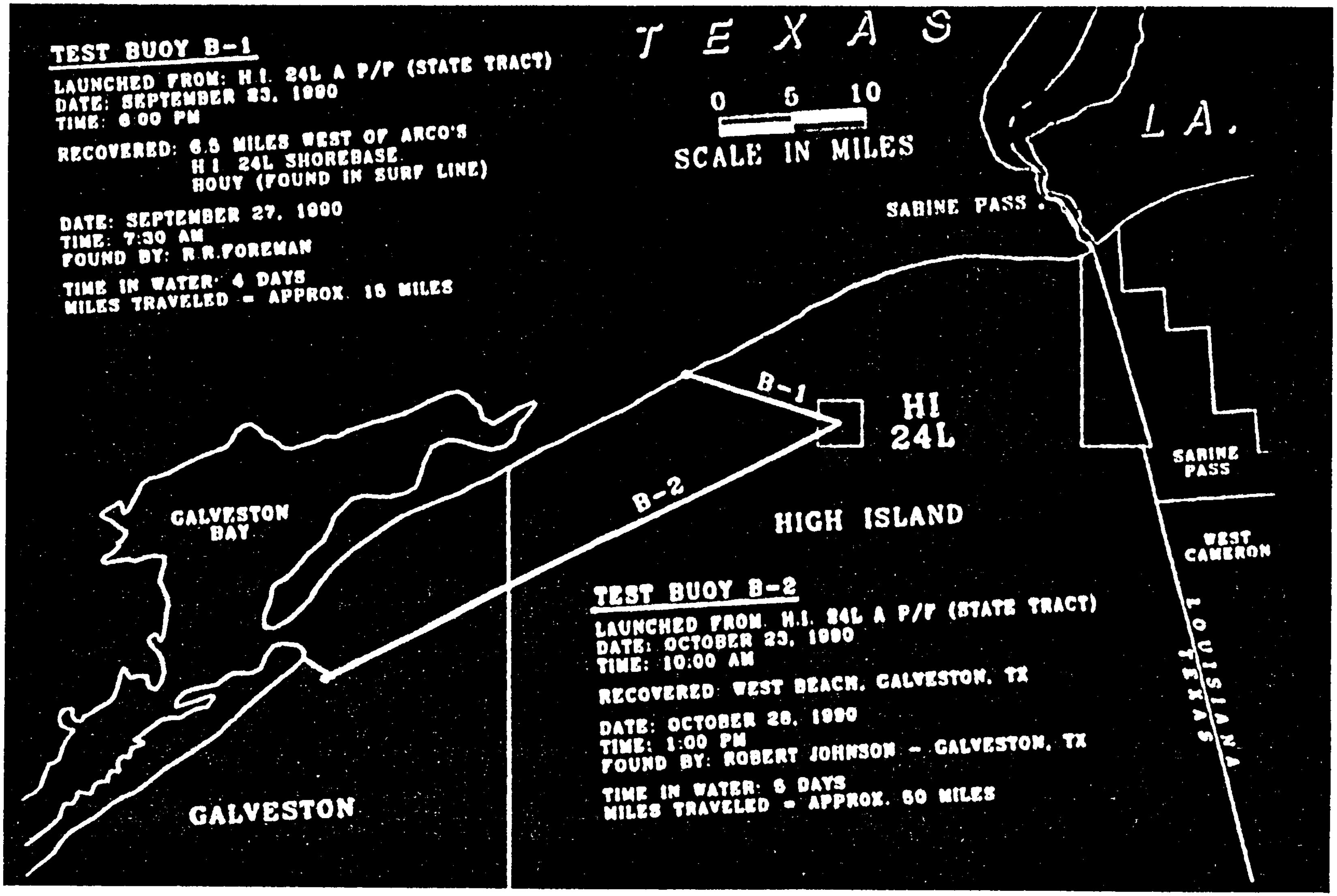

Figure 11.4. Drift buoy test from State Lease Block, High Island 24L.

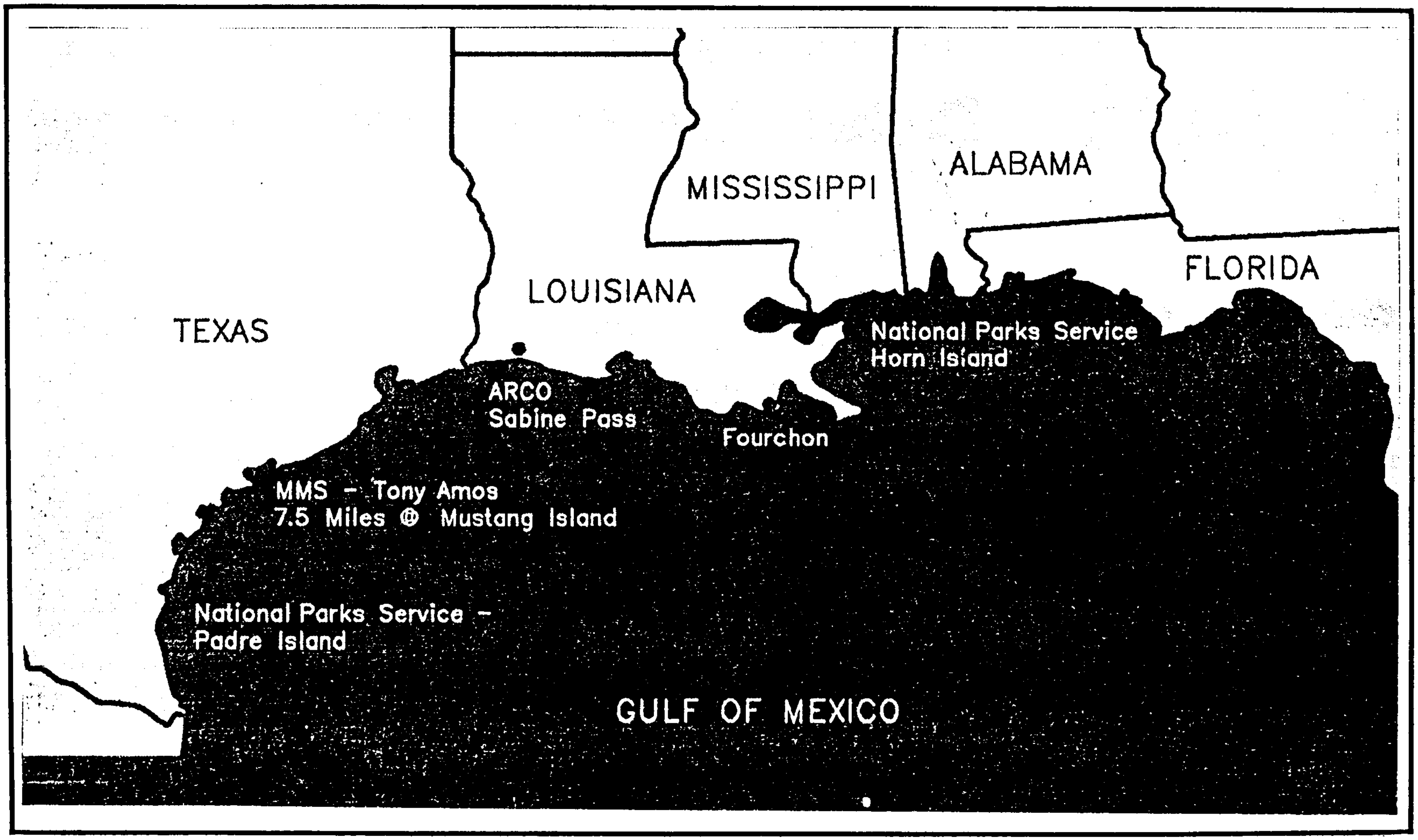

Figure 11.5. Federally funded and industry supported routine beachsweeps.

CONCLUSION

The OOC's plan to minimize the industry's marine debris is based on the strategies of monitoring, establishing sound waste management programs, and, finally, training. A comprehensive list of sound waste management practices is currently being developed and will be available in 1992. The OOC is also developing a training tape for use by our members to educate their offshore employees on proper waste management techniques. The OOC won the "Take Pride in America Award" in 1987 from the Minerals Management Service (MMS) and National Park Service for its "All Washed Up" video. This video is still being used to educate offshore personnel on the issues involved with marine debris. The OOC is proud of our historical commitment to reduce marine debris, but feels there continues to be room for improvement. The ad hoc Environmental Waste Handling-Recycling committee has set strategies and goals which should assure continued improvement.

ACKNOWLEDGEMENTS

The following companies, agencies, and organizations currently provide members to the OOC's Environmental Waste Handling-Recycling Committee:

Industry	Federal Agencies	Organizations
Chevron	MMS	OMSA
Exxon	Coast Guard	NOIA
Texaco	NPS	IADC
Arco		PESA
Amoco		
CNG		
Mobil		
Shell		
Conoco		
ODECO		
Koch		
British Petroleum		
Poole Co.		

Mr. Bernie Herbert received his B.S. in civil engineering (1977) from Mississippi State University. For the last 10 years he has been the Environmental Coordinator for Amoco Production Company. Mr. Herbert is also Chairman of the ad hoc Environmental Waste Handling-Recycling Committee, Offshore Operators Committee.

Mr. Rodney Foreman, ARCO Oil and Gas Company, has been a Safety Training and Environmental Coordinator for the last nine years. He is a member of the ad hoc Environmental Waste Handling-Recycling Committee, Offshore Operators Committee.

USE OF MARPOL ANNEX V RECEPTION FACILITIES AND DISPOSAL SYSTEMS AT SELECTED GULF OF MEXICO PORTS, PRIVATE TERMINALS, AND RECREATIONAL BOATING FACILITIES

Mr. Dewayne Hollin
Sea Grant College Program
Texas A&M University
and
Mr. Michael Liffmann
Louisiana Sea Grant College Program
Louisiana State University

INTRODUCTION

Annex V of the International Convention for the Prevention of Pollution from Ships, 1973 (MARPOL 73/78) entered into force on December 31, 1988. Simply stated, it calls for a change in the way shipboard wastes are disposed and managed. The Marine Plastics Pollution Research and Control Act (MPPRCA) of 1987 implemented MARPOL Annex V in the United States. The legislation prohibits the discharge of any plastics into the waters of the United States, and requires that every port, terminal, and marina maintain adequate waste reception facilities.

While Annex V and MPPRCA set requirements and restrictions, neither specified how compliance was to be attained. The approaches and techniques for handling waste aboard ship are left entirely up to the vessel owners/operators. The ports, terminals, and marinas were simply mandated to have "adequate" waste reception facilities.

Exactly how the implementation of such a far-reaching program will affect port and harbor operations in the Gulf of Mexico and the rest of the United States remains uncertain. Little guidance is given for shoreside handling and even less attention is given to the landside impacts that might result from the additional volume and nature of the materials.

These concerns prompted the Texas General Land Office and Texas and Louisiana Sea Grant College Programs to collaborate in a survey of selected public ports, terminals, and marinas located throughout the Gulf of Mexico region. The primary objectives of the study were to determine the garbage and other waste handling practices at the shoreside installations; the nature, costs, and adequacy of the existing facilities; the extent of use of the facilities and implications of the impending Special Area Designation for the Gulf of Mexico.

More that 70 telephone, written, and personal contacts were made during the months of August and September 1991, by the Principal Investigator, Mr. Dewayne Hollin of Texas A&M University and Associate Investigator, Mr. Michael Liffmann of Louisiana State University (LSU). Mr. Liffmann was assisted by Mr. Michael Andrepont, a law student at LSU. A total of 61 surveys was completed. Due to special handling procedures at some port facilities, the survey instrument had to be modified by a few respondents to clarify their data and requested information.

The 61 respondents included 46 public ports, private terminals, recreational boating and commercial fishing marinas, and offshore staging bases, as well as 15 public or private organizations that are involved in waste-handling/disposal activities.

FINDINGS AND CONCLUSIONS

The 61 survey respondents were categorized as follow:

22 international/coastwise trade public ports
7 private marine terminals
7 commercial fishing ports
6 recreational boating marinas
4 offshore staging bases
11 waste management operations
2 steamship agents/stevedores
2 USDA Animal and Plant Health Inspection Service (APHIS) offices

- Most international/coastwise shipping ports reported that only five to ten percent of the vessels calling at their installations each year have used APHIS-approved reception facilities since the program went into effect in 1989. The private terminals estimated the same figure to be closer to 10 percent.

- The same ports and terminals were asked to speculate why there was such a low utilization of the approved facilities:

  - 35% perceived that vessels still dumped at sea;
  - 25% believed that vessels might be offloading waste at other domestic or international ports;
  - 20% speculated that the cost of disposal services may be too high;
  - 20% thought that vessels had alternative on-board means of storing and/or disposing of waste

- There are indications, albeit only anecdotal, from the survey responses that the volume of general waste that is being brought ashore for land disposal is steadily increasing. This is particularly the case for recreational, commercial fishing, and offshore oil and gas operations. Most respondents attribute this to a growing awareness of the marine debris problem plus a concern for possible law violations and fines.

- The APHIS-approved incinerators are available through 20 of the 22 international/coastwise trade ports and three ports have autoclave systems.

- Eighteen of the 22 ports and five of the seven terminals contract with third parties to offload and dispose of ship-generated waste. The four remaining ports use a combination of port and third-party handling and disposal. In contrast, the seven commercial fishing ports and six recreational boating marinas manage the garbage that is placed in their general waste dumpsters, although they may contract with waste disposal firms. Of the four offshore petroleum staging operations interviewed, two contract with third parties and two handle their own waste.

- The predominant payment method does not involve the port authorities, as waste disposal agreements are negotiated directly between the waste handling firms and shipping agents. In the case of fishing operations and recreational marinas, the costs of disposal are absorbed and recovered through dockage charges.

- The charges for handling restricted or APHIS waste vary widely. Coastwise, they average $1 per pound which many operators feel is excessive, and in some instances prohibitive. Plastic-lined boxes with 38-pound capacity can be offloaded for costs ranging from $25 per box (BFI-Freeport) to $75 per box (BFI-New Orleans). A 14-gallon drum (100 pounds capacity) is incinerated in Freeport for $75. The autoclave systems charge from $100 per cubic yard (Reliable Disposal, New Orleans), if the waste is picked up in the immediate vicinity to $500 per cubic yard by the same firm if the waste is hauled to New Orleans from the Baton Rouge area.

- Charges for handling unrestricted waste vary to an even greater extent than the restricted type. They average approximately $10 per ton.

- There is no consensus among those interviewed as to whether a reduction in costs will result in a greater utilization of the reception facilities.

- Thirteen ports responded that they had received user-complaints regarding APHIS facilities and Annex V. The most common complaint is cost of services and not the adequacy or availability of facilities. The cost of shoreside disposal services, plus a desire to be in compliance with MARPOL Annex V, has prompted some vessel operators to add incinerators and other shipboard disposal methods on their vessels. Companies that provide waste disposal services complained that there was lack of enforcement of the regulations and that the U.S. Coast Guard should become more active to insure compliance.

- Twenty-nine of the 40 ports and terminals are of the opinion that Special Area Designation for the Gulf of Mexico will increase use of the reception facilities and the other 11 felt that there would be no change. In addition, 71 percent of those responding to this question said that they expected more competition among waste management firms as vessels began to offload more of their waste at their facilities.

Mr. Dewayne Hollin has been Marine Business Management Specialist for the Sea Grant College Program at Texas A&M University since 1972. He received both his BBA and MBA from University of Houston. He currently provides advisory services for marine-related businesses operating along the Texas Gulf Coast; plans and coordinates training programs and seminars in the areas of safety, business management and economics, marketing, environmental issues, recreational boating and commercial fishing; and conducts basic research on environmental issues, recreational boating, mariculture economics, marine industrial development, and commercial fishing industry safety.

Mr. Michael Liffmann has been the Assistant Director of the Louisiana Sea Grant College Program since 1985. In 1991, he was also made Coordinator of Sea Grant's Marine Advisory Services Program. His main area of interest is coastal economic development. He has been involved in several projects concerning marine pollution, coastal and marine recreation and tourism development, coastal business development, and ports and navigable waterways environmental issues. Mr. Liffmann received his B.A. from Lamar University in economics and his M.A. from Louisiana State University in regional and Latin American economics.

ONE COMPANY'S RESPONSE TO OFFSHORE WASTE MANAGEMENT

Mr. Dexter A Babin
Texaco Exploration & Producing, Inc.
and
Mr. Beau Toll
Innotec, Inc.

OBJECTIVES AND GOALS

As part of our Waste Management Program, Texaco expanded its offshore recycling efforts to reduce the amount of landfilled offshore waste by 50 percent. We became aware that the volume of solid waste handled by us was steadily increasing on a year-to-year basis. Figure 11.6 shows that we have had an approximate 25 percent increase in the total solid waste stream from 1989 - 1990. In fact, with no dramatic increase in personnel, drilling, or production activity, we have averaged a 25 percent compounded increase for each of the last five years (see Figure 11.7).

Texaco is committed to spending the time and money to make offshore recycling a part of its Waste Stream Management Program. Recycling makes good sense all around. It saves our resources and environment for current and future generations to enjoy; and it saves us money, too, by reducing waste management costs.

We manage the waste stream from an environmental point of view by setting specific goals:

- Generate less waste - Review purchasing practices to determine if alternative commodities can be obtained that have equal quality and value but that generate less waste after consumption. One example, we now purchase only 32 oz. refillable ketchup bottles instead of the smaller 16, 18, and 24 oz. nonreusable bottles. A 9-man platform generates 5-6 bottles of the 16 oz. size per week. By using the 32 oz. refillable, we eliminate 5 bottles per week per platform, or 4,800 bottles per year that we don't have to handle.

- Recycle as much generated waste as possible - Expand existing recycling efforts so that they become a cornerstone of a revised waste management program. We had been recycling some iron, oils, antifreeze, and other metals. This revised waste management program will only increase and improve on what we were already doing.

- Reduce the volume and cost of landfill waste - Investigate and implement methodology to reduce the volume and cost of waste disposal for those commodities that can not be recycled. This must be achieved in order to generate savings that can pay for recycling. During the last 20 years Louisiana has had a tremendous reduction in operating landfills. By the year 2000 Louisiana will only have nine operating landfills. The cost of disposal for one ton of solid waste is projected to be over $100/ton by the year 2000. It is extremely important to reduce the solid waste for those commodities that can't be recycled. Savings will be generated from:

  - labor - less handling
  - storage containers - fewer containers are needed shoreside since 60 percent of solid waste is recycled.
  - transportation
  - disposal cost - reducing the volume of waste generated by 60 percent will result in savings.

Objectives of the recycling program are:

- high employee participation rate;
- reduce solid waste stream by highest possible percentage;
- be applicable to any Texaco Facility; and
- educate Texaco employees on reasons for, how to, and the benefits of recycling.

The commodities to be recycled in this program are found on Figure 11.8.

METHODS

The implementation of Texaco's program involves methodology, education, performance standards, and related activities.

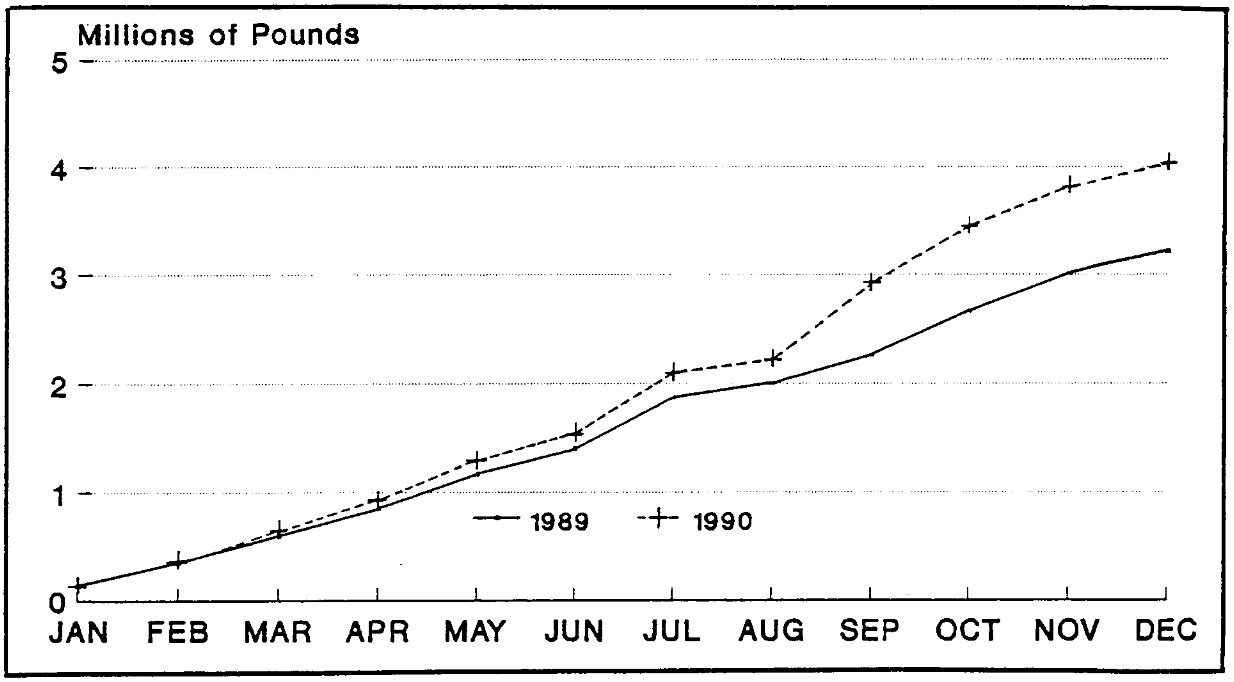

Figure 11.6. Cumulative yearly volume of non-hazardous waste excluding hazardous and oil field exempt.

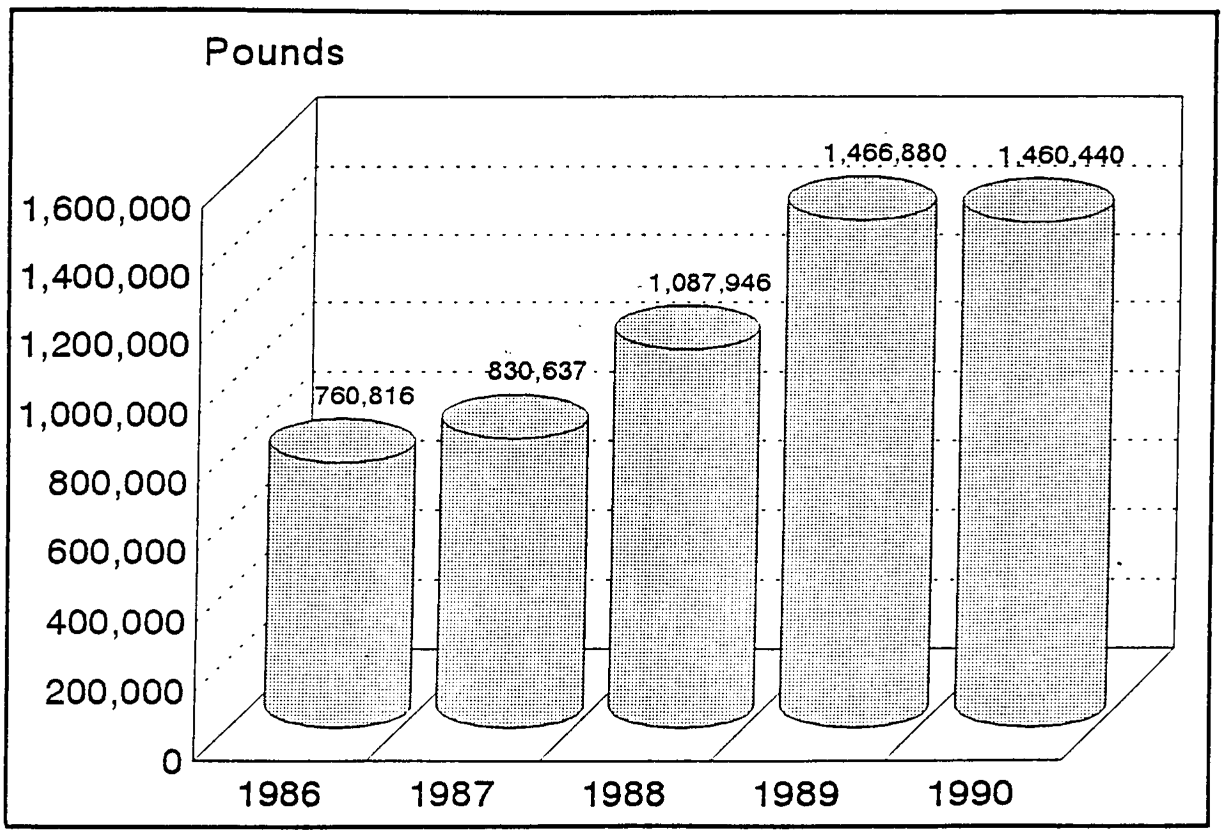

Figure 11.7. Yearly landfilled non-hazardous waste excluding oil field exempt.

	Paper Items	Plastics	METAL CANS	Glass
YES	* newspaper * corrugated cardboard * computer paper (any color and may contain lines) * file stock (white or colored paper any color ink) * white ledger (white bond, black ink)	Plastic soft drink bottles, milk jugs or any plastic continers with 1 2 3 on the bottom. 1 2 3 PETE HDPE PVC	Aluminum cans, tin cans, & bi-metal cans (which are a combination of metals.	Glass food and beverage containers of any color.
HOW & WHERE	Place in large recycling waste basket. No sorting of different paper grades is required.	Place in small wet recyclable container. Please remove lids and tops.	Place in small wet recyclable container. Should be reasonably clean and empty.	Place in small wet recyclabale container. Please remove lids and tops
NO	No: * Shiny magazines * junk mail * phone books * inter-office kraft envelopes * pre-printed paper or forms * plastic windows or attachments * coated, waxed or treated papers * carbon paper or carbonless copy paper * paper with rubber base glues	No: Plastic wrap or any plastic bottles that do not have the 1 2 3 symbol on the container.	No: Siding, aerosol cans or scrap metal.	No: * ceramics * drinking glasses * light bulbs * plate glass * mirrors * auto glass * crystal or other non-food or beverage containers * lids or tops

Figure 11.8. Texaco commodity recycling chart.

Methodology
(Separation, Collection, and Processing)

Separation: The only thing we ask our employees to do is decide if an item is recyclable or is it simply "trash". Once this is done you dispose of the item in the same manner as you have always done...into a waste basket receptacle. Texaco has minimized the impact recycling has on everyone's job. Taking lots of extra time to decide what to do with recycled waste isn't smart or effective. We require separation at the source of generation by the employee at his or her work station or living area.

Collection: In all living, recreation, and office spaces, two new containers are placed, one inside the other. In the large container, all paper products will be placed. In the smaller container, which contains a plastic bag liner, all glass, aluminum, plastic, and tin recyclables will be placed. These are what we call wet recyclables. The galley area will generate the majority of the recyclables. The galley stewards will collect all recycling containers daily from the living quarters and galley, and sort the recyclables into the compactor compartment or storage container.

Storage containers for the platforms and rigs:

- Unmanned platform - three 95 gallon storage containers. One container will accept tin and aluminum cans, recyclable plastic, and glass. The second container will be used for all recyclable papers. The last container will contain all of the real trash that can not be recycled.

- Manned platform, nine or less workers - seven 95 gallon storage containers. One each of the 95 gallon containers are used for aluminum cans and containers, tin cans, and recyclable papers. Three of the 95 gallon containers are divided into two compartments with separate collection bags in each half of the container. One container will hold brown glass on one side and green glass on the other. Another container will hold clear glass on one side and unknown plastics on the other. The last will have PETE and HDPE in the two separate bags. The non-recycling container will contain the normal trash.

- Manned platform or rig, 10 or more workers – compactor plus two 95 gallon storage containers. There are three models of the compactor that Texaco uses:

  - a six compartment
  - a six plus one
  - a six plus two

The term "six" plus one or two means that the compactors have either one or two larger 15 cubic foot compartments for bulkier items, in addition to the standard six 5 cubic foot compartments (see Figure 11.9 for an overview of the 6 + 2 compactor).

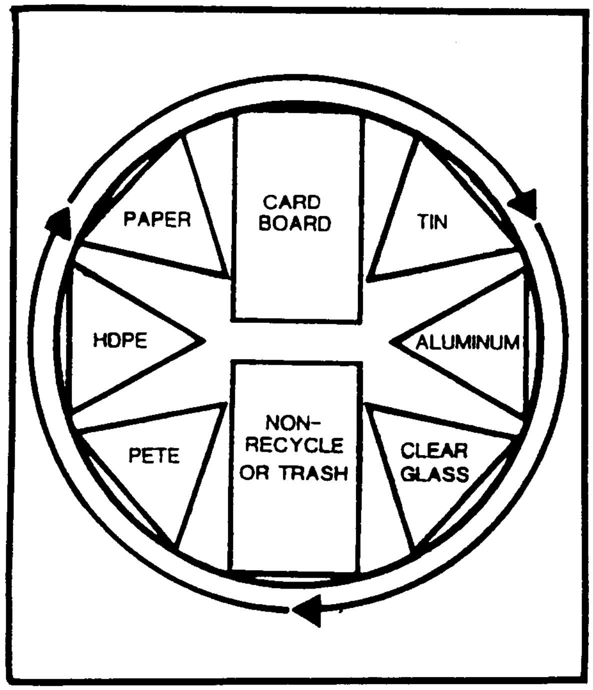

Figure 11.9. Texaco's 6 + 2 compactor.

In the first 95 gallon container you will have two bags, one in each half of the container, each holding brown or green glass. In the second container you will again have two compartments with one for PVC and unknown plastics and the other for cardboard. If a platform does not have a compactor, in many cases recyclables are shipped to a nearby "command platform" for compacting.

Processing: Why do we use recycling compactors?

- You can only recycle waste that is separated by material type. Example - glass must be separated by color; clear/brown/green.
- Once products are separated by commodity and material, the space requirements to keep them separate increases beyond the capability of most platforms and rigs.
- Compaction of recyclables reduces the number of storage containers required and the associated labor to handle.
- Compaction reduces the amount of transportation necessary between points of generation and shore bases, and between shore storage points and end buyers of recyclables.

Education

One on one training classes on why, how, and what to recycle is given to all employees prior to the start of the program. This is followed by a written brochure which contains Texaco's recycling policy and instructions on how to comply with the program. We produced a training film to give our foreman the tools necessary to ensure that all personnel under their supervision are in compliance with the program.

Performance Standards

All recyclables and trash are periodically checked to see if a particular platform is in compliance with the program. Allow a platform to dispose of by mistake five containers or papers. Also, quarterly visits are made at each platform and rig to ensure compliance by all Texaco personnel and contractors.

Related Activities

We are reviewing our purchasing practices to keep consistent with recycling goals. We buy in bulk in lieu of smaller containers to reduce packaging. To illustrate this point, we are now using reusable plastic containers and ice chests in lieu of cardboard boxes for groceries and supplies. This will significantly reduce the amount of cardboard waste being generated.

RESULTS

National Standards	Texaco Results
Only 60% of office workers will participate in a recycling program.	98%
A successful recycling program reduces waste by 25-30%.	66% reduction in solid waste stream

Figure 11.10 reflects the comparison of recycled waste versus landfilled waste through September 1991. Figure 11.11 shows the 1991 commodities by shipment. Figure 11.12 shows the recycling percentages compared to the total yearly solid waste volumes. Figure 11.13 shows the comparison of cumulative recycled versus landfilled waste through September 1991. Figure 11.14 shows the 1991 solid waste stream.

SUMMARY

What Happens Next?

- Home programs: Many of our employees do not have recycling programs in the communities in which they live, but are very interested in recycling. We invite them to bring their recyclables from home and drop them off in containers located at the shore base.
- Expansion into other projects.
- Take it to the public: Show industry groups and community service groups what Texaco has accomplished.
- Recycling programs sponsored by Texaco: Schools, shopping centers, etc.

Future Project Objective

- Recycling
  - Continue to monitor recycling performance monthly and report to all personnel using graphs, charts, and posters.
  - Continue to monitor the market for recyclable commodities and add new ones

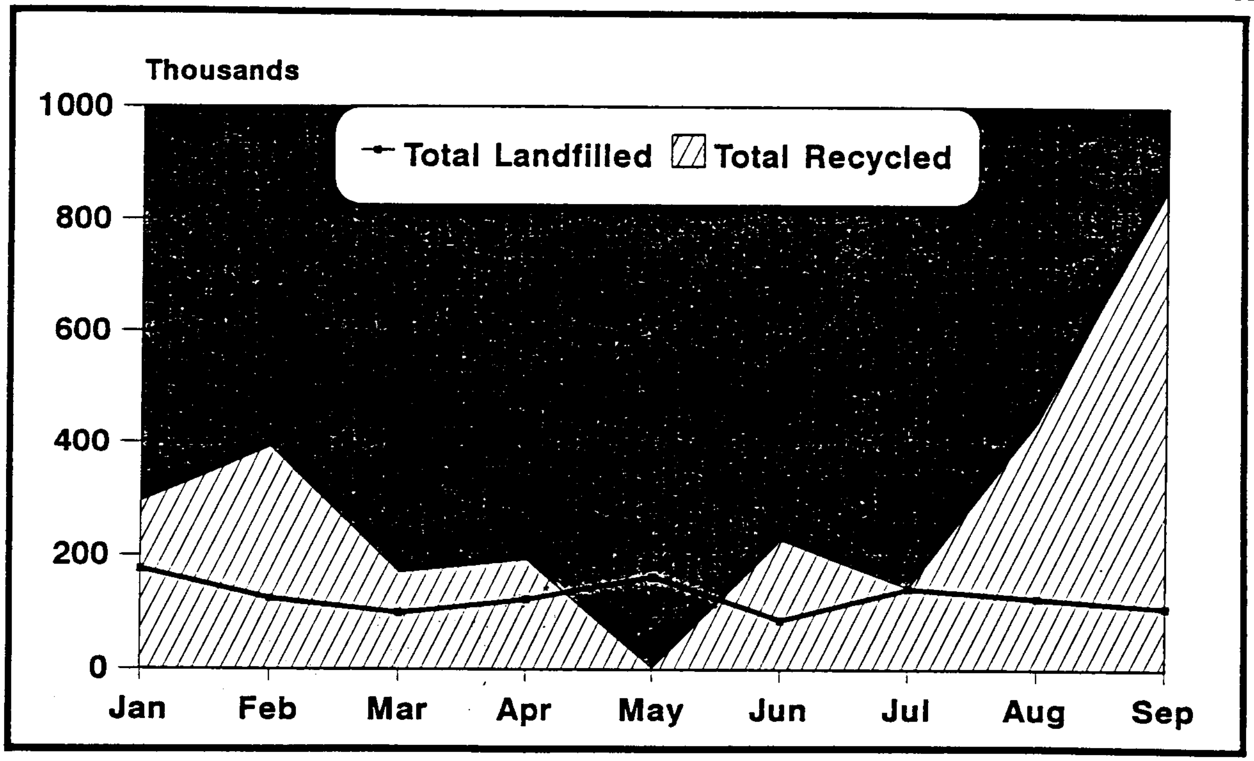

Figure 11.10. 1991 total non-hazardous waste stream comparison of recycled vs. landfilled.

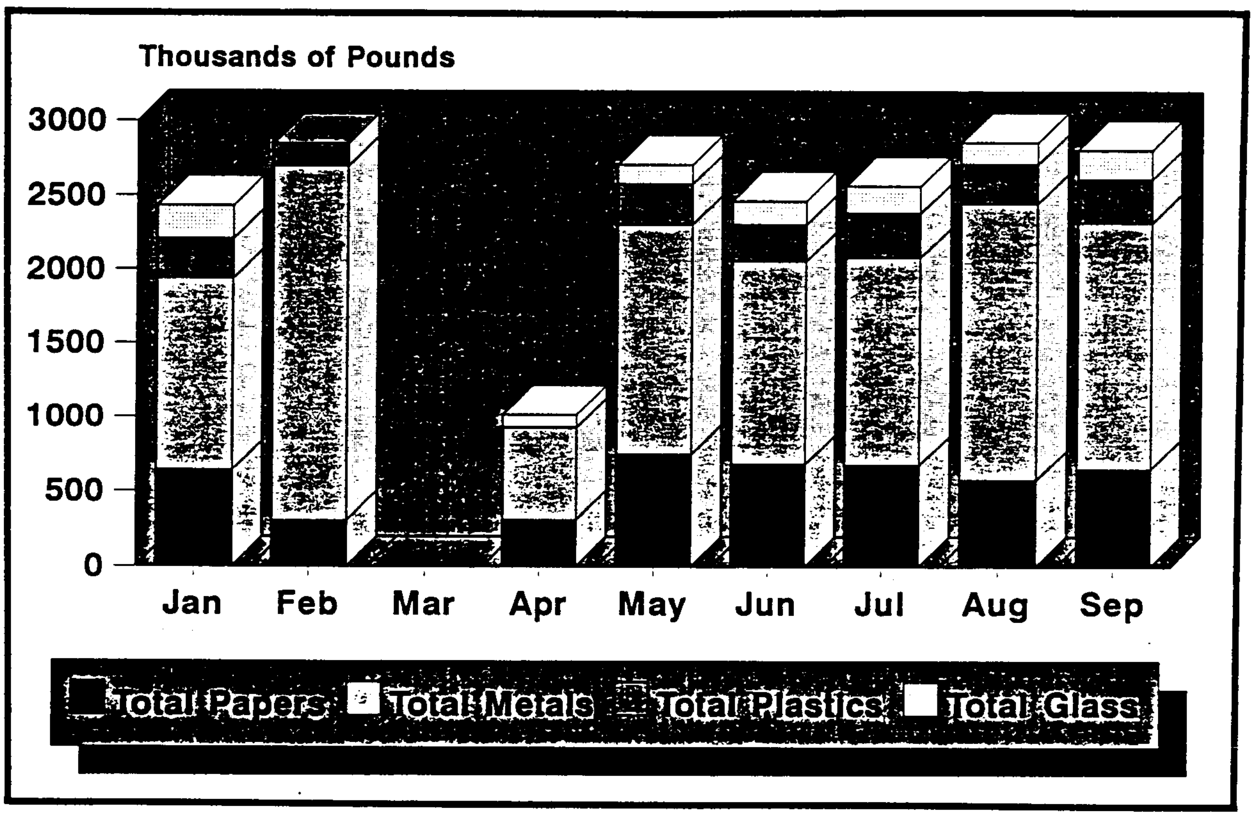

Figure 11.11. 1991 recycling commodities by shipment excludes bulk iron recycling.

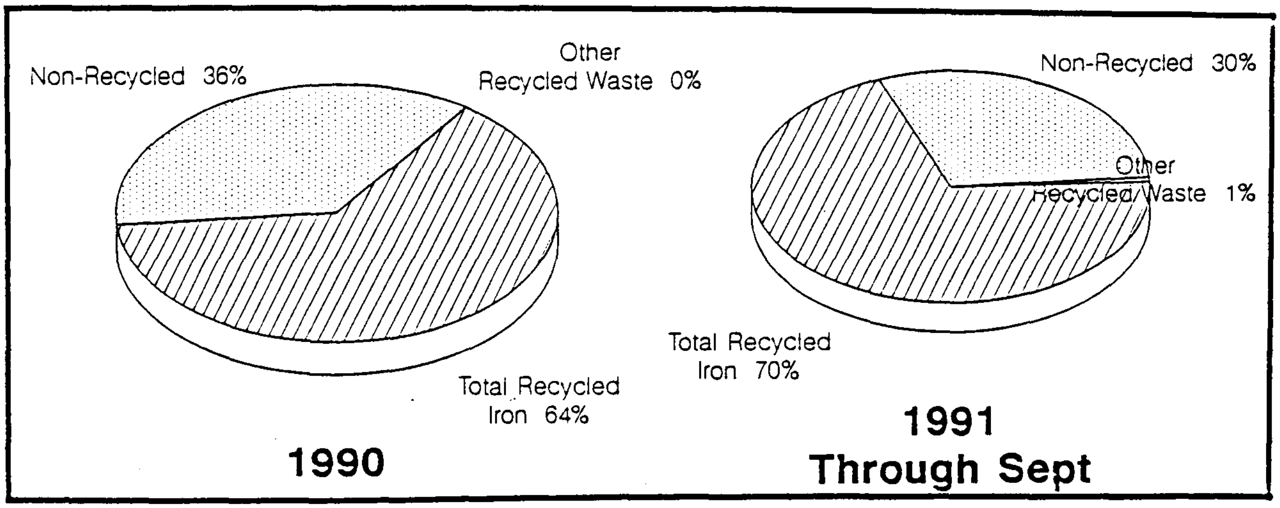

Figure 11.12. Recycling percentages compared to total yearly non-hazardous waste volumes.

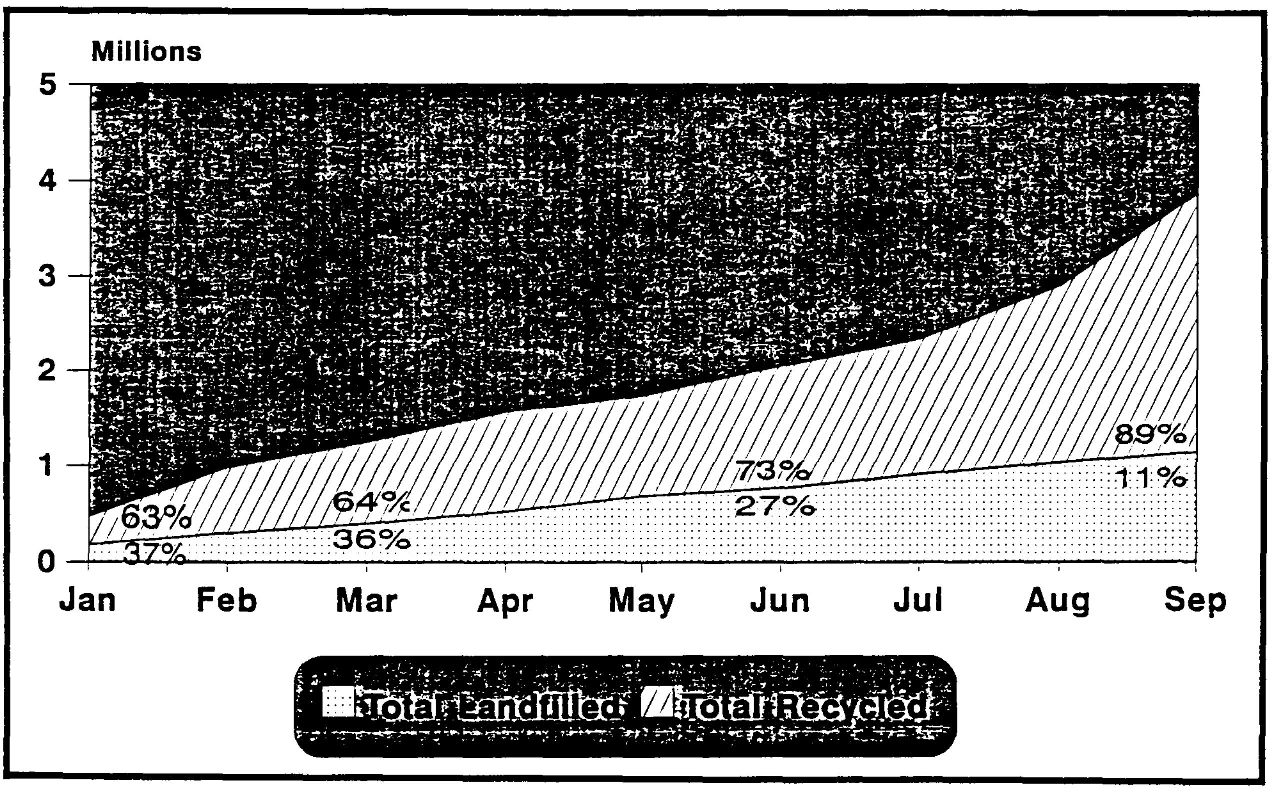

Figure 11.13. 1991 total non-hazardous waste stream comparison of cumulative recycled vs. landfilled.

	1991											
	Landfilled Waste		Iron Recycling		All Other Recycling						Total Non-Hazardous Waste	
Months	Number of Loads	Total Pounds	Number of Loads	Total Pounds	Number of Loads	Total Pounds Paper	Total Pounds Metal	Total Pounds Glass	Total Pounds Plastic	Total All Other Recycled	Number of Loads	Total Pounds
January	19	175,560	12	292,512	1	642	1,297	224	270	2,433	32	470,505
February	16	123,800	16	388,916	1	307	2,391	0	151	2,849	33	515,565
March	12	99,120	7	171,138	0	5,590	0	0	0	5,590	19	275,848
April	16	122,440	8	192,764	1	311	619	85	0	1,015	25	316,219
May	17	162,632		0	1	750	1,556	129	274	2,709	18	165,341
June	13	86,120	9	226,240	1	683	1,375	157	250	2,465	23	314,825
July	18	141,840	6	141,120	1	676	1,407	182	302	2,567	25	285,527
August	15	124,440	18	436,800	1	579	1,872	144	267	2,862	34	564,102
September	12	108,480	35	851,200	1	651	1,668	196	296	2,811	48	962,491
October												
November				0		0	0	0	0	0	0	0
December				0		0	0	0	0	0	0	0
Totals	138	1,144,432	111	2,700,690	8	10,189	12,185	1,117	1,810	25,301	257	3,870,423

Figure 11.14. 1991 solid waste stream disposal.

to the program that become economically viable.

- Generate Less Waste
  - Continue to review purchasing practices to buy in bulk to reduce the quantity of solid waste packaging.

  - Eliminate consumables that can be replaced with non-generating items.

- Reduce Ultimate Disposal Costs
  - Investigate additional processes to identify the existing solid waste stream thus reducing its volume and associated handling, storage, transportation, and disposal costs.

  - Further process the existing solid waste in order to change the classification of this waste to a lower grade thus reducing its disposal costs.

Texaco is committed to protecting our Nation's limited resources and leading our community in developing programs which reduce the impact we have on our environment. Recycling gives each of us a chance to be a part of one of the solutions to our country's waste disposal problems. WE CAN MAKE A DIFFERENCE!

Mr. Dexter Babin has been employed at Texaco E&P, Inc. for the past 18 years. He presently serves as Advanced Materials Coordinator for the Offshore Division Materials Department. His area of responsibility includes all phases of transportation and waste management. Mr. Babin has 11 years experience in handling waste management issues and problems. He attended Nicholls State University where he studied marketing.

Mr. Beau Toll is President and owner of Innotec, Inc. - an environment consulting company. His current area of interest is offshore recycling. Mr. Toll received his B.S. in aviation engineering technology from Western Michigan University.

RESEARCH PLANS BY PRINCIPAL INVESTIGATORS: "TEXAS-LOUISIANA SHELF CIRCULATION AND TRANSPORT PROCESSES STUDY"

Session: RESEARCH PLANS BY PRINCIPAL INVESTIGATORS: "TEXAS-LOUISIANA SHELF CIRCULATION AND TRANSPORT PROCESSES STUDY"

Co-Chairs: Dr Murray Brown
Dr. Worth D. Nowlin, Jr.

Date: November 6, 1991

Presentation	Author/Affiliation
Research Plans by Principal Investigators: "Texas-Louisiana Shelf Circulation and Transport Processes Study": Session Introduction	Dr. Murray Brown Minerals Management Service Gulf of Mexico OCS Region and Dr. Worth D. Nowlin, Jr. Texas A&M University
A Preview of the Minerals Management Service Ocean Modeling Program in the Gulf of Mexico with Emphasis on the LATEX Area	Ms. Terri Paluszkiewicz and Dr. Walter Johnson Minerals Management Service Environmental Policy and Programs Division
An Overview of the Texas-Louisiana Shelf Physical Oceanography Study	Dr. Worth D. Nowlin, Jr. Texas A&M University
Critical Shelf Phenomena and Processes	Prof. Robert O. Reid Department of Oceanography Texas A&M University
A Study of Extratropical Cyclogenesis Events Along the Mid and Outer Texas-Louisiana Shelf	Dr. S. A. Hsu Coastal Studies Institute Louisiana State University
A Shelfwide Program of Direct Current Measurements: Moorings, Drifters, and Shipboard Acoustic Doppler Current Profiles	Mr. Robert C. Hamilton Evans-Hamilton, Inc.
A Program of Standard Grid Hydrography for the Texas-Louisiana Shelf	Dr. Denis A. Wiesenburg Texas A&M University
Critical Aspects of Information and Data Management for LATEX A	Dr. Norman L. Guinasso, Jr. Texas A&M University

RESEARCH PLANS BY PRINCIPAL INVESTIGATORS: "TEXAS-LOUISIANA SHELF CIRCULATION AND TRANSPORT PROCESSES STUDY": SESSION INTRODUCTION

Dr. Murray Brown
Minerals Management Service
Gulf of Mexico OCS Region
and
Dr. Worth D. Nowlin, Jr.
Texas A&M University

The Minerals Management Service is pleased to announce that the "Texas-Louisiana Shelf Physical Oceanography Program" (LATEX Program) has been initiated. The LATEX contracts will provide a complex, multidisciplinary research program, lasting from October 1991 to October 1996, with a period of field measurements lasting from May 1992 to May 1995. The study includes a large array of current meter moorings, hydrographic and chemical pollutant surveys, drifting buoys deployments, aerial probe deployments, satellite observations, and related biological and nutrient analyses.

This session is the first of three sessions devoted to descriptions by the principal investigators of their plans for the field work, the analyses, and the information management activities required by the individual contracts. This is Part A, the LATEX Shelf Circulation and Transport Processes Study. This information is being provided both to inform the public of the scope of the work, and to assist coordinating program managers in forming their plans for collateral use of the data which will be shared throughout the Gulf of Mexico marine science community.

Dr. Murray Brown received a B.S. in chemistry from Duke University in 1969, and a Licentiatus Scientiarum (Ph.D.) in marine chemistry from the Institute of Physical Oceanography of the University of Copenhagen in 1975. He manages physical oceanography studies in the Gulf of Mexico for the Minerals Management Service, as well as air quality studies and information management projects.

Dr. Worth D. Nowlin, Jr. studied at Southern Methodist University, the Georg August Universitat in Goettingen, and received his Ph.D. in oceanography from Texas A&M University in 1966, where he is a Distinguished Professor. He has worked for the Office of Naval Research and the National Science Foundation, and been a visiting scientist at Scripps Institution of Oceanography, the Woods Hole Oceanographic Institution, the Oregon State University, and the Institute fur Meereskunde of the University of Kiel. His major research programs have concentrated on the circulation of the Gulf of Mexico and Caribbean Sea, the description and physics of the Antarctic Circumpolar Current, and the interaction of the Southern Ocean with the world ocean.

A PREVIEW OF THE MINERALS MANAGEMENT SERVICE OCEAN MODELING PROGRAM IN THE GULF OF MEXICO WITH EMPHASIS ON THE LATEX AREA

Ms. Terri Paluszkiewicz
and
Dr. Walter Johnson
Minerals Management Service
Environmental Policy and Programs Division

INTRODUCTION

The Minerals Management Service (MMS) is sponsoring research to improve the modeling methods used for risk assessment. Research initiatives were identified in the Offshore Oil Spill Movement and Risk Assessment workshop held by MMS in November 1990. This workshop discussed methods of using models together with Lagrangian and Eulerian observations to improve risk assessment. The recommendations of the workshop were as follows:

- The MMS should develop dynamically-based coastal ocean models that extend sparse databases to generate near-surface particle trajectories.

- The MMS should develop statistical models, based on advection and diffusion and used in conjunction with observations, to give probability density functions of particle position.

These models should also:

- resolve the upper ocean and include an appropriate dynamical or statistical representation of the eddy variability and particle dispersion;

- include the processes and features observed on the Gulf of Mexico shelf; and

- be well validated and documented.

The objective of this modeling research initiative is to develop deterministic and statistical coastal ocean models that provide information on near-surface particle trajectories. An essential feature of this research initiative is the joint use of models and observations. While the overall area of application is the continental shelves and slopes of the Gulf of Mexico, particular attention is being given to the northern Gulf of Mexico to take advantage of the extensive data set being collected in the MMS-funded Texas-Louisiana Shelf (LATEX) field program. The modeling program includes the entire Gulf of Mexico shelf and basin. The recently awarded study features the development of a dynamical coastal ocean model and a statistical model based on observations.

These coastal ocean models are being developed systematically by incorporating, in logical steps, improved statistical and dynamical understanding of the circulation. The modeling program will attempt to coordinate and share information with the LATEX program investigators to help provide the statistical and dynamical understanding that will help guide development of the models.

The model research program has the following supporting tasks and objectives:

- the joint use of observations and modeling to further develop the dynamical and statistical models,

- a systematic exploration of processes and features on the Gulf of Mexico shelf through modeling and model-observation comparisons,

- an appropriate dynamical or statistical representation of the eddy variability and particle dispersion in the upper ocean,

- the validation of the models through a systematic and scientific evaluation using ocean observations, and

- the documentation and dissemination of the results and procedures through publication in the juried literature.

THE COASTAL OCEAN MODELING RESEARCH PROGRAM

The MMS announced the opportunity to work on these research initiatives through a Broad Agency Announcement. Subsequently, contracts were awarded to Dynalysis of Princeton and subcontractors for the development, application, and validation of a deterministic model and a statistical model to be applied to the Gulf of Mexico with emphasis on the LATEX study area. A contract was awarded also to Dr. Sidney Leibovich of Environmental Sciences of Ithaca to study the distribution and movement of oil at the sea surface with particular emphasis on the role of Langmuir circulations.

A primary component of the Gulf of Mexico modeling program is the interaction, through joint meetings and data sharing, with the LATEX program. The sharing of experience and intuition between scientists involved in the field program and the modelers would result in substantial benefits. In addition to intellectual exchange, the coordination between the field and modeling programs will facilitate a data exchange. The process studies conducted in the field can be used to gauge the skill and help interpret the dynamics tested in the modeling process studies. Ultimately, the conclusions of these types of comparison will be used to critically evaluate the model physics. Observations from the LATEX study, as well as past sources of observations in the Gulf of Mexico, would be used to evaluate the simulations from the deterministic model. These observations will also serve to feed the statistical model. Coordination and planning between the investigators and the steering panel will help identify the data sets that can be used to formulate, constrain, or force the model, versus those that can be used to assess the physics and the validity of the simulations.

SCOPE OF THE GULF OF MEXICO MODELING PROGRAM

The following major tasks are part of the Gulf of Mexico modeling program:

- process studies,
- deterministic modeling,
- statistical modeling, and
- skill assessment.

There are many sub-tasks that support the approach to these major components and that will contribute to the process studies and deterministic and statistical modeling work.

- data assimilation,
- improvement and enhancement of the surface physics in the model,
- interactions with LATEX, and
- support of the data management group.

The circulation and mixing on the Gulf of Mexico shelf are influenced by the following processes:

- buoyancy forcing from the Mississippi River plume;
- atmospheric forcing, cold fronts, hurricanes; and
- Loop Current eddy intrusions, coastal-trapped waves, and others.

The modeling group will look to the observationalists for advice and insight in selecting these representative scenarios. The model will be run to simulate these processes. Both modelers and observationalists will evaluate the performance of the model and interpret the model simulations in terms of the physics of the circulation.

The deterministic circulation model will be based on the Princeton/Dynalysis Eddy-Resolving Circulation Model. The domain will encompass the entire Gulf of Mexico, although emphasis will be given to the shelf region. Supporting components of this task include:

- data assimilation,
- enhanced surface physics, and
- interaction with the LATEX component.

Through this study, all components and tasks will interact. The information gained from the process studies will feed back to improve the deterministic model. The deterministic model will go through a period of sensitivity studies and initial simulations to refine the model and incorporate enhancements. Skill assessment will proceed from the initiation of the modeling work and will constantly be giving feedback to make further refinements and enhancements of the deterministic model. The ultimate goal will be to produce statistically representative circulation fields that will be used in conjunction with the statistical model to produce particle trajectories.

A statistical model is being developed that will be able to predict the statistical behavior of an oil spill as a function of source location and time release. The model will be constructed using available Lagrangian drifter data, as well as other observations and data sets such as satellite imagery. Observations will be used for the following reasons: (1) to characterize the natural variance levels, length and time scales (Eularian and Lagrangian); (2) to tune the numerical model to these characterizations; and (3) to develop space and time dense fields from the tuned numerical model. These corrected, or constrained fields will then be used in a particle trajectory model.

The skill assessment of the modeling will continue throughout the research program. The interaction with the LATEX program in this component is clear. Data and the analysis of the observations from the LATEX program will be used throughout the program to accomplish the following goals: (1) to evaluate and enhance the model physics, (2) to evaluate the skill of the simulations, and (3) to serve as a test case of the model.

In early stages, the skill assessment team will evaluate the candidate data sets to determine relevant spatial and temporal scales in coordination with the process studies team and the statistical modeling team. During the model evaluation, the skill assessment team will evaluate the sensitivity studies to help formulate the model. They will provide the statistical analysis of the long-term model simulations against observational records and will work on evaluating the process studies and the statistics of the "event" scale simulations. It is anticipated that this component will be performed with close cooperation and coordination with the similar component of the LATEX program. The shared expertise of the observationalists and modelers should contribute to form one of the strongest skill assessment programs to date.

The distribution of the tasks among the key personnel is displayed in Figure 12.1. Dr. Larry Atkinson has been designated as the LATEX liaison and will serve as a key contact, in addition to the Dynalysis team of Dr. Herring and Dr. Patchen, for coordination of the two programs. The model will encompass the entire Gulf of Mexico, but emphasis will be placed on the shelf and LATEX region.

DISTRIBUTION AND MOVEMENT
OF OIL AT THE SEA SURFACE

As part of the coastal ocean modeling program, Dr. Sidney Leibovich of Environmental Sciences of Ithaca received a contract to study and model the distribution and movement of oil in the near-surface region of the oceans. This study will concentrate on oil movement, both surface and subsurface, that is attributable to wind effects. The study will put particular emphasis on the important phenomenon of Langmuir circulations (LC). In this program, the role of windrows will be investigated with the specific intent to clarify the effect of this upper ocean phenomenon on the distribution of oil on and below the sea surface, and the effects windrows have on the movement of surface and subsurface oil. The approach will be to simplify the full Craik-Leibovich model of LC by approximating the full nonlinear partial differential equations with an amplitude equation. The result, a single nonlinear partial differential equation, gives the time evolution and horizontal pattern of convection. This simplification will enable the theoretical development of the upper layer ocean response to given wind stress, sea state, eddy viscosity (reflecting small-scale incoherent turbulence), and mixed layer thickness. The primary input to the model will be the wind field. As the program proceeds, interaction with the LATEX program is expected to contribute field data, such as stratification, wind and wave fields, to application of the model in the LATEX region.

Ms. Terri Paluszkiewicz joined the MMS Branch of Environmental Modeling in October 1987. Prior to that, she worked in physical oceanography at Oregon State University. Her expertise is in coastal oceanography, including equatorial oceanography, buoyancy driven flows, and numerical modeling. Ms. Paluszkiewicz received her M.S. at the University of Alaska in physical oceanography and expects to complete her doctorate at the University of Maryland in the near future.

Dr. Walter Johnson joined the MMS Branch of Environmental Modeling in July 1989. Prior to that, he was a faculty member at the Institute of Marine Sciences, University of Alaska, Fairbanks. His expertise is in the fields of coastal oceanography, including wind-driven and buoyancy-driven flows and numerical modeling. Dr. Johnson received his B.S. in physics and his M.S. in marine studies from the University of Delaware.

AN OVERVIEW OF THE TEXAS-LOUISIANA SHELF PHYSICAL OCEANOGRAPHY STUDY

Dr. Worth D. Nowlin, Jr.
Texas A&M University

INTRODUCTION

The purpose of this presentation is to provide an overview of the research plans for Part A of the Texas-Louisiana Shelf Physical Oceanography Study: LATEX A.

The contract for LATEX A was awarded by the Minerals Management Service (MMS) of the Department of the Interior to the Texas A&M University System, a combination of institutions of higher learning and state agencies dedicated to training, research, and extension. In addition to the support from the MMS, financial backing for the work is being made available from the Texas Institute of Oceanography, the Texas Engineering Experiment Station, and the Texas A&M University (TAMU), all components of the System. We in the TAMU System will be assisted in this program by

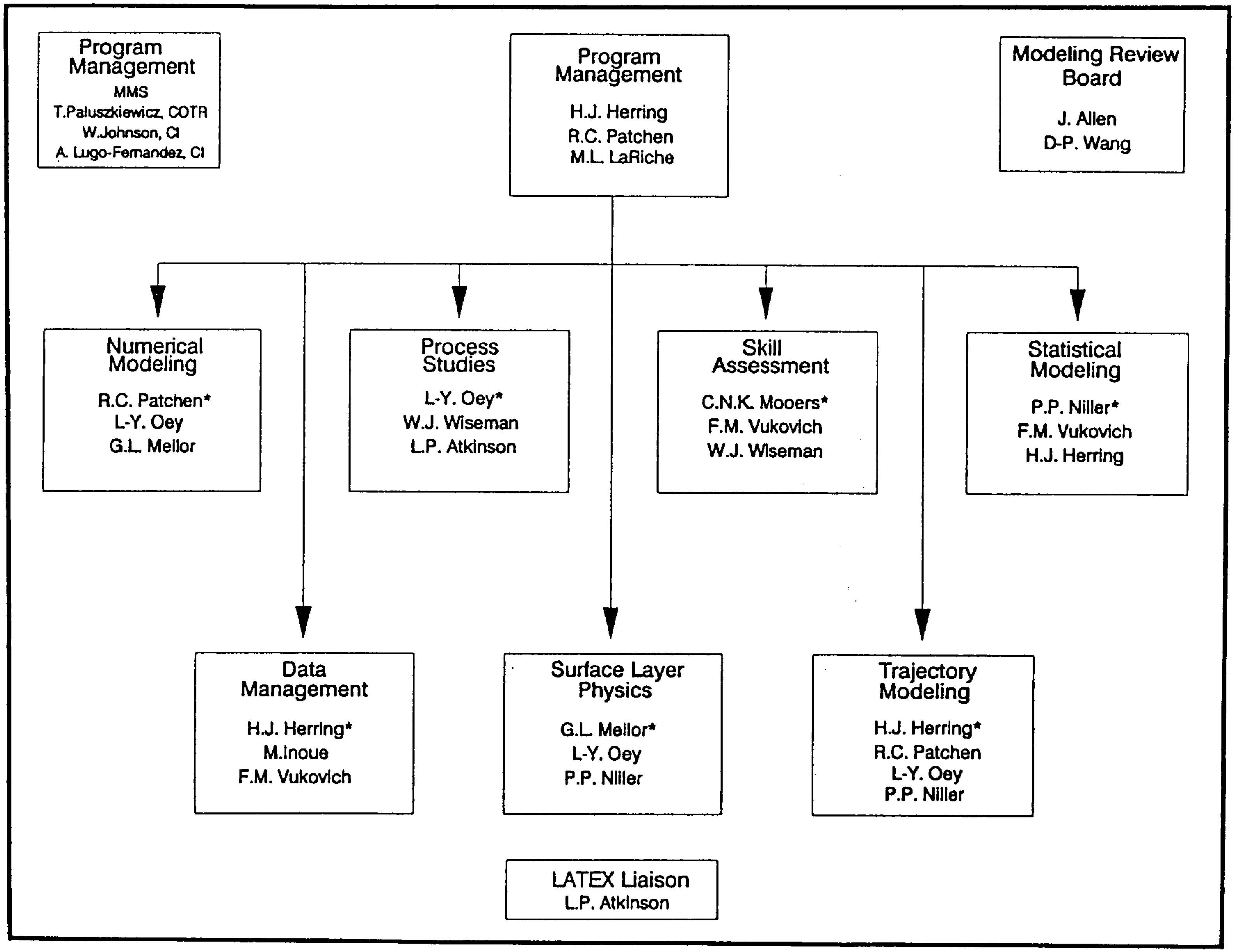

Figure 12.1. Organizational Chart for Gulf of Mexico Coastal Ocean Model.

subcontracts with Evans-Hamilton, Inc., the Louisiana State University (LSU), and the Maine Maritime Academy.

I am the Program Manager for our team; Ms. Ann Jochens is the Deputy Program Manager. The Logistics Manager is Mr. Robert Hamilton of Evans-Hamilton, Inc., a small business incorporated in Texas. The Data Manager is Dr. Norman Guinasso of TAMU. The management diagram for LATEX A and principals responsible for various tasks are shown in Figure 12.2.

PURPOSES OF THE LATEX A PROGRAM; RELATIONSHIP TO OTHER LATEX AND MODELING COMPONENTS

I group the objectives of our LATEX A program into three general goals which follow.

1. To conduct a 3-year program of observations over the LATEX Shelf, with the objective of providing data adequate to describe and better understand the circulation and transports of properties over that shelf.

2. To synthesize, interpret, and report the data so collected, together with existing data syntheses and data collected by the other components of the LATEX field program. These components follow:

    - The LATEX B is a 3-year observational study of the Mississippi River plume and its behavior and influence on this shelf, as well as thermal and visible satellite information from the Gulf of Mexico. Awarded to the LSU, this program will be managed by Dr. Steve Murray.

    - The LATEX C is a 3-year observational study to map eddies and other circulation features within the Gulf of Mexico, with one objective of providing data to assess their impacts on shelf circulation. This program will be managed by Dr. Tom Berger of Science Applications International Corporation.

    - An ongoing program of monitoring marine meteorological information using buoys maintained over the shelf.

    - The ongoing opportunistic observational program of hydrographic transects across the Texas Shelf, called TIGER. This project, managed by Doug Biggs of TAMU, was outlined two years ago at the MMS Information Transfer Meeting and will be reported at the November 1991 meeting of the Marine Technology Society.

3. To provide a milieu in which the observational data from LATEX is compared with results from the MMS modeling efforts directed at the LATEX Shelf. Specifically, we hope to encourage and facilitate the use of observational data to aid in the development and validation of the numerical models described earlier by Ms. Terry Paluszkiewicz.

LATEX A OBSERVATIONS

In reviewing the planned LATEX A observations, only brief statements of the objectives, mention of the principals, and indications of the locations of observations will be presented here.

Oceanographic Observations from Moored Instruments

The objective is to provide a shelf-wide network of current, temperature, and salinity time series with which to identify, characterize, and parameterize circulation processes. In addition, directional wave spectra and other special measures will be obtained at selected locations. The Principal Investigator, Mr. Robert Hamilton, describes this project in another paper.

This moored array (Figure 12.3) consists of a boundary array along the shelf edge; cross shelf arrays to allow longitudinal transports to be studied and enable the construction of box models for transports over the shelf; a wild card array originally located in the southwestern corner of the region which is a focus for the onshore migration of rings (Figure 12.4); and two deep-water inverted echo sounders (Figure 12.4) to monitor the westward passage of rings into the shelf region.

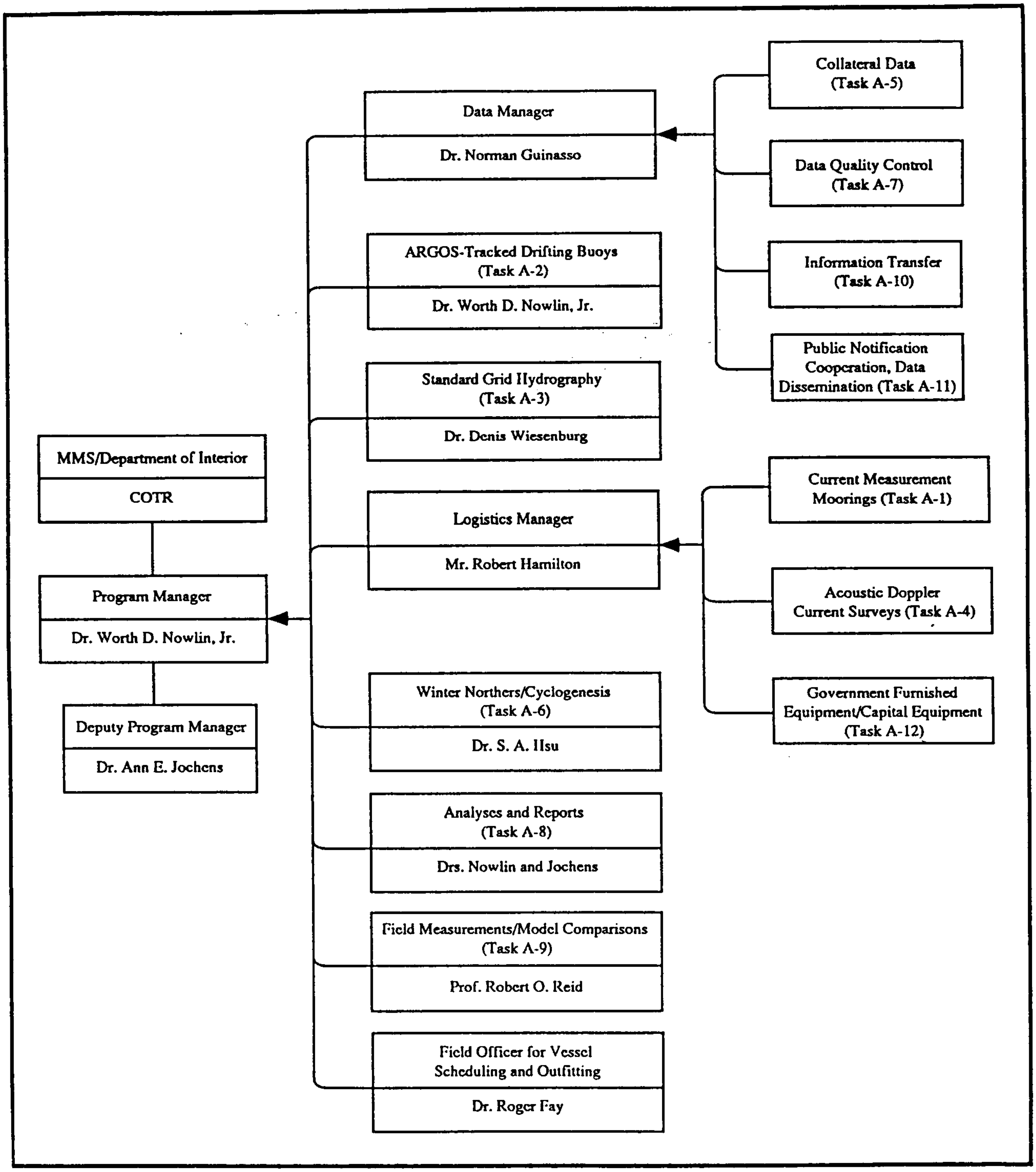

Figure 12.2. LATEX Study Unit A Organization.

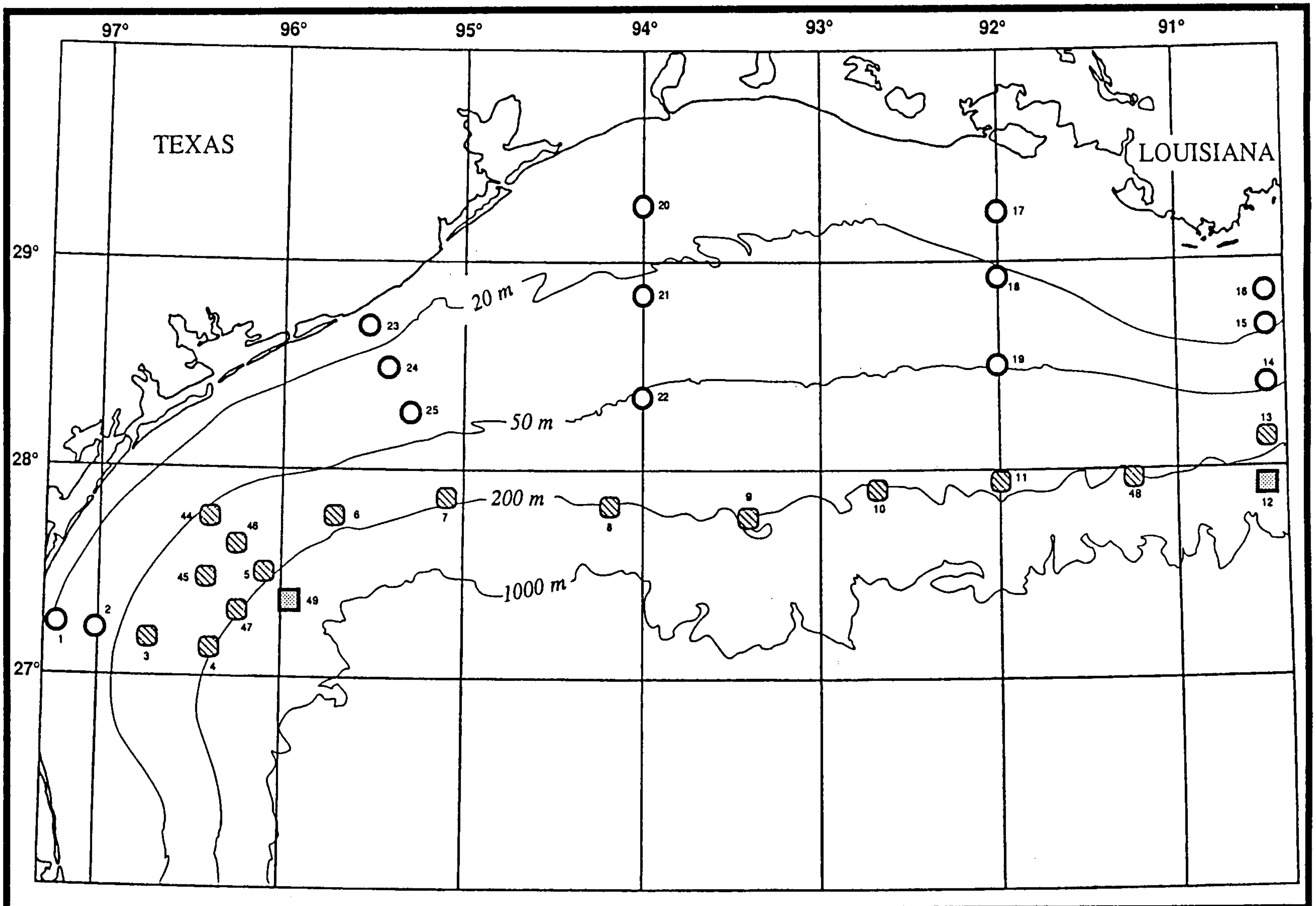

Figure 12.3. Current meter locations for LATEX A.

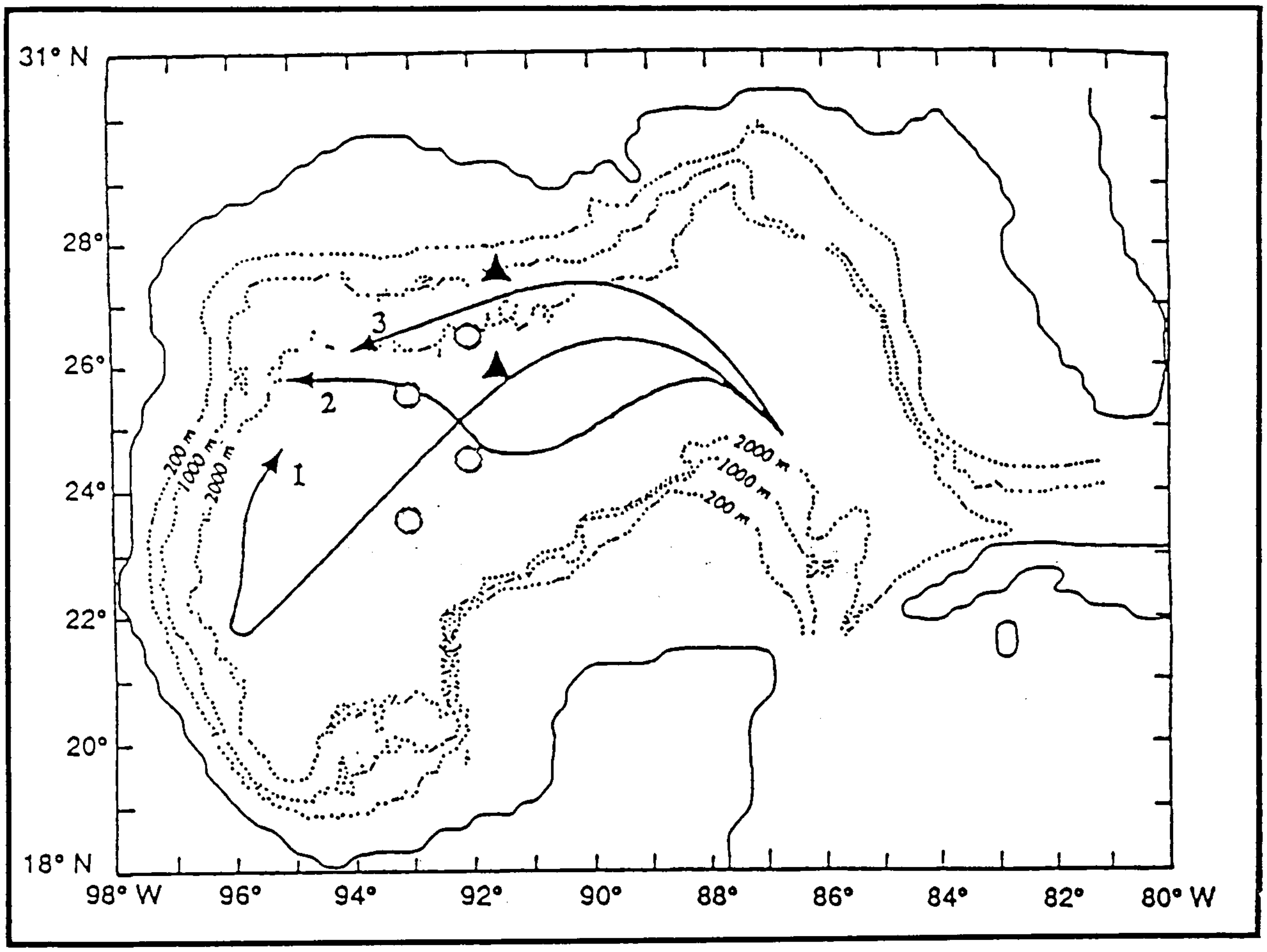

Figure 12.4. Characteristic paths of warm rings in the western Gulf of Mexico based on the positions of warm ring centers obtained using GOES and NOAA satellite data for the periods of 1973-1984. (Also shown by solid triangles are the approximate locations for Inverted Echo Sounder [IES] units.)

Observations of Winter Extratropical Cyclogenesis Resulting from Cold Air Outbreaks

The objectives are to obtain wind stress curl and related information during wintertime cyclogenesis events over the mid- to outer-shelf and to interpret and report the results. The Principal Investigator is Dr. S. A. Hsu of LSU, who describes the rationale for this planned work in another paper. Eight additional FGGE-type moored meteorological buoys to be maintained as part of this program are shown in Figure 12.5. Data from other moored buoys as well as operational data from the National Weather Service will be utilized. Some of these existent buoys are shown in Figure 12.5.

Seasonal Hydrographic Stations and Shipboard Acoustic Doppler Current Profiling

This work will characterize seasonal patterns of water mass characteristics and circulation and begin to assess interannual variability. The Principal Investigator for the hydrography is Dr. Denis Wiesenburg of TAMU, who describes this work in another paper; for the acoustic doppler current profiling (ADCP) effort, Mr. Robert Hamilton is the Principal Investigator. The ADCP will be conducted during all hydrographic cruises. The track for the standard grid hydrography and the ADCP planned for year 1 is shown in Figure 12.6.

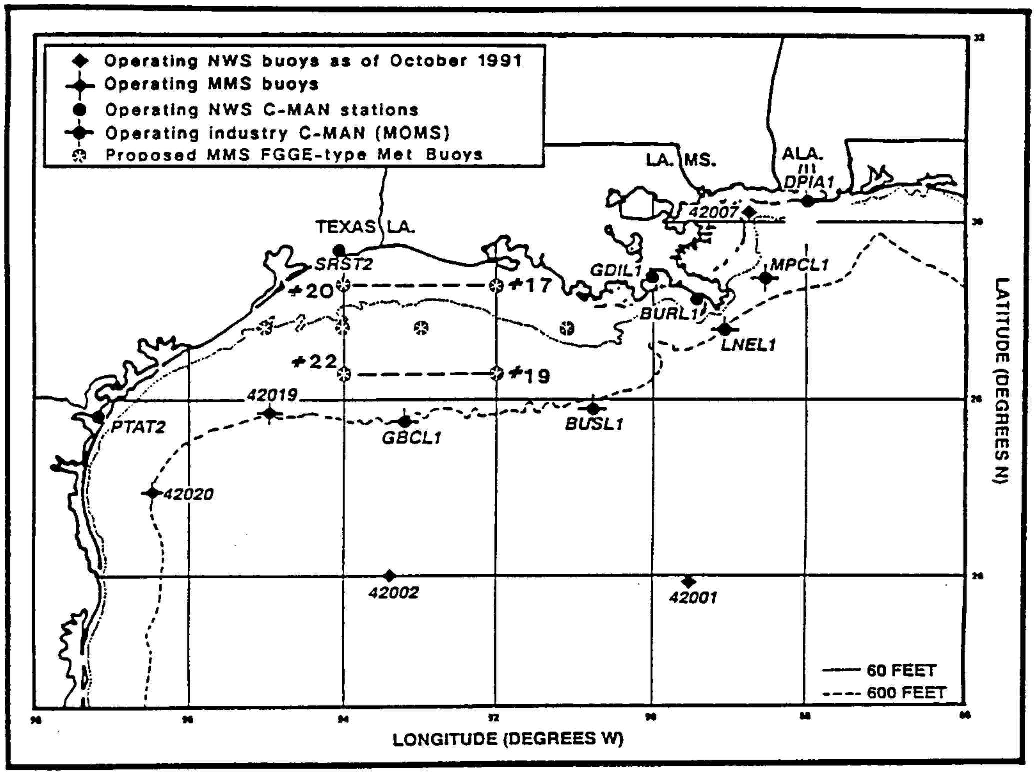

Figure 12.5. Proposed locations for eight FGGE-type buoys to be maintained as part of the Program.

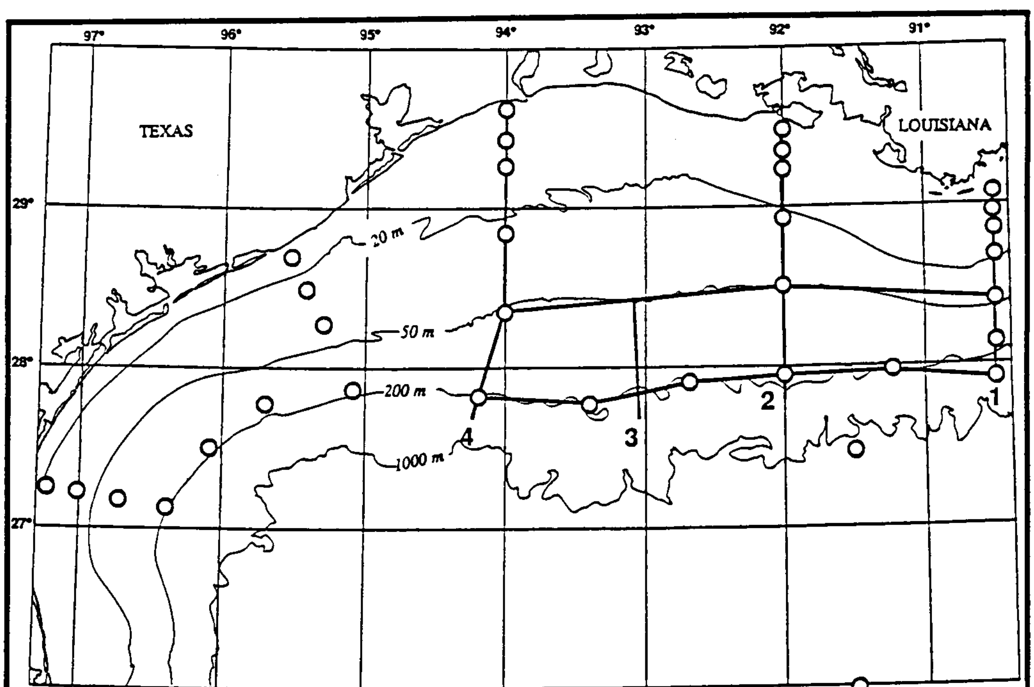

Figure 12.6. Standard grid hydrography and ADCP for Year I of LATEX A. (Current meter locations are shown as O.)

ARGOS-Tracked Drifters

This modest program will study circulation patterns using 16 drogued surface drifters tracked by service ARGOS. I am the Principal Investigator for this work. Cochrane and Kelly (1986) synthesized existing shelf data to obtain monthly patterns of geostrophic shear, four of which are shown in Figure 12.7. This is the best existent concept of seasonal current variability, but it remains to be validated via synoptic work. Drifters will be released in each of four seasons along the line shown.

INFORMATION TRANSFER AND DATA MANAGEMENT

Dr. Norman Guinasso is our Data Manager and the Principal Investigator for data quality control, information transfer, and public notification. He describes key elements of these critical efforts in another paper. We will strive for the sharing of high quality data and the release of programmatic information at the earliest possible time.

COLLATERAL DATA ASSEMBLY AND DATA SYNTHESIS

We will survey existing resources for data syntheses and interpretations. Then, using the new LATEX data we will interpret and report. Dr. Guinasso, with assistance from Dr. Robert Whitaker, is the Principal Investigator for the assembly of collateral data; Ms. Ann Jochens and I are co-Principal Investigators for the analysis and reporting functions. We are aided by an array of experienced scientists, including Dr. David Brooks, Mr. John Cochrane, Mr. Frank Kelly, Dr. Lauren Sahl, Dr. Norman Guinasso, Prof. Robert Reid, and Prof. Robert Stewart.

COMPARISON OF MODEL RESULTS WITH OBSERVATIONS

This is a key element in our program. Data collected by LATEX will be used to determine the credibility of, and to improve numerical models of shelf circulation. The observations will provide an opportunity for intensive examination of the physics used in deriving the models as well as an evaluation of the ability of the models to describe the flow field on the shelf and further offshore. We are assembling a team of experts as a Science Advisory Panel to assist and advise in this effort. The Principal Investigator for this effort is Prof. Robert O. Reid of TAMU, who will be assisted by Prof. Robert Stewart.

PERSONAL EMPHASIS

In closing, I wish to state three areas in which I place heightened emphasis with regard to this Program:

- The importance of placing results in open literature and in the training and encouragement of students and other researchers in study of this region.
- The potential for cooperative add-on programs to enhance the benefits of this MMS study. We welcome cooperative efforts.
- The necessity that the modeling and observational programs work very closely during the five year effort.

REFERENCES

Cochrane, J. D. and F. J. Kelly. 1986. Low-frequency circulation on the Texas-Louisiana continental shelf. J. Geophys. Res. 91(C9): 10645-10659.

Dr. Worth D. Nowlin, Jr. studied at Southern Methodist University, the Georg August Universitat in Goettingen, and received his Ph.D. in oceanography from Texas A&M University in 1966, where he is a Distinguished Professor. He has worked for the Office of Naval Research and the National Science Foundation, and been a visiting scientist at the Scripps Institution of Oceanography, the Woods Hole Oceanographic Institution, the Oregon State University, and the Institute fur Meereskunde of the University of Kiel. His major research programs have concentrated on the circulation of the Gulf of Mexico and Caribbean Sea, the description and physics of the Antarctic Circumpolar Current, and the interaction of the Southern Ocean with the world ocean.

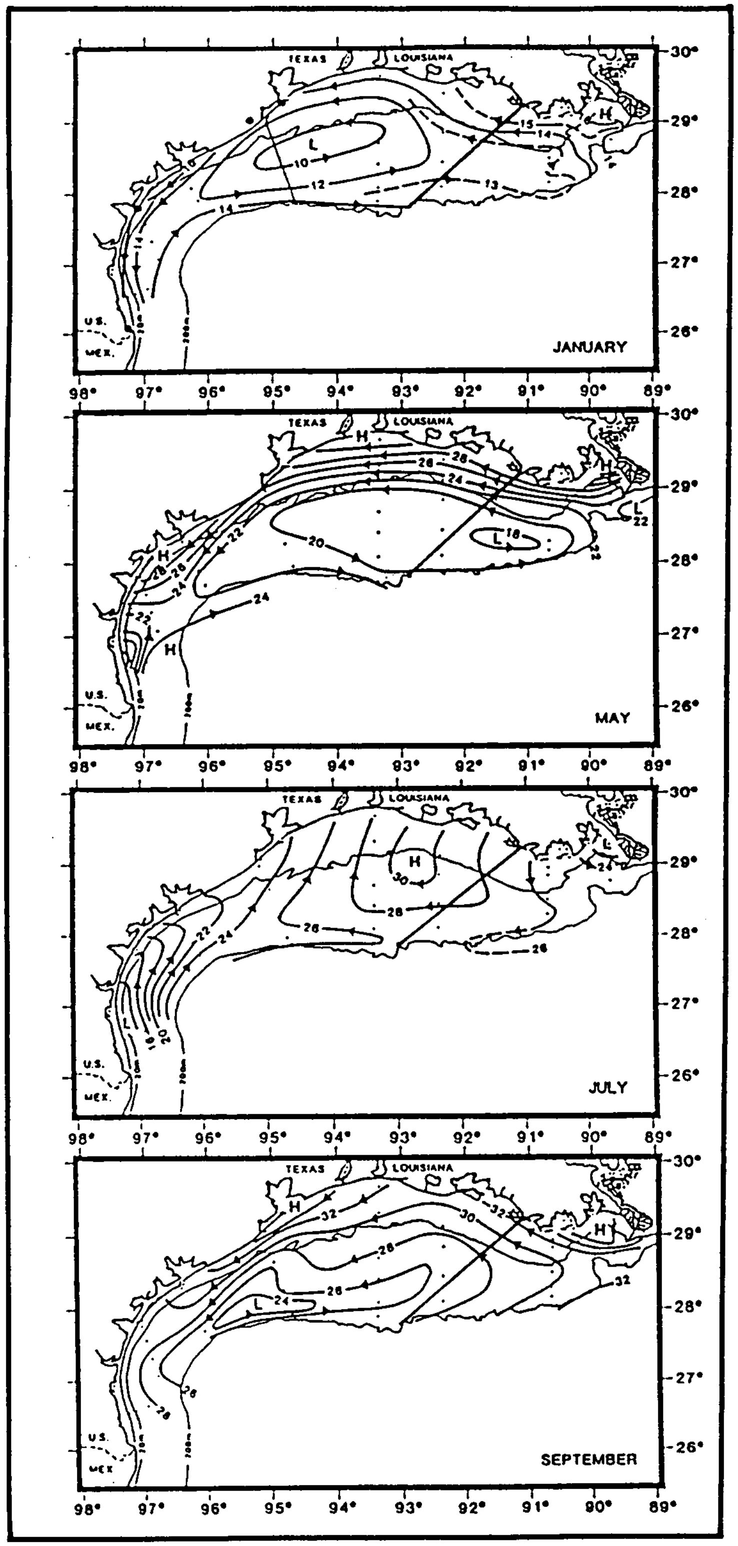

Figure 12.7. Contoured field shows mean geopotential anomaly (10^{-1}J kg^{-1}) of sea surface relative to 0.70 MPa for selected months (after Cochrane and Kelly 1986). (Section [heavy line] approximately along which we propose to release four ARGOS-tracked surface drifters in each season during the first field year of the LATEX study.)

CRITICAL SHELF PHENOMENA AND PROCESSES

Prof. Robert O. Reid
Department of Oceanography
Texas A&M University

INTRODUCTION

The strategy of the LATEX field measurement program is based on our presently incomplete understanding of the circulation regimes, variability, transfer processes, and of spatial/temporal scales derived from prior shelf studies or from conceptual models. Our goal is to further quantify what we have learned and perceive to be important and to try to gain some insight relevant to those processes or phenomena for which our understanding is presently very fragmentary. My objective in this presentation is to identify, what I believe to be, the most important and/or least understood but potentially important processes for prediction. But first, let's look at some observational facts and inferences from these facts for the LATEX shelf.

COCHRANE AND KELLY CIRCULATION

Figure 12.8 shows seasonal patterns of sea-surface salinity based on data from the series of GUS III cruises during 1963 to 1965 (Temple *et al.* 1977), as depicted in the synthesis of Cochrane and Kelly (1986). There is no doubt that the massive supply of fresh water from the Mississippi-Atchafalaya River system has a profound effect on the spatial and temporal variations of salinity (and hence of the mass density) of the shelf water. The monthly mean discharge of fresh water for the period 1977 to 1983 had a peak in April with three times that of the minimum discharge in October (Cochrane and Kelly 1986). The evidence provided by these data, particularly for the May picture, is that the brackish water is swept downcoast (toward the southwest) near the coast and ultimately across the shelf, with some indication of upcoast return flow near the shelf break. The associated monthly pictures of sea-surface dynamic topography from the Cochrane and Kelly (1986) analysis (Figure 12.9) are based on an integration of the steric anomaly with pressure relative to 70 decibars. For stations whose bottom pressure is less than 70 decibars, the integration includes a part along the sea bed across the shelf to the reference pressure. According to Csanady (1981), this method of estimation of the sea-surface dynamic topography is valid provided that the density does not vary along isobaths. Bearing in mind this caveat, the inferred geostrophic circulation indicates an elongated cyclonic gyre extending over most of the shelf for the greater part of the year (September through May). Thus, during the fall, winter, and spring, the flow is downcoast near shore with return flow near the shelf break. Only during the summer months is this pattern appreciably changed, the near shore geostrophic current being upcoast in the southwestern sector.

Cochrane and Kelly (1986) show further that the available direct current measurements prior to 1986 are qualitatively consistent with the inferred geostrophic flow, particularly in the near shore region. The least certain is the flow regime near the shelf break. Moreover, the alongshore flow regime near shore is found to be well correlated with the alongshore component of the monthly mean wind stress. In fact the cross-spectral analysis of alongshore wind stress with alongshore current in the near shore region off Freeport, Texas shows significant coherence squared for virtually all frequencies lower than 0.5 cycles/day. Moreover, the current lags the wind stress by an amount proportional to the frequency at least up to about 0.2 cycles/day (Lewis and Reid 1984; Cochrane and Kelly 1986).

Off Freeport, Cochrane and Kelly (1986) show that the alongshore components of monthly mean wind stress and current are downcoast for 10 months and upcoast or slack for 2 months. During much of the year the prevailing monthly winds are from the east or northeast, which provides a downcoast component of wind stress over much of the shelf east of 96°W longitude. But winds out of the southeast and south during the summer months produce an upcoast wind stress component that is most pronounced in the southern sector of the shelf. Moreover, the downcoast component of the wind during the majority of the year tends to keep the brackish water near shore due to the surface Ekman transport towards shore (downwelling near shore). Only during the summer does the wind-induced surface Ekman transport produce nearshore upwelling in the seasonal regime. The inference of

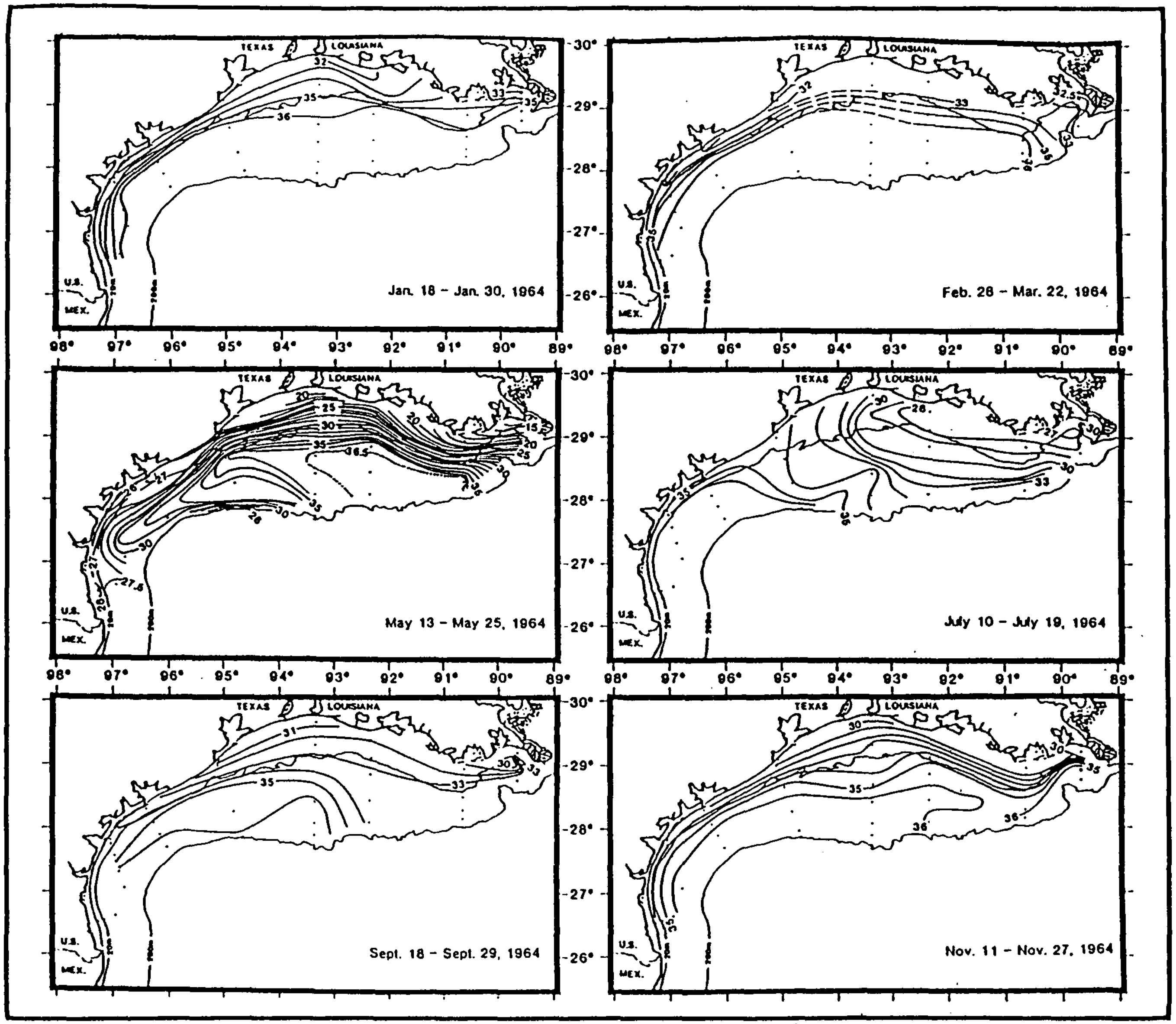

Figure 12.8. Sea surface salinity (psu) for GUS III cruises of 1964 (from Cochrane and Kelly 1986).

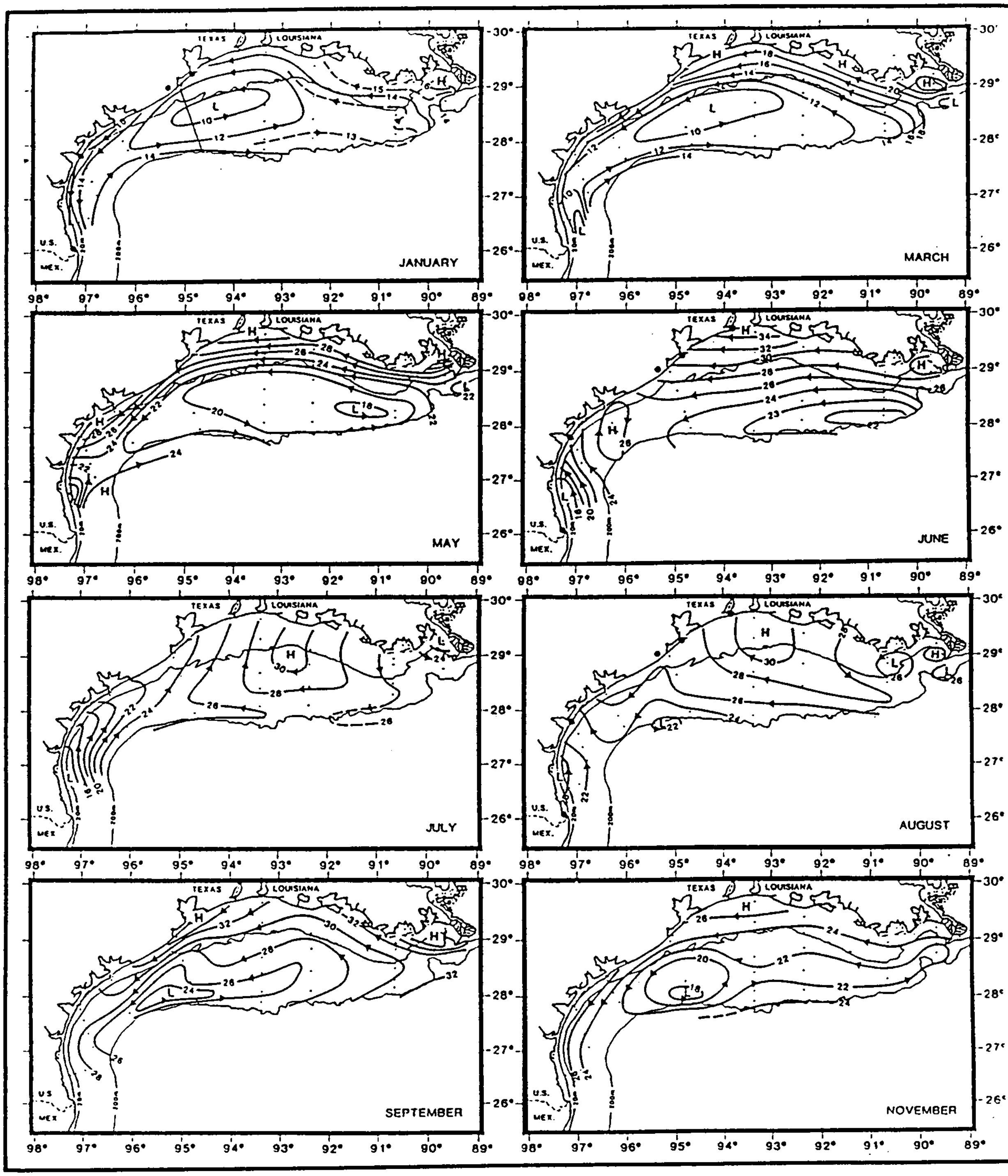

Figure 12.9. Monthly mean geopotential anomaly (dyn cm) of the sea surface relative to 70 decibars based on GUS III cruises in 1963, 1964 and 1965 (from Cochrane and Kelly 1986).

the latter is the replacement of near shore brackish water by high salinity water from the deeper regions of the shelf. This is clearly evident in the July pattern of salinity shown in Figure 12.8.

The above patterns and inferences relevant to the seasonal circulation on the LATEX shelf will be referred to as the Cochrane and Kelly (1986) schema. It is a first approximation that the measurement program over the next five years will hopefully refine, as well as supplement with some important missing aspects. The Cochrane and Kelly (1986) schema implies that, to a first approximation, the seasonal circulation on the LATEX shelf is wind-driven. The fresh water effects are included only in a passive sense and any buoyancy driving from river discharge or cold air outbreaks during winter is not considered. Nor is any driving considered at the open boundaries by import of momentum, vorticity, and/or energy from eddies shed from the Loop Current. The Cochrane and Kelly (1986) analysis does recognize that the alongshore current in the near coastal region is coherent with the alongshore wind stress only for the region west of 92.5°W longitude, in view of the findings of Chuang and Wiseman (1983) for the region between 92.5°W and the Mississippi Delta. The evidence opens the door to some direct driving effect from river flow. Finally, the source of mesoscale structure so prevalent in satellite advanced very high resolution radiometer imagery of the LATEX region is unknown, as is its impact on the flow field.

Accordingly, I have selected the five following related topics for discussion and emphasis in the remainder of this presentation.

1. the role of wind stress in driving shelf circulation;
2. the role of buoyancy in driving shelf circulation;
3. the role of shelf mesoscale features;
4. the stability of the coastal front; and
5 eddy-shelf interaction at the open boundary.

These can all be discussed within the context of vorticity tendency considerations.

VORTICITY TENDENCY CONSIDERATIONS

The dynamics of the low frequency circulation of the shelf, like that of the oceanic regimes, can best be understood in the context of the vorticity equation. This can be formulated either in terms of the depth averaged flow or in terms of coupled equations for barotropic and baroclinic modes (Flierl 1978). For simplicity in this presentation we will consider the depth-averaged case (Csanady 1981, 1988). The local time rate of change of the column-averaged vertical component of vorticity is equal to the sum of nine distinct vorticity tendency terms. These are:

1. Advective tendency, that exists when vorticity varies along a streamline;

2. Stretching tendency, that exists when depth varies along a streamline;

3. Planetary tendency, that exists when latitude varies along a streamline;

4. Solenoidal tendency, that exists when column-average density varies along an isobath;

5. Ekman pumping, a forcing caused by curl of wind stress divided by depth;

6. Buoyancy pumping, a forcing caused by heating or cooling of the water column;

7. Bed torque, a resistance caused by bed stress divided by depth;

8. Lateral torque, a resistance caused by lateral mixing of vorticity; and

9. Mode coupling tendency, associated with transfer of vorticity to or from baroclinic modes.

For steady state circulation, the sum of all the above tendency terms is zero. The classical Stommel or Munk oceanic wind-driven gyres represent a balance where the tendency terms (3), (5) and (7) or (8) alone are considered. Rossby waves, on the other hand, represent an imbalance where tendency term (3) produces a local time rate of change of vorticity. In the application of vorticity tendency considerations to the shelf, however, the tendency terms related to variable depth become important.

Wind Stress Driving

For the shelf, the counterpart of a Stommel/Munk type circulation regime would be a balance among the tendency terms (2), (5), (7) and (8). The effective Ekman pumping term (5) for the shelf deserves special comment. If we let T be surface wind stress and h the depth, then it is the curl of T/h that is important. If the scale of the wind system is large compared to the shelf dimensions, then curl (T/h) is nearly proportional to the vector product of wind stress with the gradient of depth. In particular, when the wind stress is directed such that the shallow water is to the right (i.e., downcoast), then a cyclonic vorticity tendency is produced by the winds. Clearly, this is consistent with the Cochrane and Kelly (1986) circulation picture for September through May. Moreover, such driving should give a coastal current whose magnitude is proportional to the longshore component of wind stress. The stretching tendency term (2), even in a linear model, will have its biggest effect in the turning regions of the gyre at the downcoast and upcoast ends of the shelf. Finally, during the June through August wind episode, the effective Ekman pumping changes to an anticyclonic regime (again consistent with Cochrane and Kelly 1986). Bear in mind however that this simple model is restricted to very large scale wind systems and neglects any buoyancy driving.

Buoyancy Driving

If one replaces the Ekman pumping tendency term (5) by the buoyancy pumping term (6) in the above model then it becomes a buoyancy driven one associated with the annual cycle of heating and cooling. However, the solenoidal tendency term (4) can introduce a further (and perhaps more important) buoyancy driving effect related to river discharge (Elliott and Reid 1976). The solenoidal tendency term is proportional to the Jacobian of the column-averaged density and the water depth. This gives a cyclonic tendency for circulation provided the density increases downcoast along an isobath, as is expected for the LATEX domain. Its strongest tendency for generating cyclonic vorticity should be in the region east of 92.5° longitude (the region that Chuang and Wiseman (1983), assert has currents least coherent with wind stress). In this region one might expect the current to be more coherent with the strength of the discharge, that must control the magnitude of the downcoast gradient of density. Thus, the direct driving effect by the solenoidal term near the Mississippi-Atchafalaya River outfall may explain why the cyclonic tendency occurs in the region between 92.5° and the Mississippi delta throughout the year. In addition, it is of interest to note that for the shelf region east of the Mississippi delta, the solenoidal tendency term related to river discharge has the opposite sign (i.e., anticyclonic).

Shelf Mesoscale Features

One of the striking features of infrared imagery of the sea surface, seen by satellites over the LATEX shelf domain, is the detailed structure of filaments and eddies extending across the shelf. These are of horizontal scales consistent with shelf mesoscale (the first baroclinic radius of deformation, that varies from about 10 km near shore to about 25 km near the shelf break). These features moreover are ever evolving with time scales of weeks. A possible source of such evolving features of the surface thermal structure may be the flow fields associated with shelf wave activity excited by wind stress. For free shelf waves the stretching tendency (2) causes local time change of vorticity. Forcing by Ekman pumping at space and/or time scales comparable to those of the free waves could contribute to the variance of the surface mesoscale features. Another possible source is intrusion of vorticity from Gulf eddies impinging on the continental slope. Still another possible source is instability of the coastal current. Whatever the source, the shelf mesoscale structure must be important in cross shelf transport of properties.

Stability of the Coastal Front

It is well known that currents with a barotropic component tend to follow f/h contours, where f is the Coriolis parameter. An example is the Gulf Stream flowing over the continental slope in the region south of Cape Hatteras. Any perturbation of the core of the current produces a restoring effect provided that the flow is such that deep water is to the right of the stream (for the northern hemisphere). This is consistent with conservation of potential vorticity of the vertically averaged flow. On the other hand, a current tending to follow bathymetric contours with deep water to the left is apparently unstable, the restoring effect on perturbations being of opposite sign. Another way of stating this is that currents prefer to follow f/h contours in an anticyclonic sense. During most of the year, the wind and river discharge force a cyclonic circulation over the LATEX shelf. While the forcing maintains such a mean circulation, it is possible that instabilities of this regime can occur and lead to elongated anticyclonic loops extending across the shelf.

Gulf Eddy Intrusion

It is now well established that warm core anticyclonic eddies spawned from the Loop Current drift into the western Gulf of Mexico and can reach the continental slope seaward of the LATEX shelf. Those anticyclonic eddies with centers near the base of the continental slope may tend to migrate further onto the slope region and even allow the northern (or western) flank to penetrate onto the shelf, for eddies in the eastern (or western) quadrant of the slope. If this happens, the eddy is now in a domain where the radius of deformation is reduced relative to its deep water value. Under these circumstances the eddy has more kinetic energy than is consistent with equal partitioning and it is vulnerable to instability and spawning of parasitic smaller scale cyclonic eddies, the total enstrophy (integral vorticity squared) and energy of the system being conserved. Some evidence for such parasitic cyclonic eddies on the northern flank of a warm core ring near the southwestern quadrant of the LATEX shelf is given by Vukovich and Waddell (1991).

SUMMARY

The seasonal cycle of circulation on the LATEX shelf as described by Cochrane and Kelly (1986) is consistent with vorticity tendency considerations, in a climatological sense, including the solenoidal driving by river discharge as well as by the effective Ekman pumping over a domain of variable depth. However, superimposed on such a seasonal cycle is undoubtedly significant variance of current (and vorticity) at shelf mesoscale in time and space. Such mesoscale structure may be directly forced meteorologically, or caused by import of vorticity due to Gulf eddy intrusion onto the shelf, or by instability of the cyclonic circulation that tends to occur on the shelf during most of the year. Which of the last three processes is most important for maintaining the shelf mesoscale noise is presently unknown. Hopefully, the LATEX measurement program will shed light on this question as well as quantifying the statistical aspects of the shelf mesoscale dynamics.

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A STUDY OF EXTRATROPICAL CYCLOGENESIS EVENTS ALONG THE MID TO OUTER TEXAS-LOUISIANA SHELF

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Louisiana State University

INTRODUCTION

Cyclogenesis is defined as any development or strengthening of cyclonic circulation in the atmosphere. The term is usually applied to the development of cyclonic circulation where it previously did not exist (commonly, the initial appearance of a low or trough, as well as the intensification of existing cyclonic flow) (Huschke 1959). It is an important phenomenon over the Gulf of Mexico (Gulf).

Winter cyclogenesis in the western Gulf of Mexico has been studied by Saucier (1949), among others, and recently by Johnson *et al.* (1984). The latter found that in most cases, an upper-air low developed over a climatological surface baroclinic zone in the Gulf. Strong tropospheric dynamics over the Gulf coupled with existing strong thermodynamics resulted in a number of strong and intense cyclones.

An example of extratropical cyclogenesis and its effects is illustrated by Figure 12.10, for one of the top five cyclones generated over the Gulf during the 1982-1983 El Niño period as listed in Johnson *et al.* (1984). They summarized that this cyclone had 12 millibar maximum 24-hour pressure fall (which may be considered as a meteorological "bomb" according to the criterion used by Sanders and Gyakum 1980; i.e., 0.5 mb drop per hour at 25°N). The minimum pressure was 996 millibars and reported maximum wind was 20 m/sec. Measurements made on a platform in the shelf water off Louisiana indicated that the lowest pressure was approximately 1,001 millibars, maximum wind 15 m/sec., and significant wave height 4.3 m. Note that the time series characteristics of these parameters resemble those of a hurricane (Hsu 1988).

WINTER BAROCLINICITY

During the winter season the shelf water is colder than the deep Gulf (Hsu in press). Therefore, a baroclinic field should exist over these two water masses. If a cold front moves from northwest to southeast, it may bring cold air to the northwestern Gulf. Figure 12.11 shows locations at which temperatures were measured along a transect from deep Gulf Buoy Station #42002 through National Data Buoy Center (NDBC) C-MAN station SRST2 via Lake Charles (LCH) to Shreveport (SHV), Louisiana. Note that station GBCL1 was located about 15 km south of the shelf-break on an underwater bank in 209 m of water and station SRST2 was located about 100 m inland from the shoreline. Monthly variation of air temperature along this transect from September 1989 through March 1990 are shown in Figure 12.12. This figure shows clearly that the largest temperature gradients exist between the shelf break and the nearshore region.

According to Lewis and Hsu (in press), the location of the most unstable air within the atmospheric boundary layer is found along the shelf break in the Gulf. Figure 12.13 further delineates this phenomenon. Note that in Figure 12.13, the C-MAN stations along the shoreline, such as at

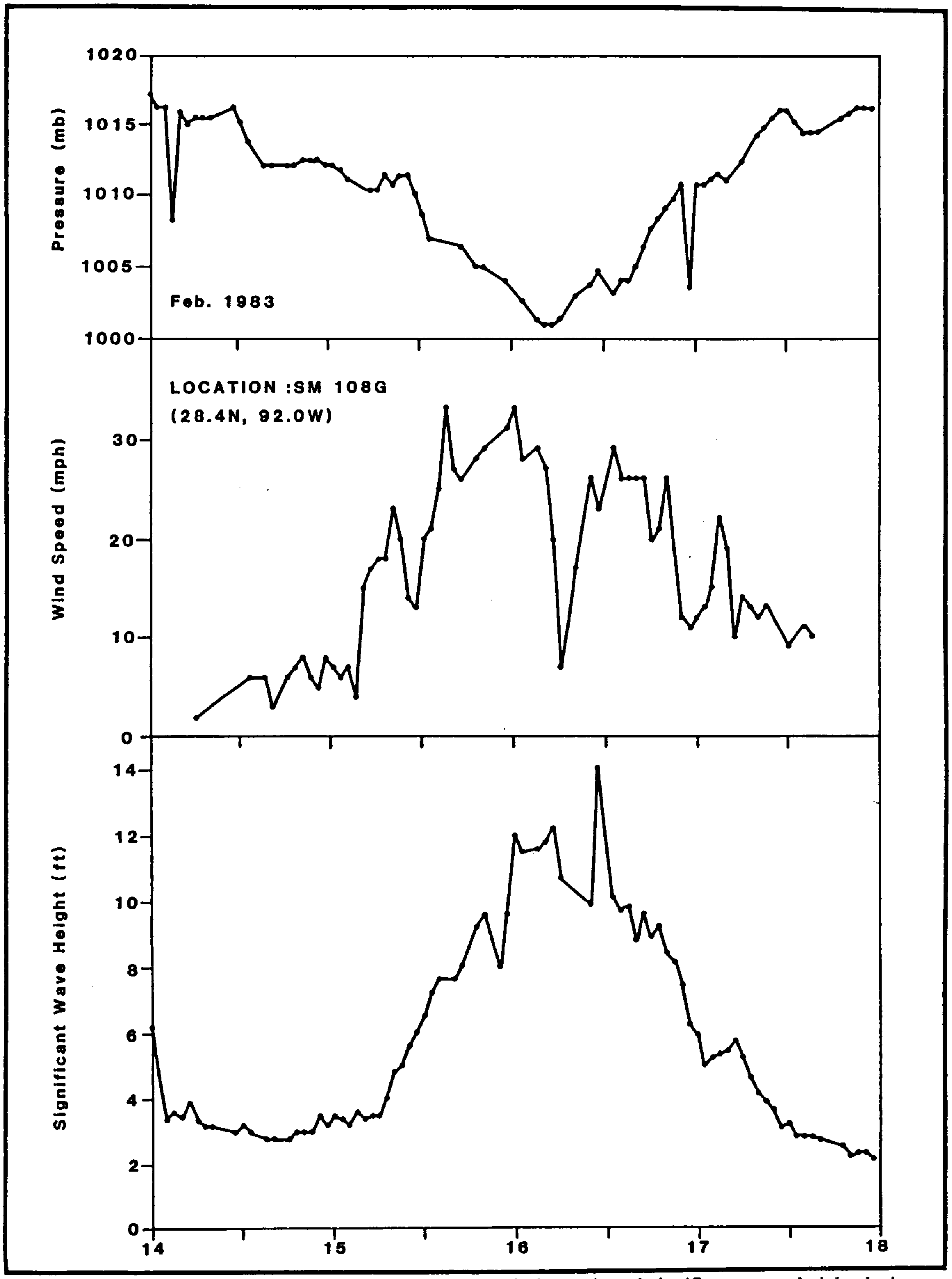

Figure 12.10. Measurements of atmospheric pressure, wind speed, and significant wave height during the cyclogenesis period shown in Figure 12.9.

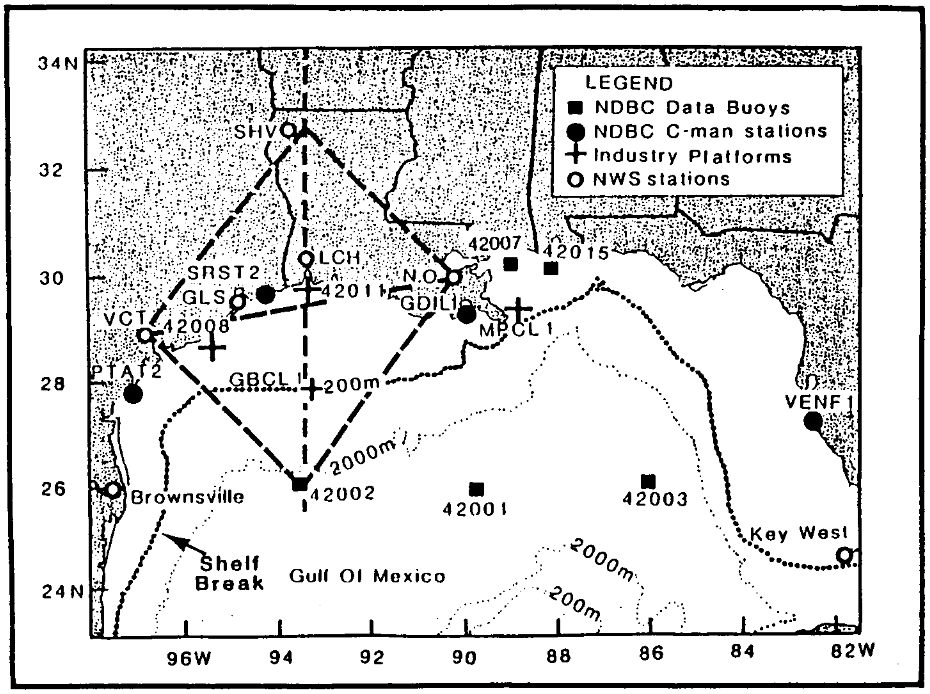

Figure 12.11. Station locations for onshore and offshore temperature distribution used in Figure 12.12 and subsequent analysis. (A 5-point stencil [see the rhombus with its center approximately over buoy station 42011] for the computation of the Laplacian of temperature field to obtain the relative or local vorticity.)

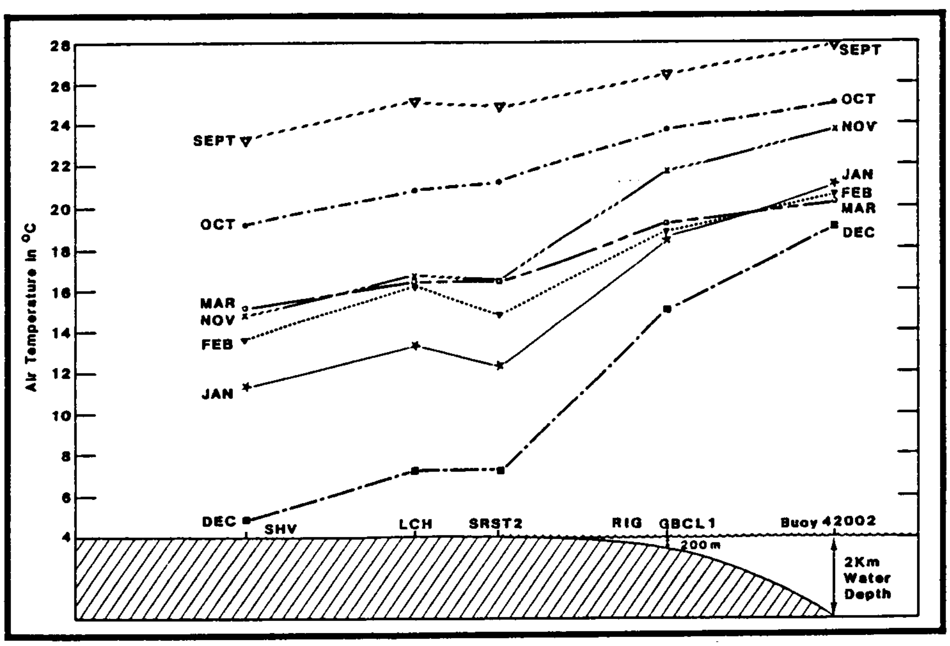

Figure 12.12. Monthly variations of air temperature from deep Gulf to Shreveport, Louisiana, via stations near shelf break and coastal areas from September 1989 through March 1990.

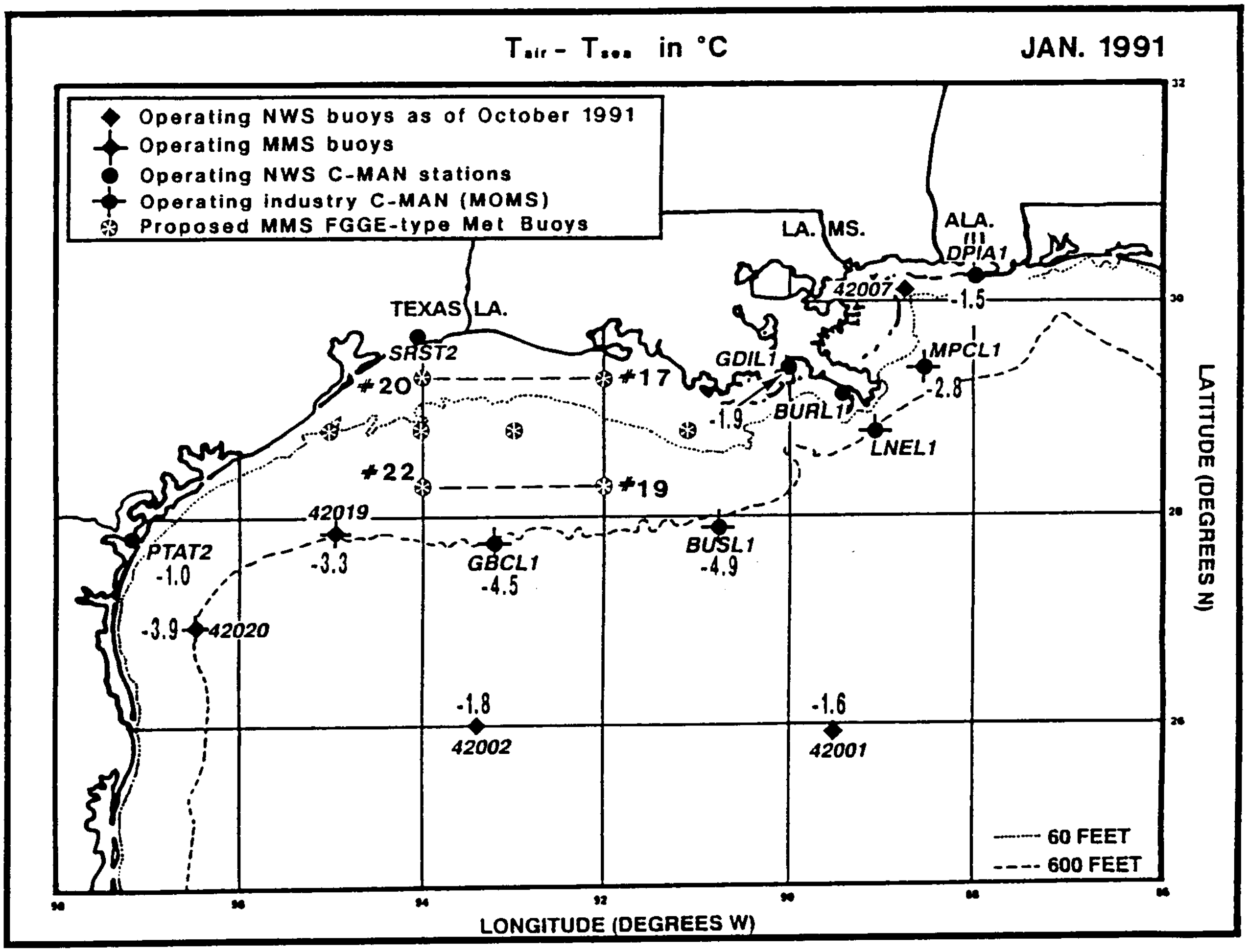

Figure 12.13. Air temperature minus sea temperature for January 1991 and station locations for MMS' buoys, industry's MOMS network, and proposed LATEX-A6 meteorological buoy experimental design.

Dauphin Island, Alabama, Grand Isle, Louisiana, and Port Aransas, Texas, report water temperatures about 1 to 2°C warmer than the air temperature; a similar difference exists for the deep Gulf. However, along the shelf break a temperature difference of 3 to 4°C is common.

VORTICITY CHARACTERISTICS

Because extratropical cyclogenesis over the northwest Gulf is often associated with frontal overrunning (Hsu in press), there is good correlation between the frequency of frontal overrunning at New Orleans and the difference in air temperature between Buoy Station 42001 and New Orleans (Figure 12.14). If one accepts 3°C difference in air temperature between New Orleans and 42001 as background "noise" as discussed in Hsu (in press), then 13 percent in the frequency of frontal overrunning at New Orleans is also "noise". Therefore, for operational purposes, a six-month period from October through March is significant. Figure 12.14 may be used as a guide for forecasters: if air temperature difference between New Orleans and Buoy Station 42001 is greater than 5°C in October or March, there is a tendency for frontal overrunning to occur.

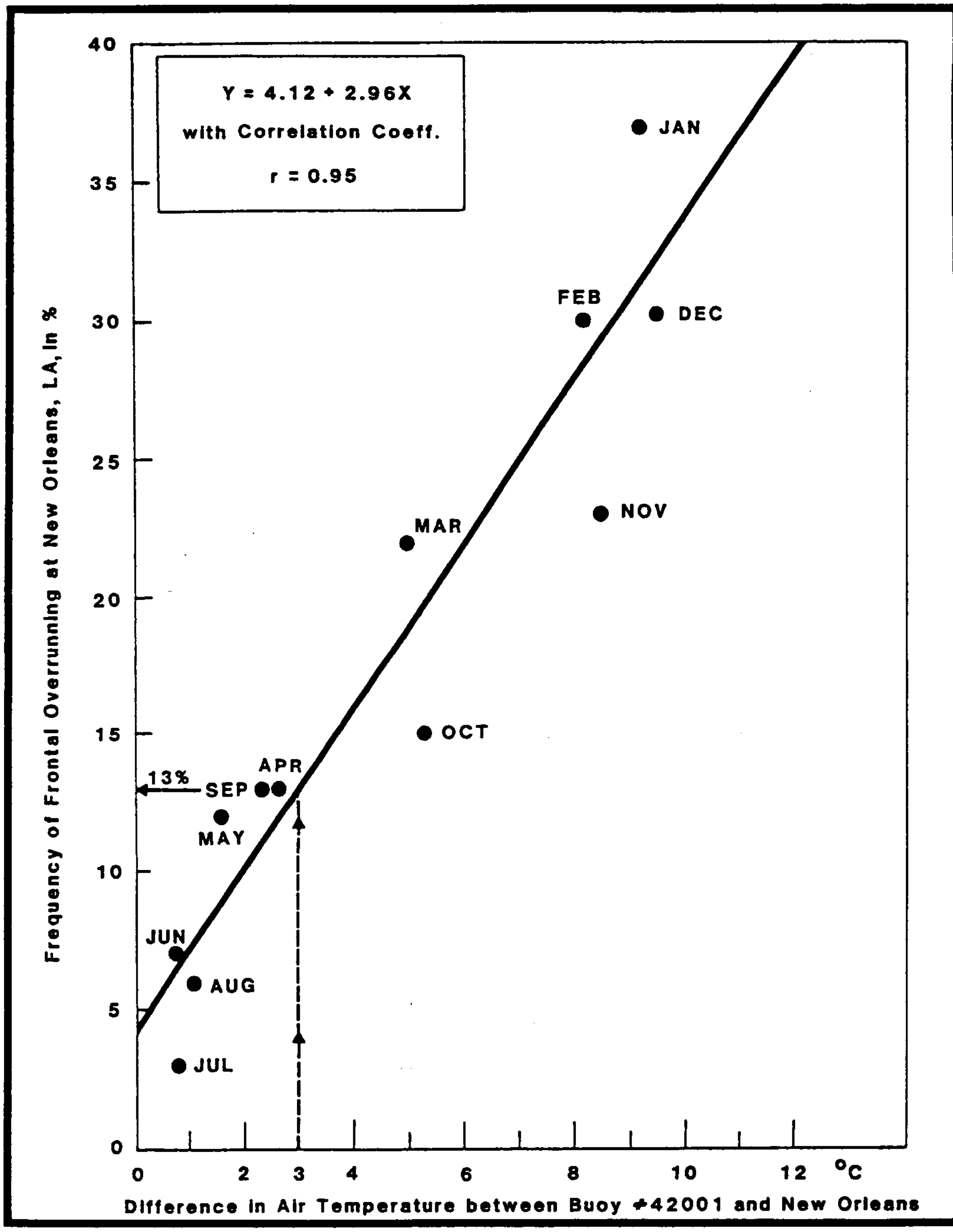

Figure 12.14. Linear regression between monthly frequency of frontal overrunning at New Orleans and the difference in air temperature between Buoy Station 42001 and New Orleans.

In order to add dynamic understanding, frequency of frontal overrunning is plotted relative to relative or local geostrophic vorticity over the west Louisiana-Upper Texas Shelf region in Figure 12.15. The vorticity is computed from a five-point stencil to obtain the Laplacian in temperature field as shown in Figure 12.11. For the computation, Lake Charles (LCH in Figure 12.11) was used as center point due to its long-term record (30 year normal, 1951-1980). The four outer points of this rhombus are Buoy Station 42002 (data period 1976-1988), N.O. (1951-1980), SHV (1951-1980), and VCT

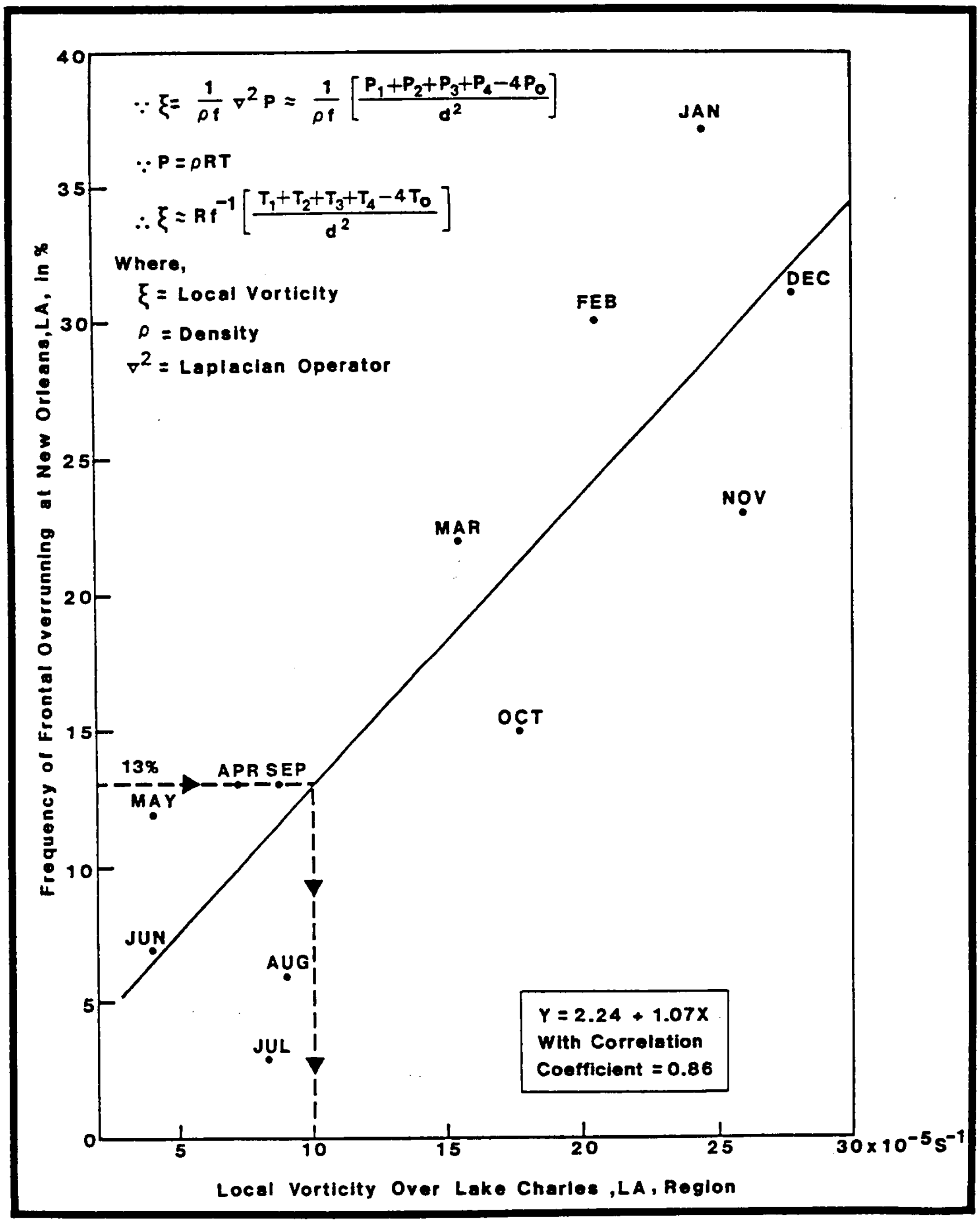

Figure 12.15. Linear regression between local vorticity (computed from Figure 12.12) over west Louisiana/upper Texas shelf and monthly frequency of frontal overrunning at New Orleans.

(1951-1980). The correlation coefficient for the variables of Figure 12.15 is 0.86 for 12 monthly data points, yielding a dynamic relation. Similar to Figure 12.14, if the value of vorticity is less than 10 x 10^{-5}-s^{-1}, it is not significant. Note that the Laplacian of the temperature field is a measure of the vorticity of the thermal wind. It is used here only as a first approximation to aid forecasters; all data needed for this computation are readily available. It is found that the alongshore variation in air temperature from New Orleans to Victoria, Texas (via LCH and Galveston) is less than 2°C whereas the onshore (e.g., at LCH) and offshore (at Buoy Station 42002) variation exceeds 8°C. Therefore, the local geostrophic vorticity can be estimated directly by the temperature difference between LCH and Buoy Station 42002 as shown in Figure 12.16.

ONGOING RESEARCH PROGRAM

Because the chilling of coastal waters in the cold season begins in shallow bays and lakes, the baroclinic and vorticity fields will also move progressively from the nearshore area to the shelf break region. Cyclogenesis affects the weather and physical oceanographic characteristics of the shelf water. Therefore, its study is important not only from the science point of view, but more importantly from the operational point of view, e.g., in case there is an oil spill in our area.

One research task within the LATEX A program addresses this particular subject. Figure 12.13 shows locations of eight additional meteorological buoys to be deployed as part of LATEX A. Note that without these proposed Minerals Management Service (MMS) buoys in the shelf water there is a data void between the shelf break and the shoreline. Furthermore, if there is no Meteorological and Oceanographic Measure System network along with MMS' #42019 and #42020, one simply cannot study the cyclogenesis, and thus warnings of storms and their related oceanographic effects will almost be impossible.

The most important consideration for the experimental design for these eight MMS meteorological buoys is to "catch" the vorticity field and its effect including wind-stress curl as it moves progressively from the nearshore region to the shelf break, with the seasonal progression from fall to winter to spring.

With the aid of standard National Weather Service stations on land and in the deep Gulf of Mexico, calculations from a series of stencils (similar to that shown in Figure 12.11) can be constructed in our LATEX A area. Thus, the wind-stress curl which affects the shelf current can be understood in detail. This mesoscale air-sea interaction network is the first of its kind in the Gulf of Mexico and its scientific and operation impact will be extremely beneficial.

ACKNOWLEDGMENTS

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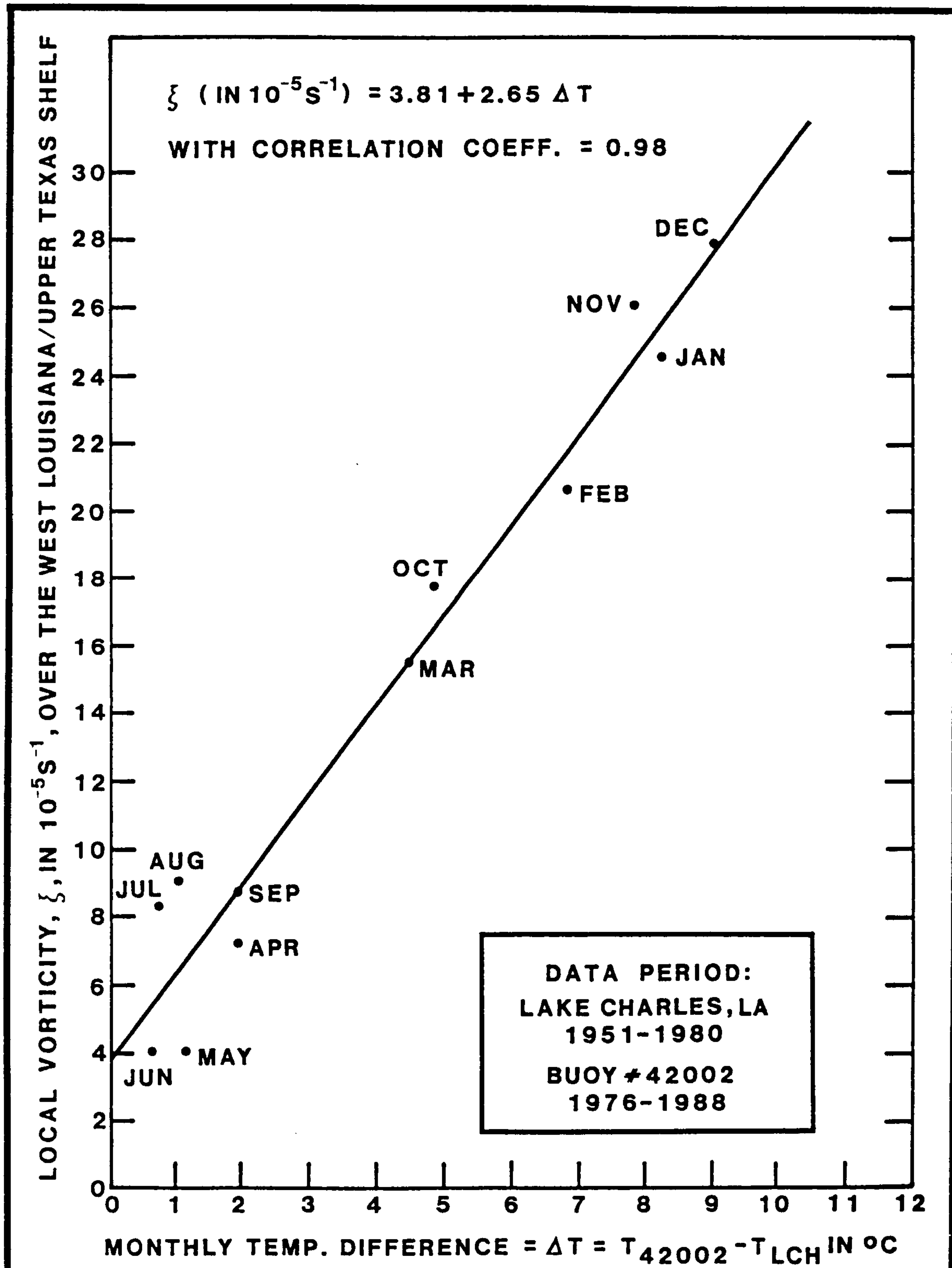

Figure 12.16. Linear regression between the local geostrophic vorticity over the west Louisiana/upper Texas shelf and the monthly temperature difference between Buoy Station 42002 in the deep Gulf and LCH.

A SHELFWIDE PROGRAM OF DIRECT CURRENT MEASUREMENTS: MOORINGS, DRIFTERS, AND SHIPBOARD ACOUSTIC DOPPLER CURRENT PROFILES

Mr. Robert C. Hamilton
Evans-Hamilton, Inc.

INTRODUCTION

The field effort of the LATEX A program will provide researchers with data which will greatly increase the understanding of circulation on the LATEX Shelf, will provide operators on the shelf with a tremendous base of information on actual physical oceanographic conditions on the shelf, and will provide modelers with excellent data for verification of their models. The data collection effort for LATEX A is a large, complex program which utilizes 31 current meter moorings, 8 moored satellite transmitting meteorological buoys, 16 satellite transmitting drifting buoys, and a large body of shipboard measurements. This paper presents an overview of the field measurement program with the exception of the shipboard hydrography which is described in a separate paper.

The majority of the field efforts involves the procurement and calibration of the required equipment and the placement and servicing of instrument moorings for the collection of current, wave, temperature, conductivity, meteorological, and sound travel time data. Additional activities included in the field program are the collection of acoustic doppler current profiles (ADCP) during the hydrography cruises and the deployment of ARGOS drifting buoys.

DESCRIPTION OF FIELD OPERATIONS AND LOGISTICS

Overview of the Data Collection Effort

The field sampling program and its associated logistics is a very large effort which requires close cooperation and communications between not only the personnel of LATEX A, but those from Minerals Management Service and the contractors for LATEX B and C as well. Within the field sampling program there are several groups which have extensive involvement in the program. Figure 12.17 shows the management of the field activities. Mr. Robert C. Hamilton of Evans-Hamilton, Inc. (EHI) is the Logistics Manager for the field measurements and is the Field Officer for the mooring cruises. He is responsible for the procurement, testing, and calibration of all instruments and for the at-sea activities associated with all mooring cruises. Mr. Hamilton will be assisted by the Field Support Group of the Coastal Studies Institute at Louisiana State University (LSU) under Mr. Rod Fredericks and by the staff at the Geochemical and Environmental Research Group (GERG) at Texas A&M University (TAMU). Dr. Roger Fay of GERG is the Field Officer for Vessel Scheduling and Outfitting and is responsible for providing the vessels, support equipment, and support personnel for each cruise at the required time and place.

The mooring activity encompasses the placement, servicing, and removal of 36 moorings which are located in water depths from 10 to 3,000 m. These moorings contain a total of 79 current meters, eight meteorological buoys, and two Inverted Echo Sounders (IES). Figure 12.18 shows the locations of the moorings and their servicing intervals.

In order to perform the required field work, we have estimated that 342 days of ship time will be required during the three years of field operations. In addition to the mooring cruises, current profiles will be obtained during the estimated 121 days of the hydrographic cruises with a shipboard ADCP.

During either the mooring or hydrography cruises, 16 ARGOS drifting buoys will be deployed to support the study of the continuity of alongshore flow.

Synopsis of the Mooring Program

Thirty-one current meter moorings will be deployed for this study. These moorings mainly contain current meters with temperature and conductivity sensors. Two to three current meters are installed on each mooring. Table 12.1 summarizes the instruments on each mooring, the water depth, the depth of the individual meters, and the mooring

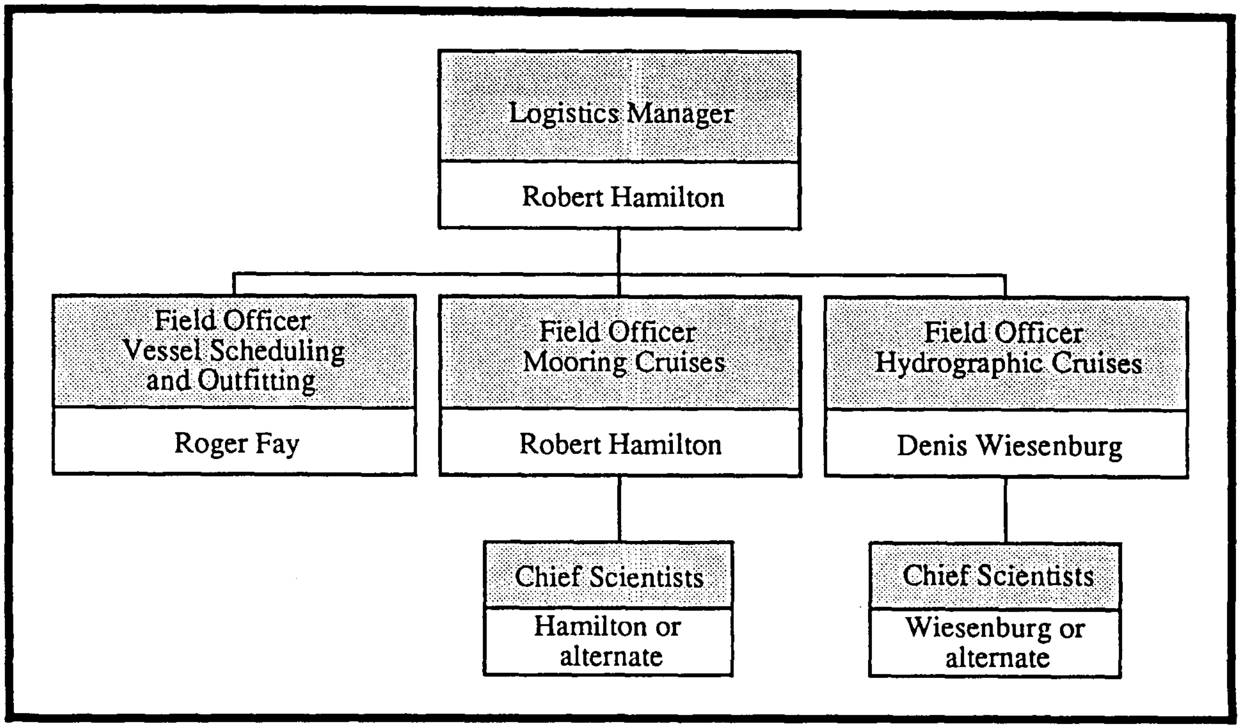

Figure 12.17. Management organization for field activities.

servicing interval. In addition to the current measuring sites, five locations with pressure, u-velocity, and v-velocity (puv) meters will collect directional wave data; two locations with IES will measure acoustic travel time; and eight meteorological buoys will collect and transmit meteorological information.

The following sections summarize the scientific rationale and the locations of the various moorings which are contained in six interrelated measurement arrays (see Figure 12.18):

- Boundary Array--The moorings in the boundary array surround the entire oceanic area of the study (Moorings 1-16, 48, 47, 17, 20, and 23). The purpose of this array, in conjunction with the hydrographic and shipboard ADCP data, is to enable the boundary conditions for the study area to be determined. This information will be useful for the box model studies conducted under LATEX A and for other conceptual or numerical models of shelf circulation and transport.

  A portion of the boundary array (Moorings 4-12, 47, and 48) is a shelf-edge array which will provide reliable estimates of phase propagation speeds of disturbances propagating along the shelf from the Mississippi Delta to the Mexican border.

- Cross-Shelf Array--20 moorings (Moorings 1, 2, 3, & 4; 23, 24, 25 & 7; 20, 21, 22, & 8; 17, 18, 19, & 11; and 16, 15, 14, 13, & 12) will be placed in five cross-shelf arrays. Additionally, four moorings of the wild card array (Moorings 44, 46, 5, and 49) will provide a sixth cross-shelf array. These six arrays will provide data enabling the study of nearly along-isobath currents that usually dominate shelf circulation particularly in the shallow depths (<60 m). The six sections provided by these arrays allow for higher resolution modeling studies of shelf circulation than were previously possible.

- Wild-Card Array--Five wild-card moorings will be placed at the western edge of the study area (Moorings 44, 45, 46, 47, and 49). These moorings, together with Moorings 3, 4, and 5, make up a "dense array" which will be located near the shelf-edge of the northwestern Gulf of Mexico. This region is an "eddy graveyard" where there is a high probability of observing

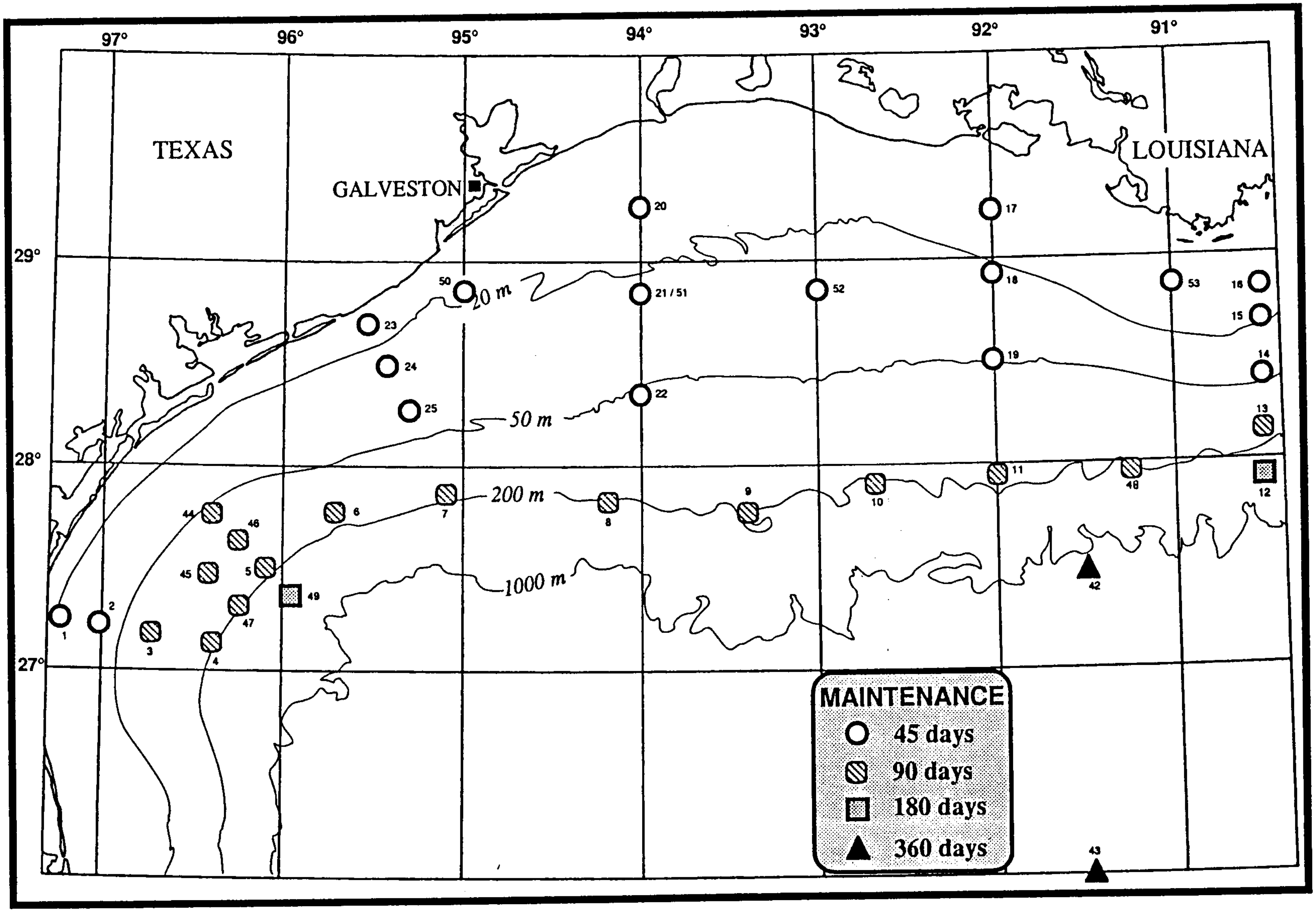

Figure 12.18. Mooring locations and maintenance schedule.

Table 12.1. Mooring Configuration and Maintenance Schedule.

Instrument Location	Mooring #	Type	Temperature	Conductivity	Waves	Meteorological	Release	Service Interval (days)	Water Depth	Meter Depth	Comments
Top	1	174	yes	yes	-	no	no	45	20	10	Witness
Bot	1	MINISPEC	yes	yes	yes	-	-	45	20	17	buoy
Top	2	174	yes	yes	no	no	no	45	30	10	Witness
Bot	2	174	yes	yes	-	-	-	45	30	27	buoy
Top	3	174	yes	yes	no	no	yes	90	60	10	
Mid	3	174	yes	yes	-	-	-	90	60	30	
Bot	3	174	yes	yes	-	-	-	90	60	57	
Top	4	174	yes	yes	no	no	yes	90	200	10	
Mid	4	Aanderaa	yes	yes	-	-	-	90	200	100	
Bot	4	Aanderaa	yes	yes	-	-	-	90	200	197	
Top	5	174	yes	yes	no	no	yes	90	200	10	
Mid	5	Aanderaa	yes	yes	-	-	-	90	200	100	
Bot	5	Aanderaa	yes	yes	-	-	-	90	200	197	
Top	6	174	yes	yes	no	no	yes	90	200	10	
Mid	6	Aanderaa	yes	yes	-	-	-	90	200	100	
Bot	6	Aanderaa	yes	yes	-	-	-	90	200	197	
Top	7	174	yes	yes	no	no	yes	90	200	10	
Mid	7	Aanderaa	yes	yes	-	-	-	90	200	100	
Bot	7	Aanderaa	yes	yes	-	-	-	90	200	197	
Top	8	174	yes	yes	no	no	yes	90	200	10	
Mid	8	Aanderaa	yes	yes	-	-	-	90	200	100	
Bot	8	Aanderaa	yes	yes	-	-	-	90	200	197	
Top	9	174	yes	yes	no	no	yes	90	200	10	
Mid	9	Aanderaa	yes	yes	-	-	-	90	200	100	
Bot	9	Aanderaa	yes	yes	-	-	-	90	200	197	
Top	10	174	yes	yes	no	no	yes	90	200	10	
Mid	10	Aanderaa	yes	yes	-	-	-	90	200	100	
Bot	10	Aanderaa	yes	yes	-	-	-	90	200	197	
Top	11	174	yes	yes	no	no	yes	90	200	10	
Mid	11	Aanderaa	yes	yes	-	-	-	90	200	100	
Bot	11	Aanderaa	yes	yes	-	-	-	90	200	197	
Top	12	174	yes	yes	no	no	yes	180	500	10	
Mid	12	Aanderaa	yes	yes	-	-	-	180	500	250	
Top	13	174	yes	yes	no	no	yes	90	200	10	
Mid	13	Aanderaa	yes	yes	-	-	-	90	200	100	
Bot	13	Aanderaa	yes	yes	-	-	-	90	200	197	
Top	14	174	yes	yes	no	no	yes	45	50	10	
Mid	14	174	yes	yes	-	-	-	45	50	25	
Bot	14	174	yes	yes	-	-	-	45	50	47	
Top	15	174	yes	yes	no	no	no	45	20	10	
Bot	15	174	yes	yes	-	-	-	45	20	17	
Top	16	174	yes	yes	-	no	no	45	10	3	
Bot	16	MINISPEC	yes	yes	yes	-	-	45	10	7	
Top	17	S4	yes	yes	-	yes	no	45	10	3	FGGE Met
Bot	17	MINISPEC	yes	yes	yes	-	-	45	10	7	buoy
Top	18	174	yes	yes	no	no	no	45	20	10	
Bot	18	174	yes	yes	-	-	-	45	20	17	

Table 12.1. Mooring Configuration and Maintenance Schedule (continued).

Instrument Location	Mooring #	Type	Temperature	Conductivity	Waves	Meteorological	Release	Service Interval (days)	Water Depth	Meter Depth	Comments
Top	19	S4	yes	yes	no	yes	no	45	40	3	FGGE Met
Mid	19	174	yes	yes	-	-	-	45	40	20	buoy
Bot	19	174	yes	yes	no	-	-	45	40	37	
Top	20	S4	yes	yes	-	yes	no	45	10	3	FGGE Met
Bot	20	MINISPEC	yes	yes	yes	-	-	45	10	7	buoy
Top	21	174	yes	yes	no	no	no	45	20	10	Same as
Bot	21	174	yes	yes	-	-	-	45	20	17	51
Top	22	S4	yes	yes	no	yes	no	45	40	10	FGGE Met
Mid	22	174	yes	yes	-	-	-	45	40	20	buoy
Bot	22	174	yes	yes	-	-	-	45	40	37	
Top	23	174	yes	yes	-	no	no	45	10	3	Witness
Bot	23	MINISPEC	yes	yes	yes	-	-	45	10	7	buoy
Top	24	174	yes	yes	no	no	no	45	30	10	Witness
Bot	24	174	yes	yes	-	-	-	45	30	27	buoy
Top	25	174	yes	yes	no	no	no	45	40	10	Witness
Mid	25	174	yes	yes	-	-	-	45	40	20	buoy
Bot	25	174	yes	yes	-	-	-	45	40	37	
Echo	42	IES	yes	no	no	no	yes	365	1000	997	Release incl.
Echo	43	IES	yes	no	no	no	yes	365	3000	2997	Release incl.
Top	44	174	yes	yes	no	no	yes	90	60	10	wild, witness
Bot	44	174	yes	yes	-	-	-	90	60	57	buoy
Top	45	174	yes	yes	no	no	yes	90	100	10	wild, witness
Bot	45	Aanderaa	yes	no	-	-	-	90	100	97	buoy
Top	46	174	yes	yes	no	no	yes	90	100	10	wild, witness
Mid	46	174	yes	no	-	-	-	90	100	50	buoy
Bot	46	Aanderaa	yes	yes	-	-	-	90	100	97	
Top	47	174	yes	yes	no	no	yes	90	200	10	wild
Mid	47	Aanderaa	yes	no	-	-	-	90	200	100	
Bot	47	Aanderaa	yes	no	-	-	-	90	200	197	
Top	48	174	yes	yes	no	no	yes	90	140	10	wild - approx.
Mid	48	Aanderaa	yes	no	-	-	-	90	140	100	location of
Bot	48	Aanderaa	yes	no	-	-	-	90	140	140	former 39
Top	49	174	yes	yes	no	no	yes	180	500	10	wild
Mid	49	Aanderaa	yes	yes	-	-	-	180	500	250	
Bot	49	Aanderaa	yes	yes	-	-	-	180	500	497	
SFC	50	FGGE Met Buoy	yes	no	no	yes	no	45	20	SFC	
SFC	51	FGGE Met Buoy	yes	no	no	yes	no	45	20	SFC	same as 21
SFC	52	FGGE Met Buoy	yes	no	no	yes	no	45	25	SFC	
SFC	53	FGGE Met Buoy	yes	no	no	yes	no	45	10	SFC	

eddy influences and eddy-shelf interaction. The data from this array will provide valuable current information for the study of general shelf circulation and for shelf wave propagation. The sixth wild card mooring (Mooring 48) will be installed as part of the boundary array to provide consistent spacial resolution along the oceanic boundary.

The wild-card array will be installed for a minimum of six months and then will be re-installed at the same or a different location as directed by the Contracting Officer's Technical Representative.

- Mass Continuity/Open Boundary Conditions/Surface Waves--All of the cross-shore exchange mechanisms outlined above have the potential to interrupt the continuity of the plume extension of the Coastal Boundary Layer. One of the purposes of the coastal boundary moorings (Moorings 1, 23, 20, 17, and 16) is to determine how continuous a feature the Mississippi/Atchafalaya plume is as it extends westward along the LATEX Shelf. These moorings will provide time series of currents, temperature, and conductivity which, in concert with the hydrographic programs of LATEX A and LATEX B and the satellite measurements of LATEX C, will help delineate the plume extension and its advection.

  Surface wave measurements at these five sites will provide a consistent climatology of the wave energy occurring along the inner LATEX shelf during the three years of the program.

- The FGGE-Type Meteorological Buoys--There are two sets of meteorological buoys associated with the field effort. The first set of moorings (Moorings 21, 22, 18, and 19) is part of the cross-shelf arrays discussed earlier. The meteorological measurements from these buoys will provide information on wind-stress forcing functions over the shelf and will supplement the database for the study of winter northers and cyclogenesis.

  The second set of buoys (Moorings 50, 51, 52, and 53) will be installed and maintained to collect meteorological data to support the study of winter northers and cyclogenesis. These buoys have no current meters associated with them; however, buoy 51 will be physically located at the site of current meter mooring 21.

  All meteorological buoys will transmit their data via Service ARGOS. These data will include wind speed and direction, air and sea temperature, barometric pressure, and, in the case of buoys 17, 19, 20, and 22, current velocity. The buoys will be serviced every 45 days and data will be stored internally to backup and augment the ARGOS transmitted data.

- Inverted Echo Sounders--Two IES moorings (Moorings 41 and 42) will be installed at the base of the continental slope in deep water. These units measure and record the time for an acoustical signal to travel from the instrument to the sea surface and back. These time series of travel time can be analyzed to provide valuable information on the time variation of several dynamic ocean variables, such as thermocline displacement and dynamic height. This information can be used to signal the approach of Loop Current eddies, as well as other mesoscale thermohaline features, to the eastern LATEX Region.

Servicing and Maintenance

Thirty-six moorings (31 current meter/wave/meteorological, two IES, and three meteorological) require substantial personnel and vessel time. Personnel to accomplish this work will be supplied by EHI, TAMU, and LSU. The vessel used will be based in Galveston, Texas, and TAMU's facility there will be used to mobilize and demobilize for the numerous cruises.

Because of the varying depths of the moorings there are different approaches and time intervals for servicing. The intervals for servicing the moorings are listed in Table 12.1 and are shown in Figure 12.18. Tables 12.2a and 12.2b summarize the number of cruises, the number of moorings per cruise, and the length of each cruise. There is a total of 25 cruises scheduled encompassing 342 days of ship time. As a great deal of work must be performed in the relatively short periods of time allotted for each mooring, each mooring cruise will be planned carefully and will be manned by a sufficient number of experienced personnel.

The shallowest moorings will be maintained by divers; whereas, the deeper moorings will be retrieved through the use of acoustic releases and rope canisters which will allow the anchors to be recovered. Only for the moorings deeper than 500 m will the anchors be jettisoned. As a backup retrieval procedure, divers will be available to attach lifting lines to the subsurface moorings.

To facilitate the maintenance of moorings, spare instruments will be carried aboard the servicing vessel. These instruments will be installed on the first applicable mooring and the mooring reinstalled. The data from the retrieved meters will be downloaded to computers. Prior to re-installation of any meter, the data recovered from it will be checked for completeness, accuracy, and reasonableness. The operation of the meter itself will also be verified, and no instrument will be reinstalled if its operation is the least bit questionable. The meters will then be repaired, if necessary, cleaned, checked, refurbished, and repainted while the ship is underway to the next mooring. These refurbished instruments will then be used to replace the meters on that mooring.

A completely equipped current meter van will be installed on the servicing vessel to provide a clean, well-equipped facility for handling the instruments. A second van will be installed on the ship for painting the retrieved meters. After each servicing, a conductivity/temperature/depth (CTD) profile of the water column will be taken with an internally recording Sea Bird CTD. These data will be used to check the calibrations of the temperature and conductivity sensors on the current meters and to

Table 12.2a. The Number of Maintenance Cruises and Their Distribution Per Project Year.

Year	Initial	45 Day	90 Day	180 Day	Annual	Final	Total
Year I	1	2	1	-	-	-	4
Year II	-	4	2	1	1	-	8
Year III	-	4	2	1	1	1	8
Year IV	-	2	1	1	-	1	5

Table 12.2b. Number of Moorings, Cruises, and Estimated Shipdays for Each Type of Maintenance Cruise.

Maintenance Schedule	No. of Moorings	Total Cruises	Shipdays/Cruise
Initial deployment	36	1	18-20[1]
45 day maintenance	17	12	10-12[2]
90 day maintenance	32	6	15-16[1]
180 day maintenance	34	3	17
Annual maintenance	36	2	19
Final retrieval	36	1	18-20[1]
Total Cruises		25	342-352

[1]included are Task A-6 Meteorological Buoys
[2]two of the 45-day cruises in Years II, III, and IV are 12-day cruises due to retrieval and deployment of meteorological buoys

augment the data taken during the hydrography cruises.

ADDITIONAL DATA COLLECTION ACTIVITIES

In addition to the work to be performed servicing and maintaining the current meter/wave/meteorological moorings, assistance will be provided for the study of winter northers and cyclogenesis and for the deployment of the ARGOS drifting buoys at designated sites.

A third activity associated with, but not part of, the current meter mooring effort is the collection of ADCP data during the LATEX A hydrographic cruises. These data will be obtained with 150 kHz RD Instrument ADCPs installed in instrument wells on both the R/V *Gyre* and the mooring vessel. These data will be obtained in the travel time between hydrographic stations and will be used to verify the operation of the fixed current meters and to provide continuity of the current velocity field between fixed moorings. Additionally, the data will be monitored in real time, and any information of significance will be relayed by radio to the Program Manager to assist other aspects of the LATEX study.

SUMMARY

The LATEX A mooring program consists of 31 current/wave/meteorological moorings, three meteorological moorings, and two IES moorings which will be installed and maintained over a three-year period beginning in April 1992. Additionally, five witness buoys will be deployed to protect particularly vulnerable shallow moorings. On these instrument moorings, a total of 76 currents meters, five directions wave/current meters, eight ARGOS transmitting meteorological buoys, and two IES units will be deployed. These moorings and instruments will be maintained at intervals varying from 45 to 360 days, depending on water depth, over a period of three years. This work will be performed by a well-trained, experienced team made up of personnel from EHI, TAMU, and LSU.

Mr. Robert Hamilton has managed the Houston office of Evans-Hamilton, Inc. for the past 20 years, and he is currently President of the company. His primary areas of interest have been in the collection of physical oceanographic data and the development of instrumentation systems. Mr. Hamilton received his B.S. in mechanical engineering from Purdue University and his M.S. in physical oceanography from the University of Washington.

A PROGRAM OF STANDARD GRID HYDROGRAPHY FOR THE TEXAS-LOUISIANA SHELF

Dr. Denis A. Wiesenburg
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INTRODUCTION

Using data to be collected during hydrographic surveys of the Texas-Louisiana (LATEX) shelf, we will characterize seasonal water mass patterns and circulation, study water mass modifications and dynamical processes of circulation, and begin to assess inter-annual variability. The proposed 13 seasonal hydrographic surveys will provide the most comprehensive study yet of water properties over the LATEX continental shelf and upper slope. Each quarterly survey will consist of a minimum of 100 stations on a grid that intensively samples two quadrants of the shelf. The results will substantially refine our view of the spatial distribution and the seasonal variability of temperature, salinity, dissolved oxygen, nutrients, particle scattering, downwelling irradiance, and phytoplankton pigments over the study area. Maps of the hydrographic parameters will be used to infer advective processes. Further, the data will be used to examine the complex relationships among the many parameters, such as suspended particulate matter, chlorophyll, and water stratification, thus contributing important physical and chemical information needed for synthesis with biological data into a broader ecological characterization of the region. Most importantly, the LATEX study provides the first opportunity to couple shelf-wide hydrographic surveys with shelf-wide current meter moorings.

SURVEY PATTERN

Hydrographic surveys will be conducted on cruises timed to coincide with (either just before or just after) the quarterly mooring cruises. The stations will be organized into cross-shelf transects, transects along the 50-m isobath, and transects along the 200-m isobath near the shelf edge. The cross-shelf transects will include transects along the cross-shelf lines of current meter moorings, supplemental transects between the current meter mooring lines, and one transect across the shelf at the Texas-Mexico border. On cross-shelf transects along the cross-shelf moorings, hydrographic stations locations will span each mooring.

There will be three major transects in each year that go across the entire shelf from the shallowest practical depth to 500 m. These across-shelf transects, together with the 200-m along-shelf transect, will provide data (hydrographic and shipboard acoustic doppler current profiler) on the oceanic boundaries of two boxes encompassing an area approximately equal to one half of the LATEX region. Together with data along the coast (e.g., river discharge data) and sea surface flux information that will be collected or assembled by this and other projects, fluxes across the boundaries of these boxes can be used to study along-shelf transports of a variety of properties of interest. Moreover, the closure of the shelf into boxes provides information that can be used as internal constraints or as verifications of future models of the physical oceanography of the LATEX region that we assume will be initialized and/or driven by data collected along the outer boundaries of the region. The 50-m along-shelf transect will divide each of the "quadrants" or boxes of the LATEX region into two smaller boxes or volumes. Sampling along the 50-m isobath also will provide data needed for the description of across-shelf fluxes in each season.

STATION SPACING

The choice of location and spacing of hydrographic stations for this study is based on our knowledge of spatial scales in the study region, and the scientific objectives of the study. The regions to be surveyed in each of the three years are roughly 220 km by 330 km in size. A uniform grid of about 100 stations would require a station spacing of about 30 km, which is patently too large. The gradients of all water properties are larger in the cross-isobath direction than the along-isobath direction, and so the number of cross-shelf transects must be sacrificed in favor of the number of stations along each cross-shelf transect. Station separation was derived from observations and theoretical considerations.

Several estimates of the first baroclinic Rossby radius were calculated with values of p taken from a cross-shelf vertical density section collected off Galveston in March 1982. A length scale based on the baroclinic Rossby radius is about 10 km over the middle shelf. Over the inner shelf and outer shelf-slope the length scales lie in the ranges of 3 to 10 km and 8 to 25 km, respectively, depending on the importance of the higher modes. Station locations we have chosen are shown in Figure 12.19.

The coastal boundary layer (CBL) typically is found in water depths of 30 m or less and is fed by the combined discharges from the Mississippi and Atchafalaya Rivers. Our study will begin in the shallowest practical depths, which is in the region of the CBL. Previous work in the CBL (Sklar and Turner 1981; Wiseman *et al.* 1986; Sahl and Merrell 1987) shows that hydrographic stations must be closely spaced (approximately 5 km) to accurately map the large gradients of salinity and other properties.

On the middle shelf the salinity gradient is weaker and the water column structure is less complicated (Smith 1980; Sahl and Merrell 1987). This region can be mapped adequately with a cross-shelf station spacing of 10 km. At the shelf/slope break the hydrographic structure is frequently complex. Small-scale features in the cross-shelf direction and the presence of a narrow eastward (shelf-edge) current necessitate close spacing of stations (approximately 5 km across-shelf) in order to delineate and describe features in the density field.

In order to maximize the data available from the resources used, the along-shelf emphasis of our hydrographic survey is on the mid- and outer-shelf regions represented by the 50-m and 200-m isobaths. The selection of the 50-m isobath as the inner along-shore transect is based on information that the CBL generally is found inshore of this isobath. The 200-m isobath has been selected as

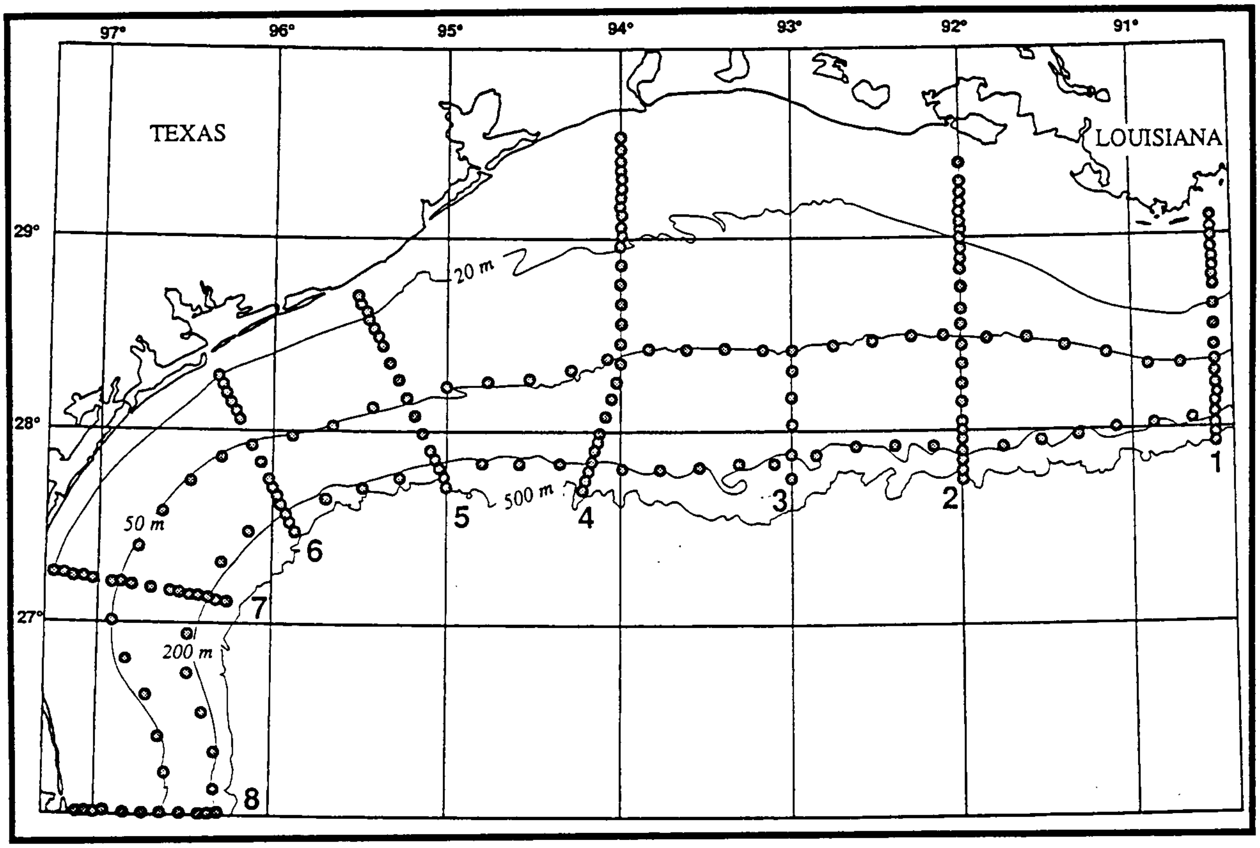

Figure 12.19. Locations of CTD stations for standard grid hydrography cruises.

the outer along-shelf transect because of its close proximity to the shelf break.

The stations on the two along-shelf transects will be spaced approximately 20 km apart. The 20-km station spacing is planned for two reasons. First, for transport along the 200-m isobath, this is the approximate length of the first baroclinic Rossby radius of deformation at the outer shelf slope and will resolve the principal baroclinic structure. Finer scale structures associated with the higher modes will not be well resolved. For the box models, the station spacing for the transect along the 50-m isobath will be made consistent with that of the 200-m isobath transect, i.e., 20 km. Second, oil spill and ocean circulation models will have typical horizontal resolutions of 10 to 20 km. Thus, 20-km station spacing should provide reasonably adequate information for modelers at the boundary of the study area.

MEASUREMENTS

At each station continuous profiles of the following parameters will be collected: salinity, temperature, dissolved oxygen, downwelling irradiance, and particle scattering. At each station we will also collect continuous profiles of *in situ* fluorescence and beam attenuation coefficient (transmissometry). These measurements are necessary as an aid in sampling and for a complete assessment of the biological and optical characteristics of the survey area. At each station, depending upon depth, water will be sampled from standard depths (0, 10, 20, 30, 50, 75, 100, 150, 200, 250, 300, 400, and 500 m) with supplemental sampling when standard depths are not sufficient to show the details in water column hydrography.

All water samples will be analyzed for the nutrients nitrate, nitrite, phosphate, silicate, urea, and ammonium. Dissolved oxygen and salinity samples will be collected and analyzed aboard ship from about 40 of the stations during each of the cruises in order to check and calibrate the continuous profile data. Water bottle measurements of salinity and dissolved oxygen will be made aboard ship at additional stations when features of interest are observed. Salinity samples will be collected from all of the water bottles, and those samples not analyzed aboard the ship will be returned to the laboratory. Analysis of these samples will be made if necessary for determining problems with bottle tripping or for further conductivity/temperature/depth calibration.

Phytoplankton pigment concentrations will be determined on water samples collected at selected stations. These stations will be determined by examining fluorimetry data in real time. We plan to analyze water samples from 40 stations per cruise for phytoplankton pigments. When a station is selected for sampling (based on location and the real-time fluorescence data), all water bottles at depths where there is measurable fluorescence will be sampled. This protocol ensures that the total phytoplankton biomass (surface to bottom) can be determined at each station where the samples are collected.

At selected stations, surface and bottom water will be collected and analyzed to determine particulate matter concentrations. We plan to analyze water samples from 40 stations per cruise for particular matter concentrations. These stations will be selected in order to obtain samples in all regions of the study area. The exact stations to be sampled will also be guided by examination of particle scattering and beam attenuation coefficient data gathered in real-time aboard the vessel. These data will be examined to identify general areas of high and low turbidity and to locate water column nepheloid layers. Water samples will also be obtained from these nepheloid layers for particulate matter analysis in addition to the surface and bottom samples. Secchi disk depth also will be determined at each station occupied during daylight hours.

A weather log will be maintained and will include measurements of standard shipboard meteorological variables. This weather log information will be transmitted to the Global Telecommunications System of the World Meteorological Organization during each hydrographic survey.

YEARLY SURVEY PLANS

In the first field year of the study, five surveys, one initial and one in each season, will be conducted in the easternmost two quadrants of the study area (Figure 12.20). On each cruise, stations shall be occupied along lines 1, 2, 3 and 4 across the shelf, and approximately along the 50-m and 200-m isobaths between lines 1 and 4. At least 100 stations will be occupied on each survey. In the second year of the study, four surveys, one in each season, will be conducted in the two middle quadrants of the study area (Figure 12.21). These surveys will be similar to those described in the Year 1 Survey Plan. During the third year of the study, four surveys, one in each season, will be conducted in the westernmost two quadrants of the study area (Figure 12.22). These surveys will be similar to those described for years 1 and 2 except that more transects completely across the shelf are proposed for Year 3. Extra transects will allow better description of the area within which the southwestward currents on the inner shelf turn across the shelf to join/become the northeastward flow along the outer shelf edge (Cochrane and Kelly 1986).

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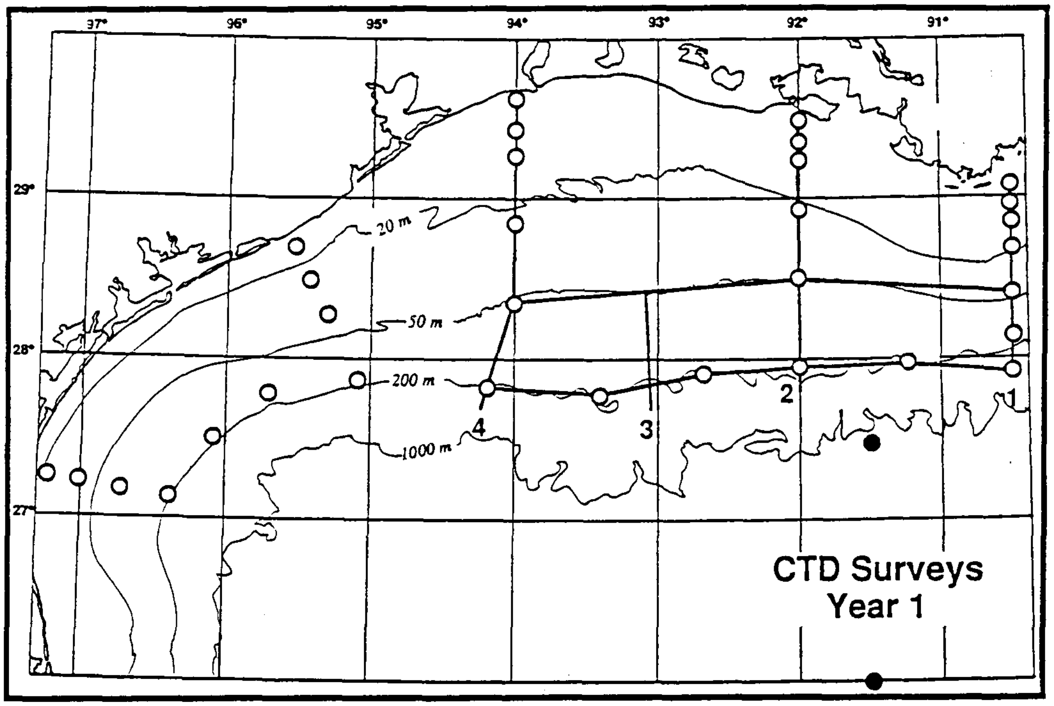

Figure 12.20. Standard hydrographic survey transects proposed for Year 1. (Solid lines are the CTD transect lines. Approximate locations of moorings are shown by open circles. The closed circles are proposed positions for the inverted echo sounders.)

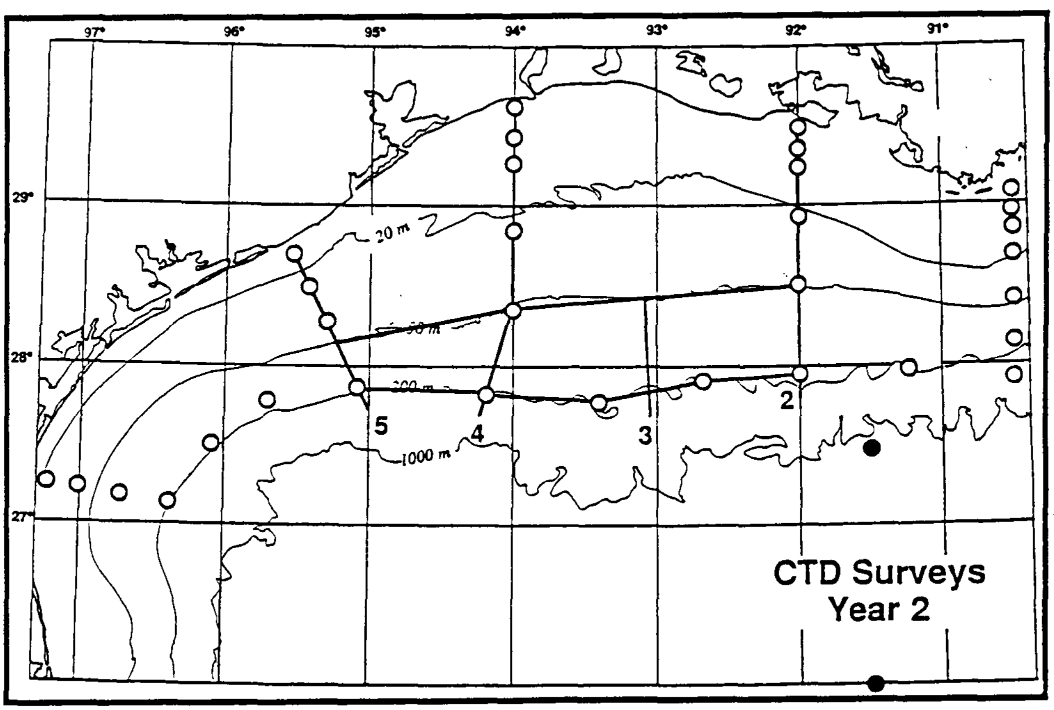

Figure 12.21. Standard hydrographic survey transects proposed for Year 2. (Solid lines are the CTD transect lines. Approximate locations of moorings are shown by open circles. The closed circles are proposed positions for the inverted echo sounders.)

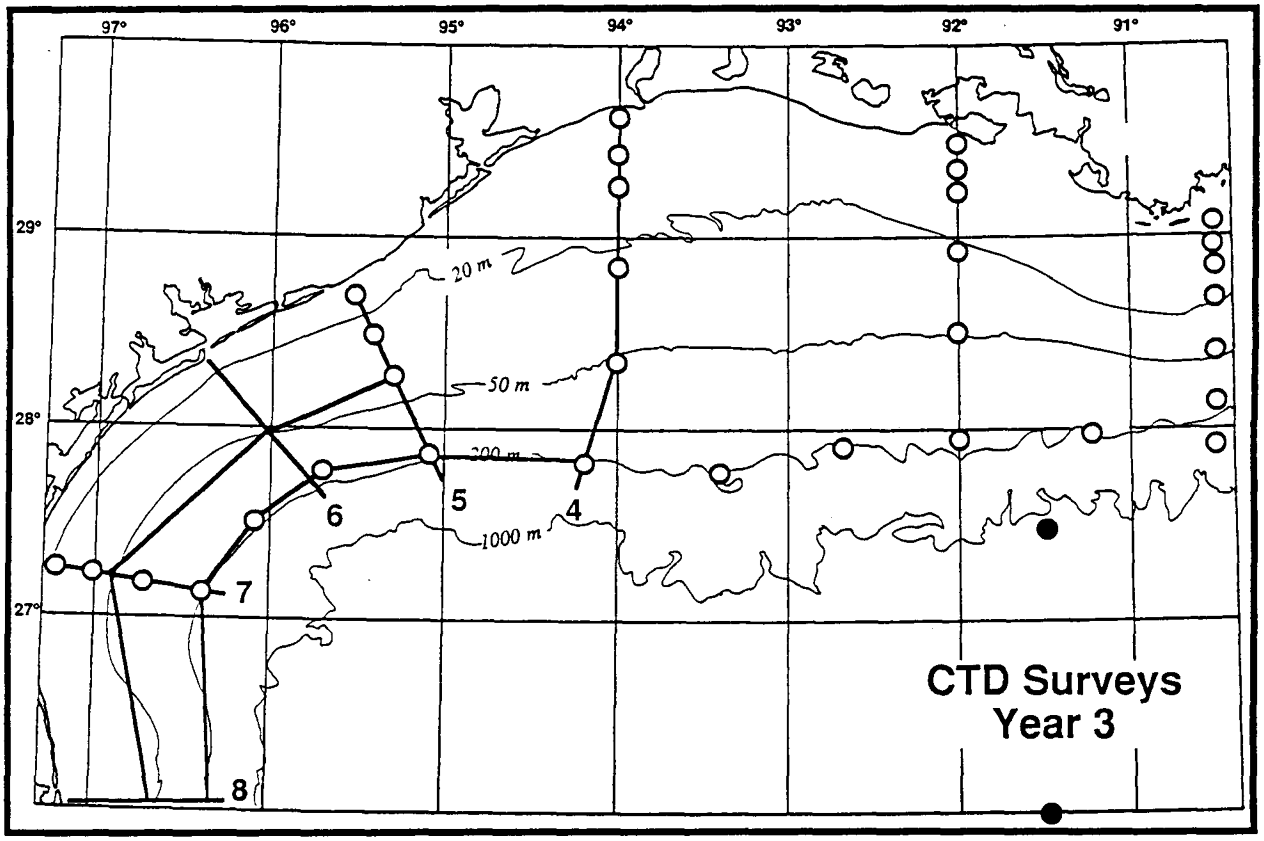

Figure 12.22. Standard hydrographic survey transects proposed for Year 3. (Solid lines are the CTD transect lines. Approximate locations of moorings are shown by open circles. The closed circles are proposed positions for the inverted echo sounders.)

Dr. Denis A. Wiesenburg has worked at Texas A&M University for the last three years and is presently an Associate Research Scientist in the Geochemical and Environmental Research Group. He serves at the Principal Investigator of the LATEX A Standard Grid Hydrography Program. His areas of research interest are ocean frontal processes, interactions of physical and biological processes in the ocean, and anoxic systems. Dr. Wiesenburg received his A.B. in chemistry from Duke University, his M.S. in oceanography from Old Dominion University, and his Ph.D. in oceanography from Texas A&M University.

CRITICAL ASPECTS OF INFORMATION AND DATA MANAGEMENT FOR LATEX A

Dr. Norman L. Guinasso, Jr.
Texas A&M University

The LATEX A will carry out all data management tasks in a centralized Data Management Office (DMO). This DMO will be responsible for all data handling, indexing, error checking, back-up, status checking, inventory reporting, secure distribution, and archiving - from postcruise processing and quality control through final data submission to NODC. In addition, the DMO will collect collateral data from other programs, transfer data and information to other LATEX programs, and facilitate notification of public and government interests about ongoing LATEX A activities.

DATA MANAGEMENT PLAN

The overall Data Management Plan is based on the following concepts:

- Data Manager institutes and maintains chain-of-custody procedures for all LATEX data.
- Calibrations are done by the data originator, and provided immediately to the DMO.
- Data Originator collects the data.
- Within two days after the end of each data collection cruise or onshore sample analysis, the Data Originator, after making copies of all data, will provide the data and supporting documentation to the DMO. Original records will not be mailed.
- The DMO copies, inventories, and archives all raw data and turns the data over to the Quality Control Group (QCG). To ensure safe storage and easy retrieval, all data files are maintained on online computer disks with multiple backup copies kept on magnetic tape. Status of all data is maintained by the DMO in a computerized data tracking system.
- The QCG will inspect each data set, perform all needed post-cruise processing, make corrections where necessary, and produce preliminary standard products and preliminary clean data sets.
- Preliminary products are returned to data originator for possible feedback.
- After receiving feedback from data originator, the QCG transfers final clean data sets and supporting documentation to central files in the DMO.
- The DMO produces standard data products and announces data availability under the Information Transfer Program. This includes posting notice of data availability on the GULF.MEX Bulletin Board.
- The DMO places data in NODC formats and transfers data to NODC as "provisional data" within three months of date of obtaining each data set.
- At the conclusion of the Contract, DMO will, after making corrections to all identifiable errors, rearchive data in standard formats at the NODC as "final contributions."
- Other tasks related to data management will be carried out by the DMO. These include assembly of collateral data, data quality control, information transfer, and public notification.

PERSONNEL

Dr. Norman L. Guinasso, Jr., manager of the DMO, will have overall responsibility for data management, collateral data assembly, public notification, and information transfer. Mr. Matthew Howard will be responsible for quality control and will head the QCG which includes members of the DMO and Principal Investigators. Mr. Frank Kelly will serve as data specialist for current meter data. Howard and Kelly will prepare standard products and analyses. A computer programmer will assist with all tasks carried out in the group. A data clerk will log in all data, update catalogs and indices, and provide routine data entry/retrieval and filing. A secretary will assist with all phases of the data management work and will assist with the preparation of the fortnightly information flier *LATEX Fortnightly News*. Howard will be responsible for the technical inclusions in the *LATEX Fortnightly News*.

DATA COLLECTION AND TRACKING

The DMO will set up a system based on a data tracking index for the data. This will ensure that no loss of information occurs in any processing step, from at-sea collection to final archiving at designated facilities.

Prior to the first data collection cruise, the DMO and the Principal Investigators (Data Originators) will agree on a format for an inventory for all data to be collected on each cruise. A form will be used that describes each intended data item (e.g., current meter record, conductivity/temperature/depth cast, acoustic doppler current profile [ADCP] data set) and provides space for entry of floppy disk ID's, data file names, time and date of collection, and other pertinent information. The form shall be partially filled out and a copy sent to the DMO before each cruise. These forms will be used to update a data tracking index that will contain an index of all data sets, derived data sets, and final products. The tracking index will be capable of producing readable reports that will indicate the status of each data item (e.g., now being collected, raw data received by DMO, in QCG, passed QCG, Originator-approved final product, IODE formatted, etc.).

After each cruise the Data Originator will send all raw data and supporting documentation together with the completely filled out form to the DMO. All data files and supporting documentation will be checked against the inventory and the tracking index will be updated.

The tracking index will be maintained on a GERG VAX computer. A duplicate version of this index will be maintained on the VAX in the Texas A&M University Oceanography Department. The tracking index will be updated daily. All data files will be tracked and their status recorded in the index through each phase of data processing.

QUALITY CONTROL

All post cruise processing and quality control will be centralized in the DMO in the QCG. Data collected by the different program tasks will be passed through the data quality procedure in which questionable data and/or erroneous data will be identified and corrected. This procedure will involve the preparation of preliminary products, such as plots and data listings, and checks of data for consistency and plausibility, both internally and by comparison to historical data. Any errors should be identified in this step. After corrections are made, the cleaned up data set will be returned to the originator for comment. After resolution of all comments, the data will then be certified as a final data set and will be transferred from the QCG to the DMO where it will be formatted according to NODC specifications. Each final data file will be verified as to its completeness and accuracy. Calibration records and logs will be maintained for all instruments and all field notes, logs, and comments stored with each set of data. Any questionable data will be referred to the appropriate task Principle Investigator for clarification or correction.

The data which pass quality control can then be disseminated to the remaining tasks for their use in analysis. All data which are received by the different tasks, except collateral data, will have passed through quality control, will be in a standard format, and will be complete and accurate. We assume the quality of collateral data will be controlled by the groups producing these data.

TECHNICAL ASPECTS OF DATA MANAGEMENT

Computer files for the program will be copied in many systematic ways to ensure that a copy of all data is maintained and available under any foreseeable circumstance. The DMO will generate a weekly inventory listing from the tracking index giving the status of all data files. The security of the data files will be controlled by the DMO through monitoring and control of access to the data files. All validated data files, documentation, information logs, management files, produced imagery, graphics, and information delivered to Minerals Management Service (MMS) will be archived and stored in a safe manner and a catalog of all final data will be maintained. This catalog will provide a brief description of each set and how it can be accessed. All final data will be stored on the VAX computer on line for easy access by local users or by others over the network. The DMO will place all final data in NODC formats and transfer data to NODC as "provisional data" within three months of the date of obtaining each data set.

DISCUSSION OF INDIVIDUAL DATA TYPES

Six sources of information will be flowing into the DMO over the course of this program: data from the moored arrays, hydrographic data, data from ARGOS-tracked surface drifters, ADCP collected aboard ship, meteorological data, and collateral data. Additionally, all correspondence and documentation from the Program Management Office will be routed through the DMO for archival.

The collateral data will consist of databases, comprehensive model simulations, and climatologies accumulated or produced by Federal or state agencies, universities and colleges, and the private sector, including the offshore industry. At the beginning of and throughout the study, we will obtain data and reports from concurrent MMS programs, internal sources, and all public domain sources. These data will be transferred and incorporated into the program data base on the DMO VAX computer. The contents of this data base will be used to supplement and expand the Program's work effort. This data base also will be used in the synthesis and interpretation of the data obtained by the Program. The assembly of collateral data sources is discussed in Section 7.0. The DMO will receive these data sets via networks or on tape.

The current meter mooring task contains 10 types of arrays and sampling strategies for describing the physical system. These data files will all be received via networks or diskette. Each current meter will have a file that will contain copies of the raw data, time history plots of that data, and a copy of the Transmittal Quality Control Record (TQCR). The TQCR will contain all pertinent information about the instrument, its setup, and the data being transferred. The TQCR will also contain a delineation of all sections of incorrect and questionable data, a description of problems associated with the record, and an estimate of the data quality. All information pertinent to a particular record will be transcribed to the TQCR. The original data records, copies of the final edited data, and the applicable TQCR will then be contained in these files. The DMO will then perform format archival, further quality control, and dissemination procedures.

The ARGOS-tracked drifting buoy data will consist of data transferred three times a week from the ARGOS computers via TYMNET network. Additionally, data will be obtained by mail from Service ARGOS data on 9 track magnetic tape every two weeks. All drifter data from this program will be maintained by the DMO in files on our VAX computers for easy access by scientific investigators via NSFNET, Internet, SPAN, or by telephone line.

Hydrographic data will consist of continuous profile measurements from a CTD instrument for temperature and salinity, particle scattering, transmissometry, dissolved oxygen, and downwelling irradiance. Discrete measurements of light penetration, nutrients, meteorological observations, phytoplankton pigments, and particulate matter will be made. All of these data will be received via network or diskette for incorporation into the data base and further quality control and dissemination.

The ADCP data will be collected continuously during each quarterly hydrographic cruise. The data will be recorded on a personal computer (PC) and backed up on diskettes. Profile number, time, date, latitude, and longitude will be recorded along with other needed information for each current profile. This will allow the data to be carefully tracked and guarantee minimal loss of data. The DMO will receive these files via computer diskette. They will include: (1) a TQCR containing all information relative to the ADCP and the data contained in a data set, such as the instrument configuration file, the time period of the record, and comments regarding the data; (2) listings and plots of the current profiles obtained at each mooring together with the corresponding currents obtained from the *in situ* meters; and (3) time history vector plots along each transect.

Meteorological data from the ARGOS moored meteorological buoys will be obtained at least monthly via networks, quality controlled by the QCG, and then archived and disseminated by the DMO. More frequent captures of small amounts of data from these buoys will be made periodically to check on the operating performance of the buoys.

Other meteorological records will contain the routine data related to the existing National Weather Service (NWS) and National Data Buoy Center (NDBC), whether they are landbased stations operated by NWS or National Oceanic and Atmospheric Administration (NOAA) buoys maintained by NDBC (including the Coastal Marine Automated Network, CMAN). These will be obtained monthly from the National Climate Data Center in Asheville, North Carolina. Standard quality assurance/quality control will be applied to these data sets prior to transmitting via network to the DMO where they will be subjected to second level quality control procedures.

INFORMATION TRANSFER

Information generated by this Program will be important to other MMS contractors concerned with the oceanography of the Gulf of Mexico, particularly to those interested in the area of the LATEX shelf.

The DMO and the Program Management Office of this Program will provide reports of progress and developments in the field measurements program to concurrent modeling and field measurements studies contracted by MMS.

This communication shall be accomplished through monthly progress reports, annual reports, cruise/survey reports, and electronic mail communications. Additional information transfer will take place at meetings including Environmental Studies Meetings, Information Transfer Meetings, and the annual meeting of the Physical Oceanography Review Board, supported by another Contractor. We also propose to provide additional communication through the dissemination of the minutes of annual meetings of the LATEX A Scientific and Technical Steering Committee.

Within three months after the completion of each hydrographic survey cruise, the DMO will provide to other MMS physical oceanographic studies contractors, as designated by the MMS Contracting Officer, the hydrographic survey results. The survey will be in the form of data report which will include a station and track chart as well as contoured charts showing areal distributions, contoured vertical sections along profiles, and scatter plots of standard hydrographic or physical parameters. The data on magnetic media will be supplied directly to other contractors upon their request.

We will provide images representing the hydrography sections via electronic mail with a mechanism similar to GULFPLOT, using posted computer programs capable of presenting graphic images other than charts.

PUBLIC NOTIFICATION

It is important that all those with interests in the Gulf of Mexico know what the LATEX program is doing, where the program's studies are being conducted, and what results have come from the program. Many kinds of agencies and individuals will be interested. Mariners and fisherman, and military interests will need to know of the locations of buoys and moorings deployed during the program. Others might be interested in the data themselves. For example if this program had been in operation during the *Mega Borg* oil operation in June of 1990, knowledge of the accurate current measurements would have been quite helpful to those forecasting the movement of the slick. It is also important to provide information to those who might be helpful to the program. For example, a fisherman who had been informed of the purposes of the LATEX program might be inclined to notify us if he found one of our moorings adrift.

Before installing any moorings, we will contact the U.S. Coast Guard and supply them with intended positions and description of the moorings. Immediately after the deployment or repositioning of all fixed moorings of all types, we will contact the Defense Mapping Agency and appropriate U.S. Navy Submarine commands with a full description of the installation(s).

We will identify and synthesize a mailing list (LATEX mailing list) of all Federal and State (Louisiana, Mississippi, Alabama, and Texas) agencies interested in marine affairs, marine laboratories, Sea Grant agents, major fishing fleet offices, oil industry operations offices, and centers of vessel and low-flying aircraft traffic (such as offshore helicopter services), in order to provide a mechanism for notifying the public of the purpose of the work and the types and locations of the emergent objects.

Beginning one month after the first deployment of the buoyed moorings, we will prepare and provide twice-monthly to the LATEX mailing list a one-page data summary sheet. This sheet, dubbed the *LATEX Fortnightly News,* will include easily read charts of the average surface current vectors from the buoyed moorings, trajectories of drifters, a summary of meteorological information gathered from the ARGOS buoys, and other pertinent information on the progress of the program.

COLLATERAL DATA ASSEMBLY

We will assemble the data sets taken concurrently with the field work of this Program and the analyses and syntheses of past pertinent studies of the Gulf of Mexico that may be included and used in the overall synthesis of physical oceanographic data for the LATEX region. The LATEX A will be the "lead field measurements contractor" for the MMS program of closely related physical oceanographic and hydrographic programs dealing with the Gulf of Mexico. As such, we shall receive, in a timely fashion, from the MMS contractors for the Mississippi River Plume Hydrography and the Gulf of Mexico Eddy Circulation both data reports and report volumes synthesizing the results of their work. Data on winds, waves, and coastal water levels that are collected concurrently with the field work for this program will be assembled from Federal and cooperating industry sources and included in our database for synthesis with the current data. Historical information, including existing databases, comprehensive model simulations, and climatologies, that are in the form of reports, publications, and other syntheses bearing on the physical forcing, currents, and transports of the LATEX Shelf will be identified, obtained, and included in our database and overall synthesis as described below.

Dr. Norman L. Guinasso, Jr. received his M.S. in 1975 and his Ph.D. in 1984 in oceanography from Texas A&M University. He is currently Associate Research Scientist in the Geochemical and Environmental Research Group at Texas A&M University. His research interests include the study of Gulf of Mexico seep communities and geological and physical oceanography of the Gulf of Mexico. He has led numerous oceanographic cruises in surface ships and deep-diving submersibles.

THE PANAMA OIL SPILL RECOVERY STUDY

Session: THE PANAMA OIL SPILL RECOVERY STUDY

Co-Chairs: Dr. James J. Kendall
Dr. Robert S. Carney
Dr. Thomas E. Ahlfeld

Date: November 7, 1991

Presentation	Author/Affiliation
The Panama Oil Spill Recovery Study: Session Introduction	Dr. James J. Kendall Minerals Management Service Gulf of Mexico OCS Region, Dr. Robert S. Carney Coastal Ecology Institute Louisiana State University, and Dr. Thomas E. Ahlfeld Minerals Management Service Environmental Studies Branch
A Review of the Spill, The First Few Weeks	Dr. Brian D. Keller Smithsonian Tropical Research Institute
Effects of the 1986 Bahía Las Minas Oil Spill on Tidal Flat Communities	Dr. John D. Cubit Smithsonian Tropical Research Institute
Effects of the 1986 Bahía Las Minas Oil Spill on Reef Flat Stomatopods	Dr. Roy Caldwell and Dr. Richard Steger University of California, Berkeley
Mortality and Long-Term Recovery of Subtidal Reef Corals After the 1986 Oil Spill in Panama	Mr. Héctor M. Guzmán and Dr. Jeremy J.B. Jackson Smithsonian Tropical Research Institute
The Effects of the Bahía Las Minas, Panama, Oil Spill on Seagrass Meadow Communities	Dr. Michael J. Marshall Mote Marine Laboratory
The Impact and Long-Term Recovery of Mangrove Forests Following the 1986 Oil Spill in Panama	Dr. Norman C. Duke Smithsonian Tropical Research Institute
The Persistence of Oil Spilled in Mangrove Ecosystems	Dr. Kathryn Burns, Ms. Lauren Yelle, Mr. David Jorissen, and Mr. Matthew Stoelting Bermuda Biological Station for Research

(Continued)

Session: THE PANAMA OIL SPILL RECOVERY STUDY (continued)

Presentation	Author/Affiliation
Fringing Mangroves and the Epibiota of Their Roots: Effects of the Bahía Las Minas Oil Spill During the First Five Years After the Spill	Dr. Sally C. Levings and Mr. Stephen D. Garrity Smithsonian Tropical Research Institute
Tying It All Together: Open Panel Discussion – All Participants and Scientific Review Board Members	Dr. James J. Kendall Minerals Management Service Gulf of Mexico OCS Region

THE PANAMA OIL SPILL RECOVERY STUDY: SESSION INTRODUCTION

Dr. James J. Kendall
Minerals Management Service
Gulf of Mexico OCS Region,
Dr. Robert S. Carney
Coastal Ecology Institute
Louisiana State University,
and
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Minerals Management Service
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On April 27, 1986 at least eight million liters of medium-weight crude oil spilled from a ruptured storage tank in the Bahía Las Minas on the Caribbean Coast of Panama. This is the greatest amount of oil spilled directly into a sheltered coastal habitat in the tropical Americas. What makes this spill of special interest is that it occurred quite "literally" on the doorsteps of the Smithsonian Tropical Research Institute's Galeta Laboratory. Here, resident and visiting scientists have been studying the ecology of the Bahía Las Minas and the adjacent areas for over 15 years.

For those of us working in the Gulf of Mexico, this spill is of particular interest because many of the coastal environments and the species affected may be very similar to those of the Gulf of Mexico. Almost immediately, the Minerals Management Service (MMS) and Smithsonian Tropical Research Institute (STRI) began discussions as to a strategy to study the effects of the spill; shortly thereafter, plans for a five-year study were finalized. The objectives of this project are to document long-term changes in spatial and temporal distribution and abundance of populations and communities of the region which may result from the spill, and to understand, ecologically, the processes which cause the observed changes.

During this session a series of reports was presented describing the studies being conducted in Panama. Because this was the final year of the study and the individual Scientists-in-Charge of the various sub-projects were dispersed from California to Bermuda, this session was also intended as the final forum for the exchange of data and ideas just prior to the final synthesis effort. To facilitate this dialogue, the members of the study's Scientific Review Board were also invited to participate, particularly during the Open Panel Discussion following the last scheduled presentation.

Dr. James J. Kendall is a biologist with the Minerals Management Service's Gulf of Mexico OCS Region, Office of Leasing and Environment, Environmental Studies Section. His research interests include the effects of contaminants on the physiology of corals, the behavior of reef animals, and procedures for aquatic toxicity testing. Dr. Kendall's experience in the effects of contaminants on marine organisms and systems began when he developed an *in situ* procedure for testing the effects of offshore drilling muds on the calcification rate, protein content, and amino acid composition of corals. He has conducted research and monitoring programs in the Gulf of Mexico, Galveston Bay, the Florida Keys, and the Gulf of Eilat, Red Sea. Dr. Kendall received his B.S. in biology from Old Dominion University and his Ph.D. in oceanography from Texas A&M University.

Dr. Robert S. Carney received his M.S. (1969) and Ph.D. (1977) degrees in biological oceanography from Texas A&M University and Oregon State University, respectively. His major research interests are deep-sea benthic ecology, animal-sediment interactions, and evolution and adaptation of sediment-feeding organisms. He is Director of the Coastal Ecology Institute at Louisiana State University. He has held academic and management appointments at the Smithsonian Institution, the National Science Foundation, and at other universities and laboratories. He has been a member of many national policy and editorial boards, panels, committees, and commissions, and has published extensively on deep-sea biology. Dr. Carney is the chairman of the Scientific Review Board (SRB) for the Panama Oil Spill Study being conducted by the STRI for the MMS. The SRB provides scientific advice and criticism, and reviews experimental designs, data, and reports as the program progresses.

Dr. Thomas E. Ahlfeld is a biological oceanographer with the Minerals Management Service's Environmental Studies Branch, Herndon, Virginia. His research interests include deep sea ecology, effects of contaminants on benthic organisms, and microbial degradation of hydrocarbons. Dr. Ahlfeld has managed the benthic ecology and marine environmental monitoring components of the Environmental Studies Program since 1975. He received his B.S. (1969) in biology from Loyola University, New Orleans, Louisiana; and his M.S. (1972) and Ph.D. (1977) in biological oceanography from Florida State University.

A REVIEW OF THE SPILL, THE FIRST FEW WEEKS

Dr. Brian D. Keller
Smithsonian Tropical Research Institute

There is little information about the effects of oil pollution in the tropics (NRC 1985). During the last five years, an intensive study of a major oil spill in Panama has been conducted by the Smithsonian Tropical Research Institute and the Bermuda Biological Station for Research. The region affected by the spill includes the coastal habitats characteristic of many parts of the Caribbean region: coral reefs, mangroves, seagrass beds, and tidal flats. Most of the species in Panama (or similar forms) are widely distributed in the region, making the study in Panama broadly applicable to an understanding of the potential effects of oil pollution in other areas of the Caribbean.

The spill occurred in April 1986 at a refinery (Figure 13.1) when a 240,000-barrel storage tank containing a medium-weight crude oil ruptured (Cubit *et al.* 1987; Jackson *et al.* 1989; Keller and Jackson 1991). The oil broke through the containment dike around the tank and overwhelmed separators and a retaining lagoon. The refinery reported that 60,000 barrels of oil had been recovered from the sea, but the total volume of oil that spilled into the sea is not known. Nevertheless, the most conservative estimate of the size of the spill makes it the largest spill reported near coral reefs (Loya and Rinkevich 1980) and mangroves (Getter *et al.* 1981) in the tropical Americas.

For nearly a week, onshore winds held the spilled oil in Bahía Cativá adjacent to the refinery (Figure 13.1). Then, after a rain storm and shifting winds, a large quantity of oil floated out to sea. Starting nearly a week after the spill, aircraft sprayed approximately 21,000 liters of the dispersant "Corexit 9527" (Exxon Chemicals) onto oil slicks. The application of dispersant so many days after the spill and the calm sea conditions during the spraying appeared to have rendered chemical dispersion ineffective. Although some coastal areas were exposed to the dispersant, particularly Bahía Cativá and near Islas Naranjos, only a relatively small amount was used and many areas, including Punta Galeta (Figure 13.1), were not directly contaminated by this compound.

By two-to-three weeks after the spill, oil had spread along the coast and washed across fringing reefs into mangroves, small estuaries, and sand beaches within 10 km of the refinery. During the first two months after the spill, the distribution of oil was surveyed from low-flying aircraft, by foot, and by boat. During these surveys, visual assessments were made of the degree of oiling (heavy, moderate, light, or absent), and of the habitats and types of organisms obviously oiled or affected by oiling. Heavy oiling was observed along much of the coast between Isla Margarita and Islas Naranjos, with the exception of two partially isolated lagoons (Figure 13.1). The length of this heavily oiled coastline is about 82 km (straight-line distance = 11 km), and includes approximately 16 km^2 of mangroves and 8 km^2 of intertidal reef flats and subtidal reefs (Cubit *et al.* 1985). Only a few patches of oil were observed east of María Chiquita and west of the entrance to the Panama Canal (Figure 13.1).

In similar habitats within the heavily polluted area, apparent degrees of oiling were highly variable. Probable causes of this heterogeneity include distance from the refinery, directions of movement of the spilled oil, and water depth. Much of the spilled oil spread to the west. Accordingly, coasts that faced north to northeast were much more heavily oiled than coasts that faced west or south. Also, seasonal low tides (Cubit *et al.* 1986, 1989) occurred during mid-May, causing oil to accumulate along the seaward margins of reef flats. As a result, visible oiling was heaviest in intertidal habitats just above mean low water, such as mangrove roots and

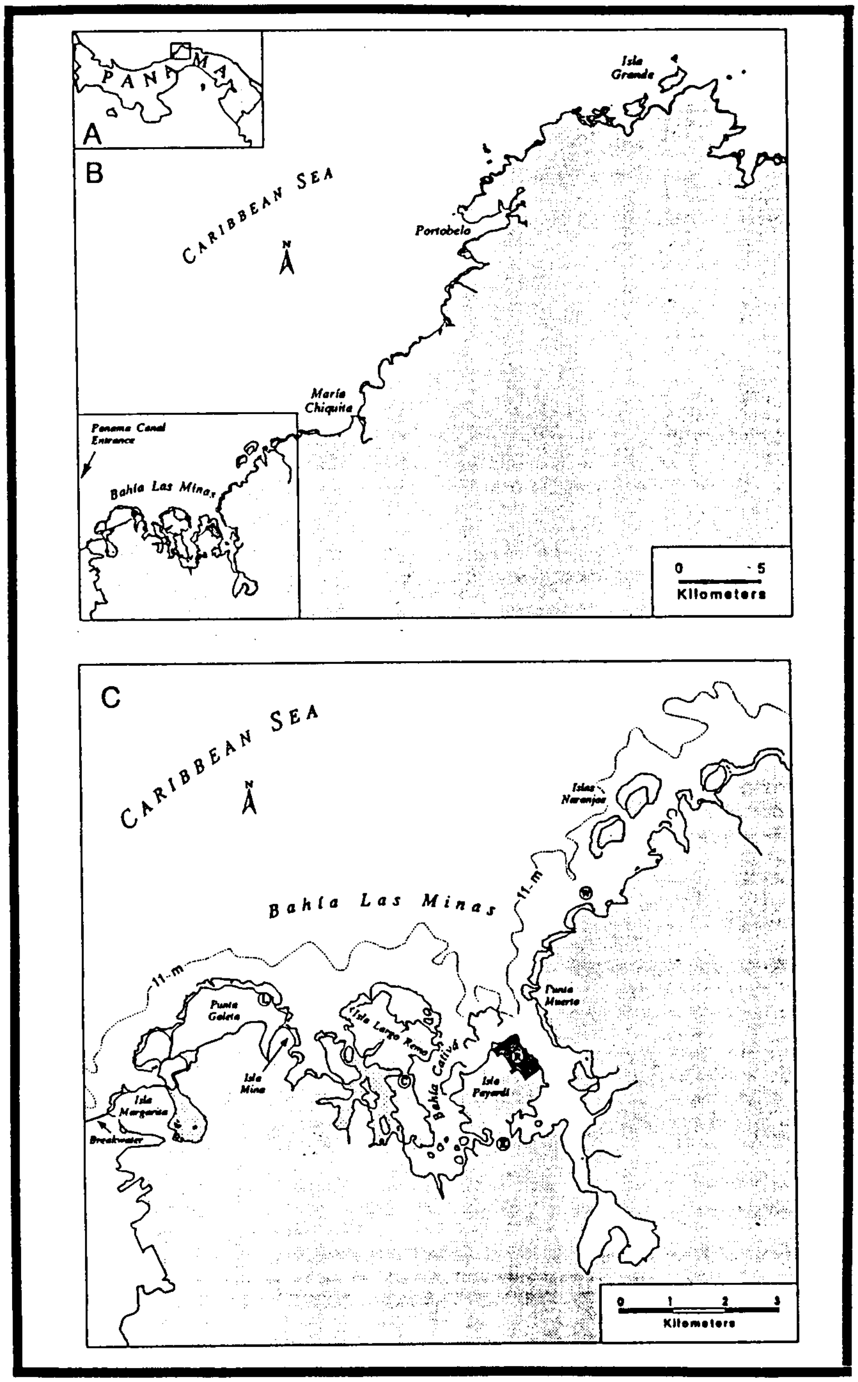

Figure 13.1 Region of Panama affected by the 1986 oil spill. ([A] location of the study area in the central Caribbean coast of Panama. [B] the boxed area includes the most heavily oiled coastal habitats. The refinery where the spill originated is located in the eastern part of Bahía Las Minas [darkly hatched rectangle]; the Galeta Marine Laboratory, Smithsonian Tropical Research Institute, is located approximately 5 km west of the refinery [filled circle]. [C] Detail of Bahía Las Minas, the most heavily oiled area. Embayments where oiling was not observed soon after the spill are lightly stippled. Encircled "L": Galeta Marine Laboratory; "C": out-of-use cement plant; "E": electrical generating station; "R": refinery; "W": stern section of the wreck of the tanker *Witwater*. The jagged line marks the seaward margin of reef flats; the dotted line shows the 11-m depth contour.)

associated sediments, reef-flat seagrass beds, coral rock, and beaches.

Several different kinds of efforts were used to clean up the spilled oil. Oil was removed from the sea using "skimmers" and shore-based pump trucks. Channels were dug through mangroves, apparently to drain oil from these areas. However, these channels appeared instead to increase the movement of oil inshore, and disturbance from workers may have increased subsequent erosion. In other areas, oiled rocks, rubble, and debris were physically removed and seawater was sprayed to move oil from sandy areas. Skimming and pumping floating oil appeared by far to be the most effective way to recover oil from this spill. Shallow water and mangroves impeded many of the clean-up operations deployed after major oil spills, perhaps for the better, since some of these procedures can be environmentally or biologically destructive.

Elsewhere in these Proceedings, the initial and longer-term biological effects and chemical fate of this major oil spill will be summarized.

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Dr. Brian D. Keller has been Project Manager of the Oil Spill Project at the Smithsonian Tropical Research Institute in Panama since 1987. He has served as the Acting Head of the Discovery Bay Marine Laboratory, University of the West Indies, Jamaica, and has held post-doctoral research positions at Yale University and Scripps Institution of Oceanography. He has a B.S. in biochemistry from Michigan State University (1970) and a Ph.D. in ecology from the Johns Hopkins University (1976). Dr. Keller's research interests include the ecology of sea urchins, seagrass communities, staghorn coral, kelp forests, and, most recently, oil spills.

EFFECTS OF THE 1986 BAHIA LAS MINAS OIL SPILL ON TIDAL FLAT COMMUNITIES

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INTRODUCTION

Tidal flats are common throughout tropical and subtropical areas of the world and are regarded as highly vulnerable to oil spills (Gundlach and Hayes 1978; NRC 1985). Although the physical structure of these flats can differ greatly, the plants and animals tend to be remarkably similar from place to place: most of the common species and genera at our Panama study sites are common worldwide. Despite the ecological and economic importance of these highly productive ecosystems, little information exists regarding the effects of oil spills on tidal flats. The National Research Council report Oil in the Sea (NRC 1985) summarizes the state of information as "totally neglected" and "nothing is known of [tidal flat] recovery potential following oiling."

In 1986, the Bahía Las Minas oil spill washed onto the tidal flat at Punta Galeta, on the Caribbean coast of Panama, which had been under study since 1970. The pre-spill database consisted of extensive, detailed monitoring of the abundances and spatial distributions of plants and animals on the tidal flat in relation to concurrent changes in weather and sea conditions. These data demonstrated that populations of tidal flat biota vary seasonally and from year to year, usually in response to fluctuations of the physical environment (e.g., Cubit 1985; Cubit *et al.* 1986). A major part of this study involves the use of baseline data to distinguish changes caused by the spill from changes caused by natural factors.

SUMMARY OF RESULTS

Deposition of Oil on the Tidal Flats

Observations of oil movement in relation to winds, tides, and waves showed these factors, plus configuration of the shore, determined the patterns of oil accumulation on the tidal flats. The onshore winds, low tides, and weak wave action at the time of the spill caused the oil to accumulate along natural berms, beaches, and the seaward margins of the tidal flats (Cubit *et al.* 1987). Analysis of the long-term database for hydrological and meteorological conditions demonstrated that during the 1986 oil spill these conditions were typical for this time of year (the early rainy season), and, as such, much different than the conditions during Panama's dry season.

Mortality of Tidal Flat Biota

Mortality of plants and animals on the tidal flats was concentrated in the heavily oiled zone at the seaward margin of the tidal flats. Before the oil spill, macroalgae and sessile invertebrates covered an average of 78 percent of the surface in this zone. After the oil spill, the coverage dropped to 12 percent. The severity of the mortality diminished with distance from this zone (Cubit *et al.* 1987; Jackson *et al.* 1989; Cubit 1991).

Recovery

Rates of recovery on the tidal flats varied among species. Within a year after the oil spill, the predominant species of fleshy algae (mainly the red alga *Laurencia papillosa*) and crustose coralline algae on the tidal flat at Punta Galeta had regenerated to abundances approximately equal to those recorded on this same flat before the spill and measured at unoiled tidal flats after the spill. This regeneration time for fleshy algae is much faster than the 10-year recovery time reported for some populations of fleshy intertidal algae in the temperate zone (NRC 1985). After the oil spill, the fleshy algae also expanded into the zone previously occupied by zoanthids and corals. As reported from other studies, these algae may interfere with the recolonization of the sessile invertebrates (e.g., Loya and Rinkevitch 1980). In continued monitoring, it was found that the recently regenerated populations of fleshy algae were more vulnerable to natural environmental stresses than populations of the same species at sites not damaged by the oil. This result indicates recovery in abundance is not the same as recovery in ability to cope with environmental rigors.

Populations of other algae, such as *Halimeda opuntia*, and sessile invertebrates, such as

Millepora spp. and *Palythoa* spp., were slower to recover, and some populations of invertebrates had not recovered by the end of our five years of monitoring. Populations of the stony corals at the seaward edge of the tidal flats (mainly *Millepora* spp. and *Porites* spp.) have not recovered at the oiled sites and have also declined at the unoiled control sites as well, leaving the crustose coralline algae as the primary reef builders at the seaward margin of the tidal flats.

Populations of infauna in beds of the alga *Laurencia papillosa* were sampled after the oil spill, from 1987 to 1990. From 880 samples, the animals retained by a 0.5 mm sieve averaged approximately 11 individuals per cm^2. Of the major groups of infauna, polychaetes and tanaids were less abundant at the oiled sites in the first samples after the spill. Amphipods, isopods, and gastropods did not show this pattern, and in some cases were more abundant at the oiled sites in the first samples after the spill. Subsequent differences between oiled and unoiled sites varied according to group; however, all major groups had recolonized the *Laurencia* beds by the last set of samples in 1990.

Rates of recovery of populations of plants and animals on the tidal flats depended on the following factors:

- the severity of damage to the population;
- the mode of recruitment and recolonization: recruitment of planktonic larvae and spores, immigration of mobile animals, regeneration from fragments surviving *in situ*, and/or vegetative spreading from fragments washed in by wave action (Table 13.1). Recolonization resulting from immigration of mobile animals or wave transport of sessile species depended on the existence of refuges only a few meters from the damaged zones, which served as sources for these organisms;
- the inherent growth rate of the species; and
- competition with other species.

DISCUSSION

The 1986 Bahía Las Minas oil spill occurred at the beginning of Panama's wet season, when extreme low tides naturally cause large-scale mortality of many plants and animals on the tidal flats (Cubit 1985; Cubit *et al.* 1986). If this seasonal mortality had not been taken into account, the oil damage would have been grossly over estimated.

The spatial pattern of oiling and the residence time of oil would have been much different for a spill occurring in Panama's dry season. In particular, the hard substrata of coralline pavement at the seaward edge of the tidal flats would have been less exposed to oil, but the porous substrata of sediment and loose rock on the landward side of the tidal flats would have absorbed much more oil, killing the fauna and flora there and creating a source of chronic reoiling.

The results of these studies have strong implications for oil-spill clean-up. Although most ecological models for colonization of intertidal zones are based on arrival of spores and planktonic larvae, this was not the case for the tidal flats. Except for sea urchins and some infauna (with planktonic larvae), recovery of most tidal flat biota depended on growth from fragments that survived *in situ*, or arrival of fragments or mobile animals from immediately adjacent habitats that suffered less damage (Table 13.1). Most of these means of regeneration would have been destroyed by common methods used to clean up oil spills, such as hot water, steam, sand blasting, scrubbing with absorbent materials, or methods involving traffic of machinery or trampling by clean-up crews. By removing the small surviving portions of tidal flat biota, clean-up activities could have prevented or delayed the re-establishment of most plants and animals on the tidal flats.

After the Bahía Las Minas spill, the rates of regeneration of fleshy macroalgae were much faster than the rates reported after oil spills in the temperate zone. This difference could be the result of two factors:

1. Many of the algae on warm water flats regularly respond to seasonal stresses by dying back to basal portions and regrowing from the bases during more favorable conditions. This adaptation also served well when oil coated and killed the upper portions of the algae on the tidal flats in Bahía Las Minas. Algae of the intertidal zone on temperate shores are more

Table 13.1. Modes of Recruitment and Recolonization Contributing to the Recovery of Tidal Flat Biota after the Bahía Las Minas Oil Spill.

Mode	Examples
Planktonic larvae	Sea urchins, some infauna
Immigration of mobile animals	Infauna of algal beds, especially those without planktonic larvae; (e.g., amphipods and isopods)
Wave transport of fragments of sessile species	Colonial animals (e.g., *Palythoa*, *Millepora*); possibly some algae
Regrowth from fragments surviving *in situ*	Most algae; some colonial animals (e.g., *Zoanthus*)

tolerant of natural physical stresses, and their usual response to such stress is to persist, rather than to die back and regrow. The lack of selection for regrowth potential is one possible explanation for slow recovery of temperate algae after oil spills and is easily testable by field experiments.

2. Oil spills in the temperate zone have been subject to more clean-up activity, including the use of detergents for earlier spills, such as the Torrey Canyon spill. As discussed above, the clean-up activities may have slowed recovery by removing the small remnants of algae that survived the oil spills.

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EFFECTS OF THE 1986 BAHIA LAS MINAS OIL SPILL ON REEF FLAT STOMATOPODS

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Stomatopods are benthic, predatory marine crustaceans found mostly in tropical and semi-tropical coastal seas. This report deals primarily with gonodactylid stomatopods that occupy and defend cavities in hard substrata. These cavities are used as refuges from predators, as sites for prey processing, and as brood chambers. Along the Caribbean coast of Panama, the primary habitat of gonodactylids is coral rubble and coralline algae nodules scattered throughout lower intertidal beds of turtle grass, *Thalassia testudinum*. Populations of stomatopods were surveyed around Galeta by Caldwell and his students between 1976 and 1984, with almost continuous monitoring occurring between 1979 and 1983. These data consist of records of over 60,000 stomatopods taken primarily from Punta Galeta, Isla Margarita, Isla Mina, and Isla Largo Remo (Caldwell 1986). For the purposes of this report, data on the three most common gonodactylids, *Gonodactylus bredini*, *G. oerstedii*, and *G. austrinus*, are combined. These species make up approximately 75, 20, and 5 percent of the gonodactylid community, respectively (Steger 1987).

The impact of the April 1986 Bahía Las Minas oil spill on the gonodactylid populations was monitored from September 1986 through September 1988 by employing the following biannual (September and February) sampling regime. At each of two control sites (Isla Margarita and Largo Remo West) and two heavily oiled sites (Largo Remo North and Isla Mina), we established a 400 m^2 plot. During each sampling period, we randomly selected from that plot 30, 0.5 m^2 quadrats and removed all pieces of rubble and coralline algae larger than 2 cm in diameter. This material was broken apart and all stomatopods found were returned to the laboratory. In addition to the quadrat samples, at each site, but not from within the sampling plots, we collected and broke apart 80 pieces of 10 to 35 cm diameter rubble that were likely to contain stomatopod cavities. To determine stomatopod-to-cavity volume ratio, we also selected from each site 50 occupied cavities. All stomatopods were characterized with respect to species, size, sex, reproductive and molt condition, and wounds. The animals were then held in the laboratory for four days to determine if any individuals molted or laid eggs. Growth was measured by comparing pre- and post-molt carapace lengths. After four days, the stomatopods were returned to a *Thalassia* bed at least 1 km from any of the sampling sites.

The initial impact of the Bahía Las Minas oil spill on gonodactylids, as first assessed in September 1986, was dramatic. Our data indicate that large gonodactylids, particularly females, were significantly absent from heavily oiled sites (Isla Largo Remo North and Isla Mina) when compared to pre-spill densities or to control, lightly oiled "reference" sites (Isla Largo Remo West and Isla Margarita). The loss of large gonodactylids, caused either by mortality or emigration, resulted in a suite of secondary, nonlethal changes in population dynamics. At heavily oiled sites, individuals utilized larger cavities, carried fewer wounds and injuries, and grew more during each molt (Jackson *et al.* 1989).

During the first two years following the spill, three significant patterns were documented. First, stomatopod densities declined due to low levels of postlarval recruitment at both heavily oiled and reference sites. Second, competition for cavities and injuries associated with competition remained correlated with gonodactylid densities. Third, the habitat at the most heavily oiled site (Isla Largo Remo North) began to deteriorate. While the *Thalassia* had been killed back at both heavily oiled sites, it did not recover at Isla Largo Remo North. As the rhizomes began to rot, sediments were washed away by strong wave action.

Assessment of the long-term impact of the oil spill was continued annually each dry season (January through March) from 1989 through 1991. Wet season sampling was discontinued since we were primarily interested in recruitment of stomatopods into the populations and this takes place primarily during the dry season. Furthermore, by analyzing the demographic structure of a population, we can characterize past recruitment events for at least a year. The complete sampling regime described above was continued at each of the four primary study sites. In addition, our sampling was expanded in 1989 to include two additional sites at Maria Soto and Escucha. The reef flat at Maria Soto is approximately 8 km west of Bahía de Portobelo and the Escucha reef flat is just west of the opening of Bahía de Portobelo. According to the Smithsonian Tropical Research Institute (STRI) staff present during the oil spill, both of these sites were unoiled. Only samples of coral rubble were taken at these sites.

From September 1988 through February 1991, there was an increase in the level of postlarval recruitment to near pre-spill levels at three of our four primary sites. This is reflected both in the number of postlarvae appearing in the February samples as well as by a subsequent increase in the number of small and middle-sized stomatopods present in the populations. The one exception was the heavily oiled site, Isla Largo Remo North. While there was a significant increase in the number of recruits in February 1990, as the site continued to deteriorate in 1991, the number of recruits again fell to very low levels.

As gonodactylid populations continue to recover at Isla Margarita, Isla Mina, and Isla Largo Remo West, competition for cavities increased and animals of all sizes were again forced to occupy sub-optimal cavities. This was not the case at Isla Largo Remo North where sterile, eroded, loose coral rubble is still being exposed.

The destruction of the *Thalassia* beds at Isla Largo Remo North, followed by the loss of sediment and exposure of previously buried coral formations, has taken five years and there is little indication that *Thalassia* is re-establishing itself in this area. At this location, oil is still present in some of the coral rubble and is occasionally released from decaying mangrove stands immediately behind the flat.

One interesting feature of our most recent samples in 1991 suggests that the relative proportion of *Gonodactylus oerstedii* to *G. bredini* recruits is changing. We recorded a much greater number of *G. oerstedii* postlarvae than is usual for this area. Whether this will ultimately change the species composition of the area remains to be seen.

One other stomatopod, a large burrowing fish-catching species (*Lysiosquilla glabriuscula*) was common on the reef flats surrounding Galeta prior to the spill. These animals obtain a maximum body length up to 22 cm, form life-long pair bonds, and burrows may persist for several years. In 1983, we recorded 17 pairs living at Isla Mina, two at Isla Margarita West, and two at Galeta. Since the spill, intensive searches indicate that these burrows are gone and not a single *Lysiosquilla* has been recorded from the area.

DISCUSSION

The major changes in the abundance of gonodactylid stomatopods that have occurred since the oil spill have been related to low levels of postlarval recruitment. After the initial mortality suffered by large individuals, population levels were not maintained by the level of recruitment at the study sites and densities of all sizes of animals declined after 1986. Oiling may not have been entirely responsible for this reduction since recruitment had been low at both heavily oiled and reference sites. The reduced recruitment could be a natural, albeit unusual, phenomenon, triggered by events unrelated to the oil spill. Alternatively, the scale of the oil spill may have been sufficient to reduce the larval pool through the mortality of large females and/or low levels of chronic oiling may have inhibiting larval recruitment. It is most likely that the oil spill and a large scale, natural phenomenon may both have contributed to low levels of recruitment from 1987 through 1989.

Evidence that oiling may have reduced recruitment comes from two points. First, there were three levels of recruitment in February 1987, the first period following the oil spill when high recruitment was expected. These levels corresponded to the amount of oiling or the proximity to heavily oiled areas. Isla Largo Remo North was the most heavily oiled site and showed the lowest level of recruitment. Isla Mina was heavily oiled, but less than Isla Largo Remo North, and Isla Largo Remo West was lightly oiled to unoiled, but surrounded by heavily oiled areas. Both of these sites showed low, intermediate levels of recruitment. Isla Margarita was lightly oiled to unoiled and the most distant of our initial sites from Bahía Las Minas. This site showed the highest level of recruitment.

Second, at heavily oiled sites, recruitment increased in 1988 and 1989, while there were no significant increases at the reference sites. That is, recruitment levels at heavily oiled sites were increasing from extremely low levels following the oil spill and converging on recruitment levels at reference sites from 1987 through 1989.

The evidence that an unexplained phenomenon not related to oiling was also affecting recruitment comes mainly from the two unoiled sites added in 1989. Both of these sites are outside of the zone of impact of the oil spill and showed low postlarval recruitment in 1989. Recruitment increased significantly at these as well as at our four primary sites in 1990 and remained high in 1991, with the exception of Isla Largo Remo North which plummeted due to a further deterioration of the habitat.

The loss of *Lysiosquilla* from the area corresponds with the spill, although we are at a loss to explain why no recruitment has been seen even in reference areas. It is possible that recruitment of these long-lived animals is extremely sporadic and has not occurred due to natural causes. Alternatively, stocks may have been destroyed and/or larval recruitment inhibited by the presence of oil in the area.

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MORTALITY AND LONG-TERM RECOVERY OF SUBTIDAL REEF CORALS AFTER THE 1986 OIL SPILL IN PANAMA

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INTRODUCTION

During the last two decades, interest in studying the effects of oil pollution on coral reefs has increased. Loya and Rinkevich (1980) reviewed our understanding of this subject and indicated that although conflicting studies exist, growing evidence suggests serious and lasting impacts of chronic oil pollution on reef communities. These effects include the lack of coral recruitment, decreases in colony viability, lower growth rates, damage to coral tissue, and damage to the reproductive system of corals.

Coral reefs are ranked among the most biologically productive and diverse of all natural ecosystems and it has been estimated that 14 percent (84,000 km^2) of the areal extent of coral reefs in the world occur in the Caribbean Sea (Smith 1978). Even though the Caribbean region is potentially one of the largest oil producing areas in the world (Rodriguez 1981) and contamination by petroleum hydrocarbons is considered to be the most serious marine pollution problem of the region (IMCO 1979), there has been no long-term study of oil pollution in coral reef ecosystems. Of particular concern are oil terminals, tanker traffic, refineries, and offshore oil reserves adjacent to reefs, all of which are potential sources of contamination (UNEP/IUCN 1988). Therefore, studies concerning the long-term effects of oil on Caribbean reef corals are a regional research priority.

Here, we briefly present the results of the initial impact assessment and subsequent recovery (five years) of subtidal reef corals affected during a major oil spill in Bahía Las Minas, Panama. This information has been partially published elsewhere (e.g., Jackson *et al.* 1989; Guzmán *et al.* 1991; Guzmán and Jackson 1991).

METHODS AND RESULTS

Annual surveys were made to measure the percent cover of different dominant groups of coral reef organisms (fleshy algae, sponges, corals, etc.) and of species of scleractinian corals at different depths on each of the 12 reefs under study, using square-meter quadrats along four transects (120 m^2/reef) perpendicular to the shore (Guzmán and Jackson 1991). Here, we report only the percent cover of total scleractinians at 10 of the reefs (six oiled, four unoiled; to simplify this presentation, two moderately oiled reefs are not discussed). Differences between 1985 (pre-spill) and 1986 (three months after the spill) revealed extensive effects of oil, followed by a dramatic decrease in coral cover at both depths. After the third (1988) survey, coral cover declined 56 percent at unoiled reef sites for unknown reasons. During the last three years (1988-1991), a small reduction in coral cover has occurred at both depths at both oiled and unoiled reefs. However, despite these decreases in coral cover throughout the region, the differences between oiled and unoiled reefs are still apparent.

The presence or absence of oil slicks over all reefs has been recorded since 1987. Oil slicks from the refinery landfill and mangroves were common from 1987 to 1991. However, during December 1989 and June 1990, spills of fuel oil occurred at an electrical power plant in Bahía Las Minas. As a result, the area has been under chronic oil pollution.

Sedimentation rates were measured monthly from 1988 to 1990 at each reef. Sedimentation varied considerably between years. Levels of resuspended sediments were high at heavily oiled reefs during all years, and increased during 1990 to about 200 mg/cm^2/day. Levels of suspended particulate matter showed no clear trend through time.

Five and a half years after the oil spill (September 1991), the number of recruits (new individuals derived from sexually produced larvae and less than 4 cm in size) for all coral species were counted along 60 m^2 transects, parallel to the shore, at two depths (1.5-3.0 m and 4.5-6.0 m) at each reef. The number of recruits/m^2 and the total number of recruits per total reef area surveyed (all coral species combined) were significantly higher at unoiled reefs than at oiled reefs (t-test, $P<0.01$). Recruits of some of the principal reef-building species were twice as abundant at unoiled reefs (e.g., *Siderastrea siderea*, *Porites furcata*, *P. astreoides*, *Agaricia* spp., *Diploria clivosa*) or were totally absent at oiled reefs (*Acropora palmata*, *Diploria strigosa*, *Montastrea annularis*) (Guzmán and Jackson in preparation).

Quarterly visual estimates of recent injuries (white skeleton devoid of coral tissue) were made along 100 m^2 transects at two depths (0.5-1 m and >1-2 m). Until May 1988, two years after the spill, the frequency of recent injuries increased significantly with the amount of oiling, particularly at the shallower depth. *Siderastrea siderea* was affected more than *P. astreoides* and *D. clivosa*. This pattern still persists after almost five years. A decrease in the frequency of injuries to *S. siderea*, the most sensitive species, was observed at oiled reefs from August 1987 to September 1989. However, an increase to levels similar to those reported during the year of the spill (1986) was observed during 1990 and 1991 following fuel oil spills from an electrical power plant and the continued release of oil from the 1986 refinery spill.

CONCLUSIONS

The Bahía Las Minas oil spill has provided an opportunity to measure the influence of a major spill on tropical reef ecosystems (Guzmán *et al.* 1991; Guzmán and Jackson 1991). However, an accurate projection for the long-term impact may not be obtained after only five years of continuous monitoring. Initial assessments of the reefs damaged during the 1986 spill have demonstrated extensive damage to the reefs within the bay. It is suggested that the ongoing chronic oil pollution in the area from several sources (e.g., the original spill from the refinery's landfill and mangrove sediments; new fuel oil spills) might have serious and lasting consequences on the recovery of reef communities. Oil in the water column may enhance algal growth and affect the viability of coral gametes and larvae and, therefore, coral recruitment. Also, reefs are under siltation stress that has increased recently at heavily oiled reefs. Thus, some oil is certainly reaching the reef bottom adsorbed by suspended and resuspended sediments. Increase in sedimentation may be due to several sources related to the oil spill: degradation of 75 hectares of mangrove forest (Teas *et al.* 1989; Duke and Pinzón M. 1991), increasing erosion of seagrass meadows (Marshall 1991), and river runoff (pers. obser.). Corals have responded with a striking increase in number of injuries, and reefs, in general, are not showing any recovery. Macroalgae and suspension feeders (e.g., sponges, tunicates, octocorals, zooanthids) are overgrowing most reef areas. Massive coral species (e.g., *S. siderea*, *D. strigosa*, *P. astreoides*, *M. annularis*, *M. cavernosa*) that partially survived the original spill in 1986 have been under continuous stress. Instead of healing from the original injuries after the 1986 spill, injuries have increased in area or colonies have died, probably due to increasing number of territorial damselfishes which take advantage of the recent injuries and kill the coral tissue to expand their territories.

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THE EFFECTS OF THE BAHIA LAS MINAS, PANAMA, OIL SPILL ON SEAGRASS MEADOW COMMUNITIES

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Seagrass meadows, along the central Caribbean coast of Panama, are located in shallow lagoons which lie between small fringing reefs and mangrove forested shorelines. The largest grassbeds of this type, on Panama's central Caribbean coast, are found on the seaward edges of coastal bays. Numerous 1-2 hectare grassbeds are located near the Atlantic entrance to the Panama Canal and to the Bahía Las Minas oil refinery (Figure 13.2). The Bahía Las Minas spill oiled all of the lagoonal grassbeds within and adjacent to the bay where the refinery is located.

Seagrass meadows elsewhere in the tropics, subtropics, and temperate zone have been contaminated with oil from tanker wrecks (Table 13.2). Despite an omnipresent threat to seagrass meadows and despite the recently perceived world-wide decrease in seagrass acreage, little is known regarding their recovery potential following oiling (Zieman et al. 1986; Thorhaug and Marcus 1987). Several observations taken from the studies listed in Table 13.2 are summarized in Table 13.3 as "predictions" of what might be expected to happen in oiled seagrass beds.

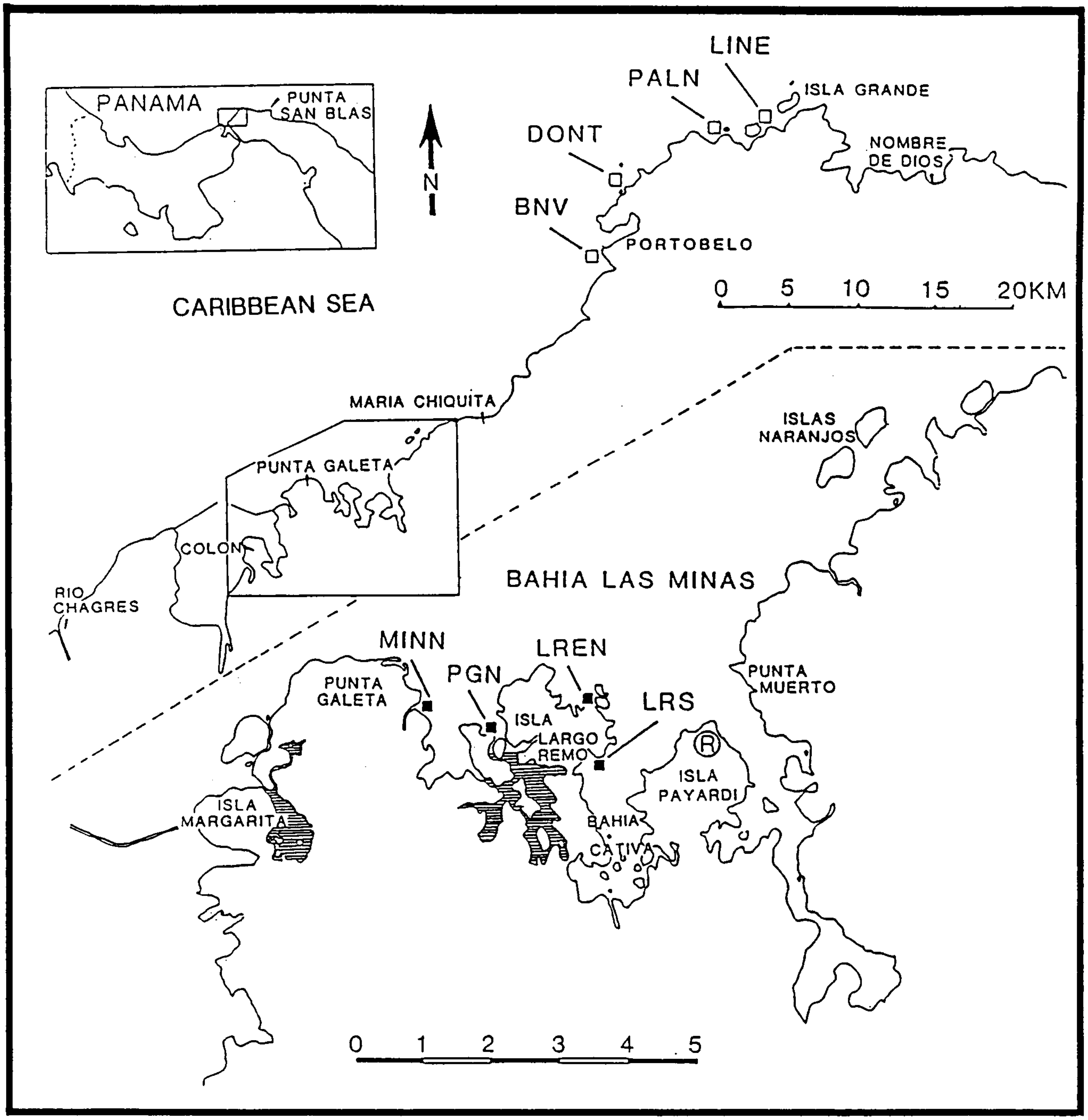

Figure 13.2. Map of the seagrass project study area and research sites.

Table 13.2. Oil Spills Affecting Seagrass Meadows.

Spill	Amount Spilled	Reported Effects	Reference
1968, *Witwater*, Bahía Las Minas, Panama	3.18 million liters diesel oil and Bunker C	No effect reported	Rutzler and Sterrer (1970); Birkeland *et al.* (1976)
1962, *Argea Prima*, Puerto Rico	10.68 million liters crude	*Thalassia* beds degenerated	Diaz-Piferrer (1964)
1973, *Zoe Colocotronis*, Cabo Rojo, Southern Puerto Rico	5.34 million liters Venezuelan crude	Some *Thalassia* died; later some areas had rejuvenated growth from formerly exposed mat of rhizomes; urchins, sea cucumbers, prawns, conchs killed; infauna not measurably affected	Nadeau and Bergquist (1977)
1975, *Garbis*, lower Florida Keys	0.24 to 0.48 million liters barrels crude oil clingage and water emulsion	*Thalassia* not damaged; *Pinctada radiata* (pearl oysters) killed in large number	Chan (1976)
1978, *Amoco Cadiz*, Roscoff, France	236.0 million liters light Middle East crude	*Zostera marina* shed leaves after they blackened but did not die; amphipoda reduced in diversity and numbers, tanaidae, cumaceans, and echinoderms reduced in numbers	denHartog and Jacobs (1980); Jacobs (1980)
1986, Refineria Nacional, Bahía Las Minas, Panama	8.0 million liters of 70% Venezuelan and 30% Mexican crude	Intertidal *Thalassia* killed and washed away exposing bare rock; subtidal *Thalassia* leaves blackened, seagrass did not die; study of effects on infauna and epifauna underway	Cubit *et al.* (1987); Jackson *et al.* (1989); Marshall and Batista (in prep.)

Table 13.3. Literature Derived Observations (= "predictions") Concerning Oil Spill Effects on Fauna and Flora in Seagrass Meadows.

1) Certain organisms are more oil sensitive than others.

2) Oil sensitivity depends on feeding types with filter feeders being the most oil sensitive.

3) Seagrass plants shelter infauna from oil exposure by preventing it from mixing into the sediments.

4) Opportunistic species become more abundant in oil exposed sediments.

5) Densities of sensitive organisms should be inversely correlated with the oil content of the sediment (recovery is dependent on oil weathering rates).

6) Reproduction and recruitment are often affected by oil exposure.

The Bahía Las Minas spill provided an opportunity to observe the levels of damage caused by oil exposure to shallow seagrass meadow communities, to observe their long-term responses to such exposure, and to examine how well these results fit predictions from earlier studies. This report is a brief summary of the results of a three-year impact and recovery study in Panamanian seagrass meadows. It does not summarize all of the findings of the seagrass project.

Seagrass meadows from Isla Margarita, near the Atlantic entrance of the Panama Canal, to Isla Linton (near Isla Grande) were selected as the study sites (Figure 13.2). Criteria used in selecting sites were that each grassbed must lie adjacent to a mangrove shoreline and that the grassbeds must be subtidal but shallow enough to be sampled without SCUBA. All of the sites were located behind small patch or fringing reefs. Water depths over all grassbeds ranged from 0.1 to 1.2 m. Extremely low tides, that occurred towards the end of the project, exposed small patches within several meadows.

Seagrasses, algae, and benthic fauna were collected, at wadeable depths, with an aluminum coring tube (10.16 cm inside diameter). Three cores, taken within a 1 m^2 area, were pooled to give a total area per core replicate of 0.024 m^2. Eight pooled core replicates were taken, beginning in September 1986, at each of eight grassbed sites (4 oiled and 4 unoiled sites).

Beginning in November 1986, mobile epifauna were collected by pushnet sampling along 10 m-long transects. The total area covered by each net haul was 7.5 m^2. Five to six replicate net hauls were collected at each of the eight sites. After January 1987, a quarterly collection schedule was established and followed until the end of this project (July 1989).

Total seagrass and seagrass leaf dry weights (Figure 13.3) were highest at the unoiled (=clean) sites during September 1986 when the seagrass project began. Since that time, seagrass biomass measurements, for whole plants and leaves, between the oiled and unoiled areas have become similar and have decreased at all sites. Increased turbidity, due to coastal deforestation throughout the oiled and unoiled areas, may be responsible for the general decrease in seagrass biomass.

Syringodium biomass did not follow the temporal pattern demonstrated by *Thalassia*. *Syringodium* decreased in abundance at the oiled sites and fluctuated in a seasonal pattern at the unoiled sites. Changes in leaf biomass accounted for some but not all of the fluctuation in total *Syringodium* biomass. Fleshy algal dry weights followed similar patterns in both oiled and unoiled sites. Calcareous algae were initially less abundant at oiled sites but gradually increased in abundance at these sites until their total biomass exceeded that seen at unoiled sites.

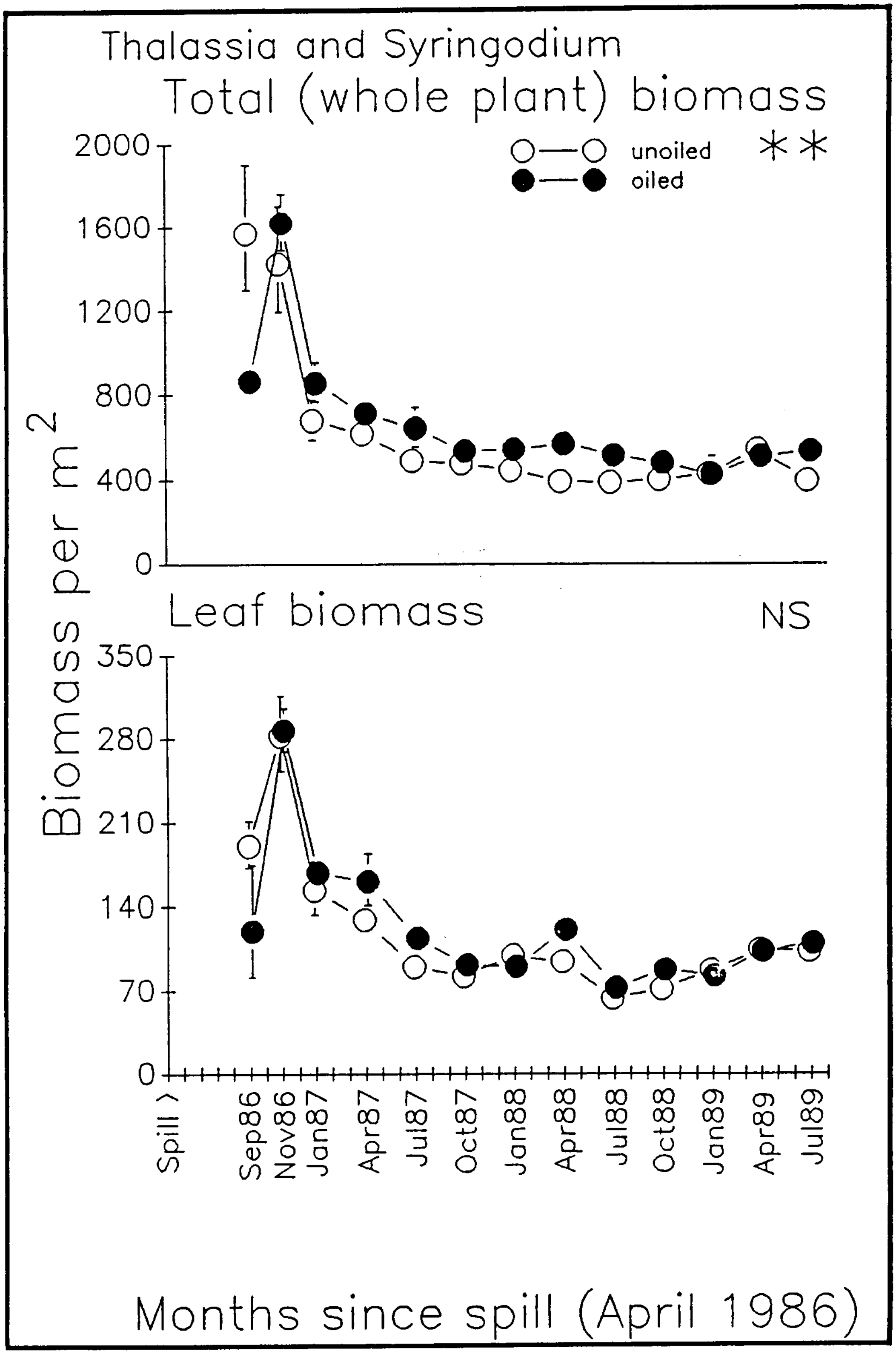

Figure 13.3. Seagrass whole plant and leaf biomass per m^2 as determined from core samples. (Error bars are standard errors back transformed from ln[x+1] transformations. Results of ANOVAs with repeated measures are given as ** = highly significant [$p < .01$], * = significant [$0.01 < p < 0.05$], and NS = not significant [$p \geq 0.05$].)

Epifauna were sorted to major taxa (Table 13.4). Most taxa were either consistently more abundant in unoiled grassbeds or showed seasonal abundance spikes in unoiled beds that were not seen in oiled areas. Amphipod (Figure 13.4) populations followed statistically different patterns of abundance in oiled and unoiled grassbeds but amphipod densities in oiled grassbeds increased slowly throughout the study. Mysids were always most abundant in oiled seagrass meadows. Decapod groups (Figure 13.5) showed no consistent temporal trends. Responses to oiling differed between taxa as indicated by the results of ANOVAs with repeated measures and by their patterns of abundance through time.

Shrimp were always the numerical dominants among the epifauna from oiled and unoiled seagrass meadows (Table 13.4). Caridean species appeared to be variably sensitive to oiling. *Hippolyte zostericola* (Figure 13.6), the most abundant shrimp, was generally more abundant at oiled sites while *Latreutes fucorum* appeared to be more oil sensitive. Beginning in October 1987, *Latreutes* density increased in oiled grassbeds, to levels similar to those seen in unoiled areas by April 1988. Other shrimps followed differing patterns of abundance between oiled and unoiled grassbeds.

Nocturnally active penaeid shrimp were not considered to have been adequately sampled by pushnetting during daylight hours. No sampling was done at night due to hazardous conditions along this coast at this time. If night samples had been collected, it might have been possible to determine if the numerous penaeid postlarvae that were collected survived to older stages in similar percentages at oiled and unoiled sites. Adult penaeids were not unusual in our samples; *Penaeus duorarum* and *Metapenaeopsis martinelli* were the two most common species. Other penaeid species may have been present among the juveniles.

The responses of the crustacea to oiling were difficult to derive based on population trends of individual major taxa and species. Combining taxa into reproductive patterns based on taxon-specific egg care strategies (Figure 13.7) appeared to be a meaningful way to look at oil impacts. Species with direct development (= eggs brooded throughout

Table 13.4. Total Counts and Percent of Total Counts for Epifauna, from November 1986 through April 1988, at Unoiled and Oiled Sites.

Taxonomic	Unoiled Sites		Oiled Sites	
Group	Count	Percent	Count	Percent
Shrimp (Caridea and Penaeidea)	53,819	46.8	41,507	55.6
Tanaidacea	26,860	23.4	658	0.9
Amphipoda	10,612	9.2	7,678	10.3
Gastropoda	4,441	3.9	2,657	3.6
Bracyhura	4,333	3.8	3,656	4.9
Paguroidea	4,217	3.7	9,865	13.2
Isopoda	2,334	2.0	1,405	1.9
Ophiuroidea	2,134	1.9	88	0.1
Fish (Gobiidae, Scaridae)	2,080	1.8	970	1.3
Ostracoda	1,102	1.0	551	0.7
Cumacea	886	0.8	394	0.5
Mysidacea	617	0.5	3,330	4.8
Pycnogonida	549	0.5	797	1.1
Stomatopoda	354	0.3	855	1.1
Holothuroidea	225	0.2	7	0.01
Echinoidea	48	0.04	2	<0.01

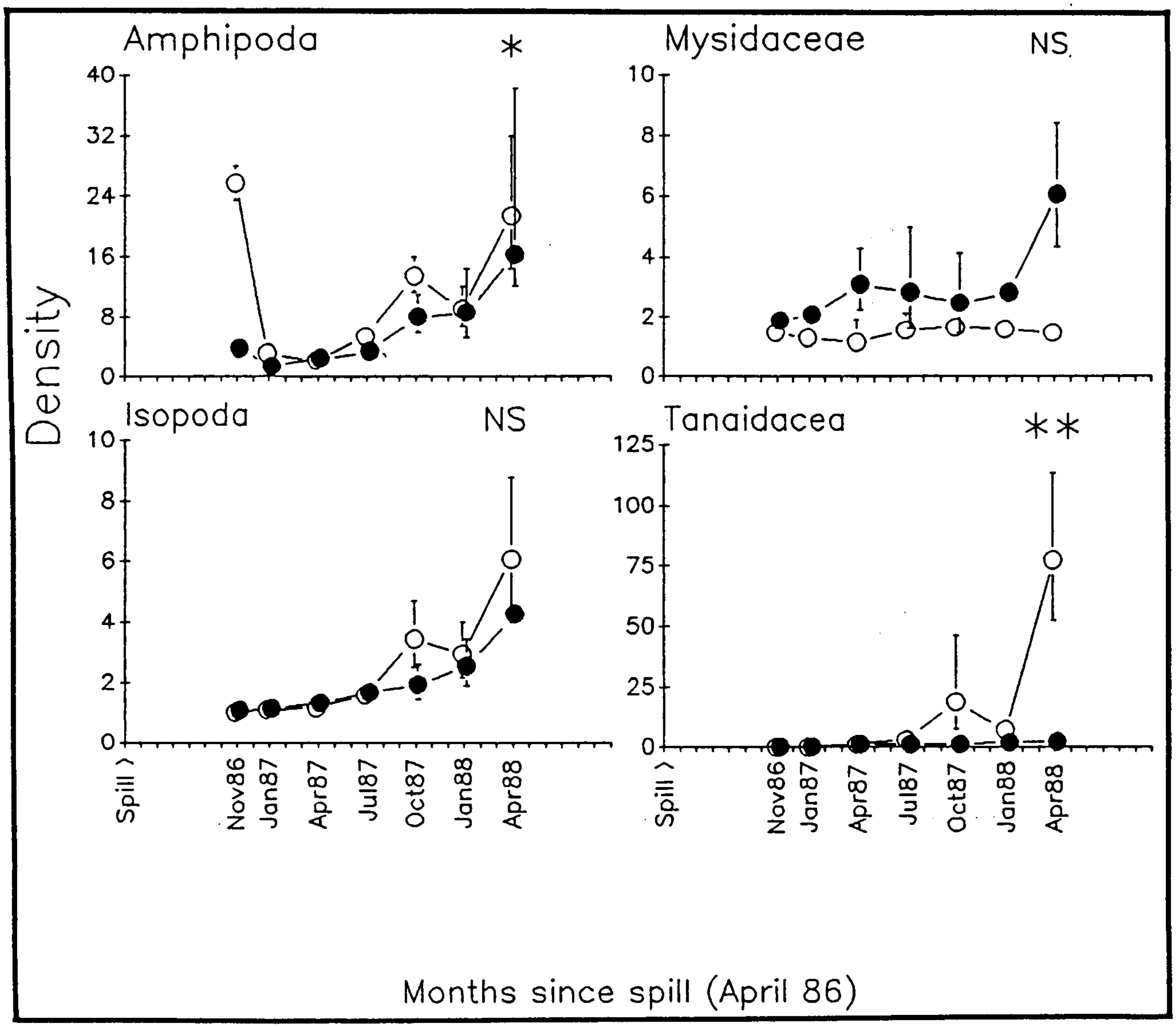

Figure 13.4. Densities (counts/m^2) of four major crustacean taxa determined from pushnet collections. (Error bars and ANOVA results are explained in the legend to Figure 13.3.)

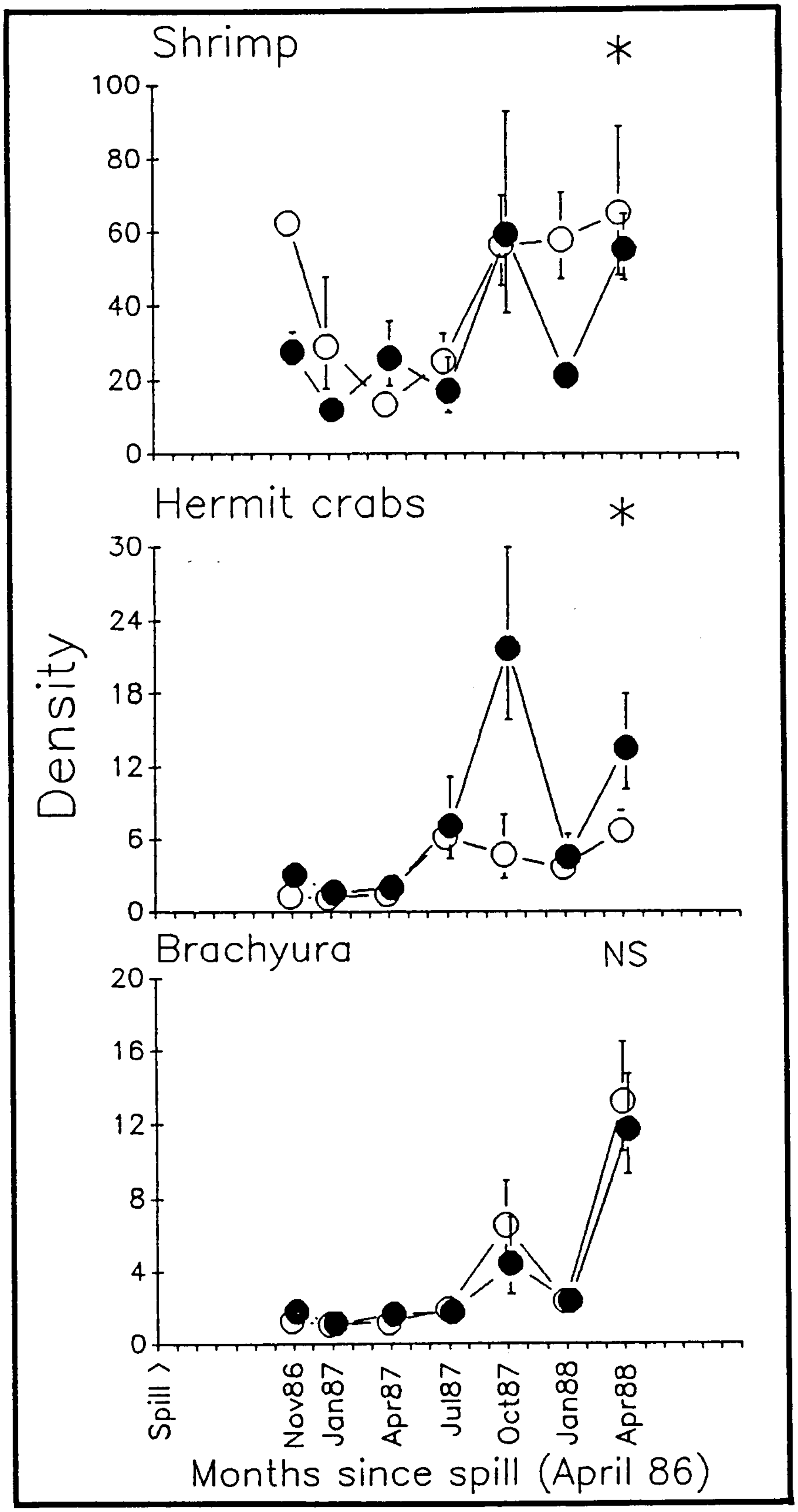

Figure 13.5. Densities of decapod crustaceans captured by pushnet. (Explanations of error bars and ANOVA results are given in the legend to Figure 13.3.)

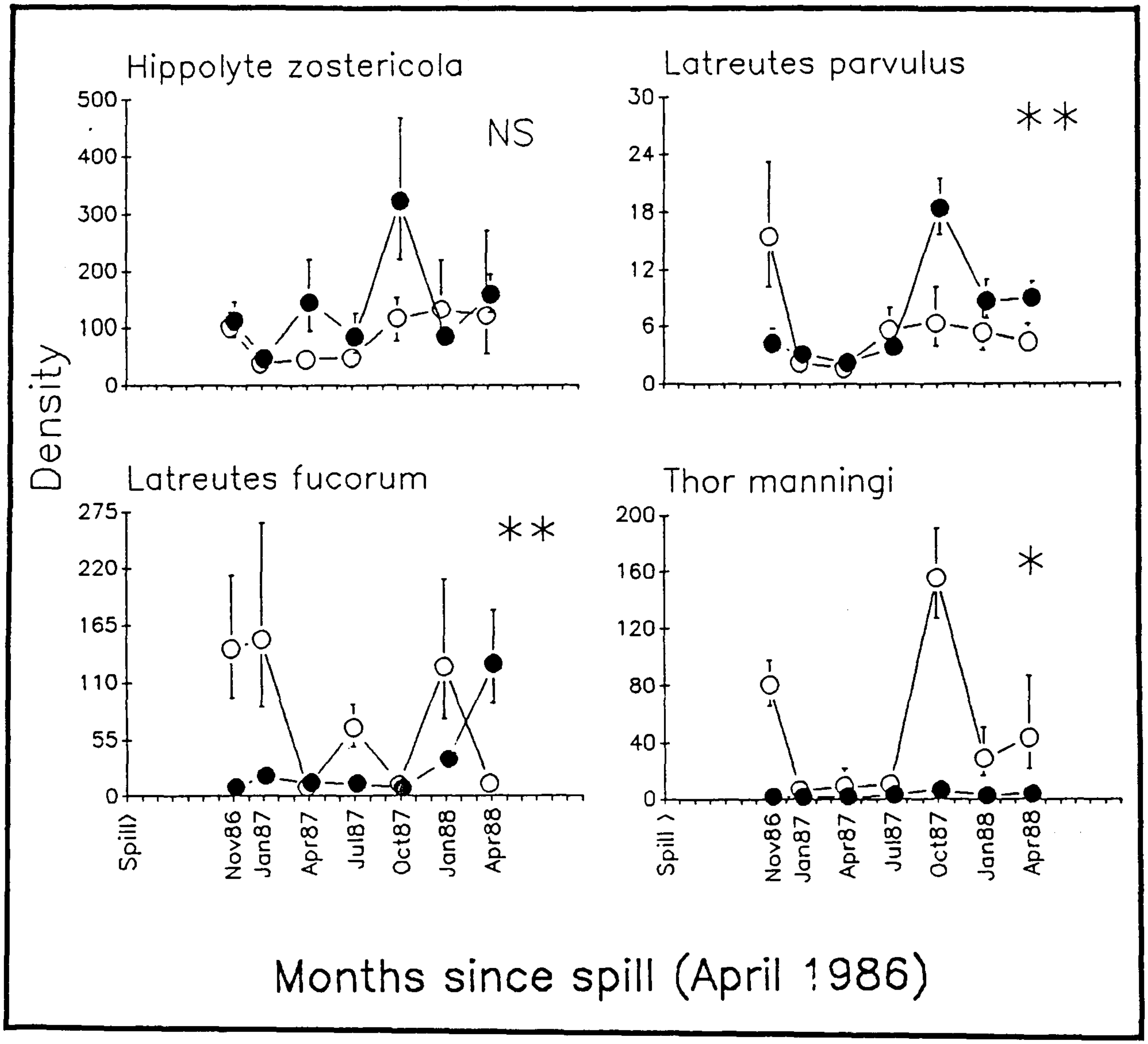

Figure 13.6. Densities of four species of caridean shrimp captured by pushnet. (Explanations of error bars and ANOVA results are given in the legend to Figure 13.3.)

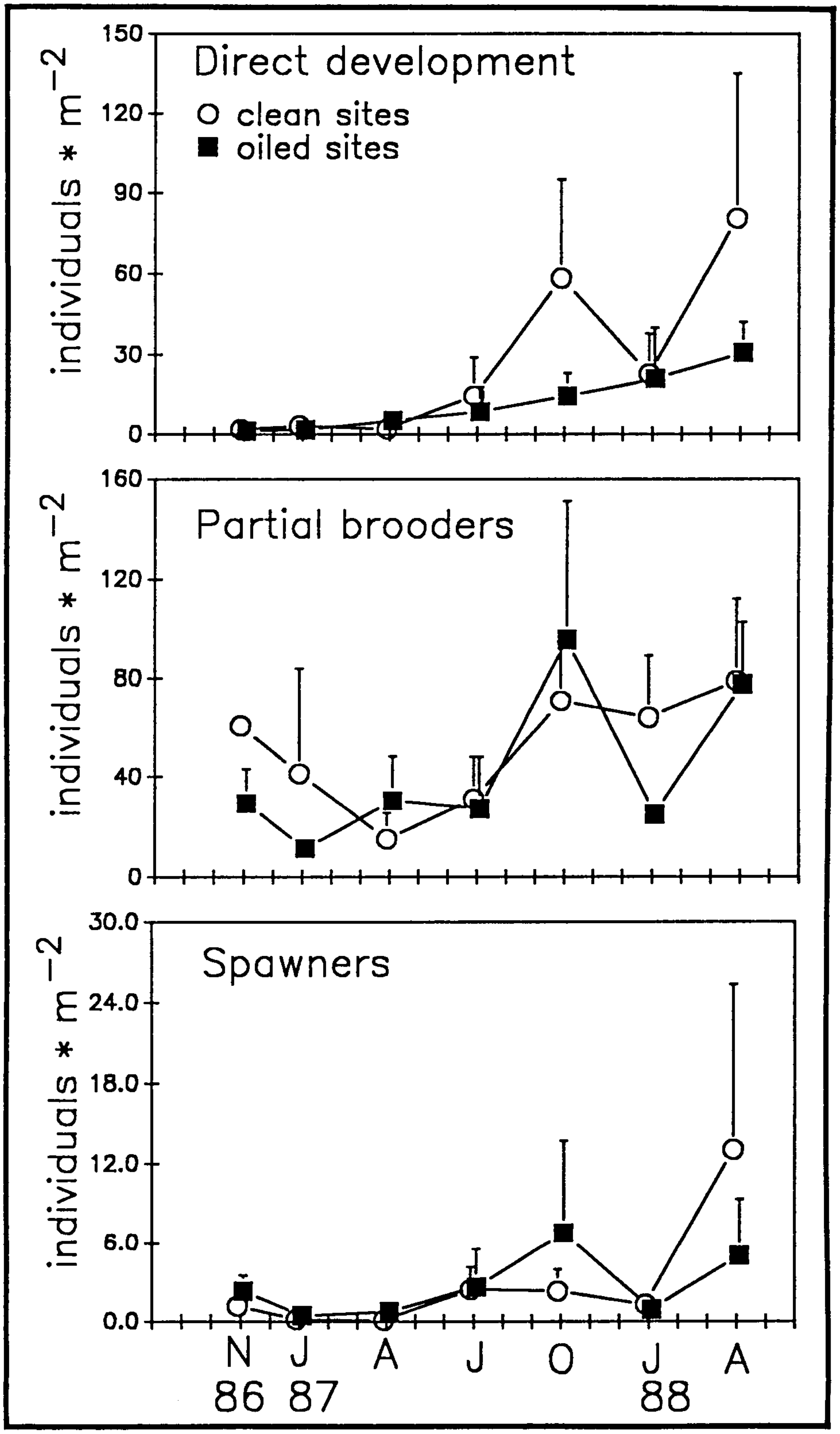

Figure 13.7. Counts of crustaceans falling into three major reproductive patterns including (1) direct development, (2) partial brooders, and (3) spawners (non-brooders).

larval development) were strongly affected by oil. Reproduction and development of these species in oiled grassbeds may have been negatively affected by oil. However, the initial toxic effects of oiling could have appeared to be long-lasting because recruitment from distant seagrass meadows would not have replaced those individuals that were killed at the onset of the spill. Mysids were an exception to this pattern; while they are complete brooders, mysid adults are highly mobile. They were always most abundant in oiled seagrass meadows (Figure 13.4). Partial brooders (= eggs hatching at a planktonic larval stage), mostly decapod crustacea, were initially less abundant in oiled grassbeds but oiled meadow densities of these species soon reached unoiled levels. Since these species have partially planktonic larvae, recruitment from unoiled seagrass meadows may have rapidly replaced those individuals killed by the initial toxic effects of the oil. If reproduction had been affected by oil exposure, the consequences would not necessarily show in population counts because of continuing recruitment from distant grassbeds. Species with completely pelagic larvae (= no brooding), including penaeid and sicyonid shrimp, by these data showed no oil effect. If adults were killed in the oiled grassbeds, which could not be determined by our sampling methods, they could have been rapidly replaced, as oil toxicity levels decreased, by recruitment from distant grassbeds.

Hippolytid shrimp were selected as models on which to observe the impacts of oil on recruitment and reproductive processes in partial brooders. All postlarval and adult stages of these species were well sampled by pushnetting. Two very abundant hippolytids, *Hippolyte zostericola* and *Latreutes fucorum*, were chosen for this comparison. Their density patterns in oiled and unoiled areas suggested that they were not equally sensitive to oil. Ovarian maturation and brooded egg stages were scored by direct observation following methods used by Bauer (1987).

Population structures of these two hippolytid species in oiled and unoiled seagrass meadows were followed through time. New recruits, defined as all individuals within the smallest 25 percent of the total size range of each species, were present in oiled grassbeds during the first month of the epifaunal study. The population structures of both shrimp (Figure 13.8) appeared to be mirror images of each other despite initial and long-lasting density differences for *Latreutes fucorum* between oiled and unoiled sites (Figure 13.6).

Percentages of egg brooding females (= berried females), within oiled and unoiled grassbeds as a fraction of reproductively mature females (defined as all females above or equal to the carapace length of the smallest berried female observed for each species), showed no trends in either species that suggested an oil effect (Figures 13.9 and 13.10). Percentages of whole clutches of undifferentiated eggs (= eggs without eyes) among berried females of both species suggested that oil exposure did not stop egg development. A toxic effect on embryos might have halted development at an early stage; a larger percentage of undifferentiated eggs would then have been expected at oiled sites. Incidences of concomitant external incubation and ovarian maturation were similar in oiled and unoiled seagrass meadows. From these results, reproductive processes seemed unaffected by oil exposures in either of these two very abundant caridean species.

Initial post-spill densities of numerous epifaunal taxa suggested a widespread sensitivity to oil. Populations of other taxa appeared to be insensitive or sensitive but able to recover rapidly after the spill. Amphipod density fluctuations in Panamanian seagrass meadows fit the pattern displayed by amphipods in *Zostera* meadows following the *Amoco Cadiz* oil spill (denHartog and Jacobs 1980). Ophiuroids were also strongly affected in French and Panamanian grassbeds. Brittle stars remained rare at oiled sites throughout our study.

Ultraviolet fluorescence (UVF) and gas chromatography/mass spectrometry (GC/MS) analyses of a set of deep sediment samples (Table 13.5) demonstrated that, unlike *Zostera marina* in French grassbeds, the root and rhizome mats of Panama's seagrasses did not prevent oil penetration into deep sediment layers. Oil concentrations were higher in deep sediments, at 8-10 cm and at 18-20 cm, than at the sediment water interface (0-2 cm). The UVF analysis of sediment surface scrapes showed that oil concentrations in some areas (especially LREN) remained high through 1987. After that date, surface sediment oil concentrations decreased by an order of magnitude. Characterization of the oil at the initial and the later sampling dates would provide an important

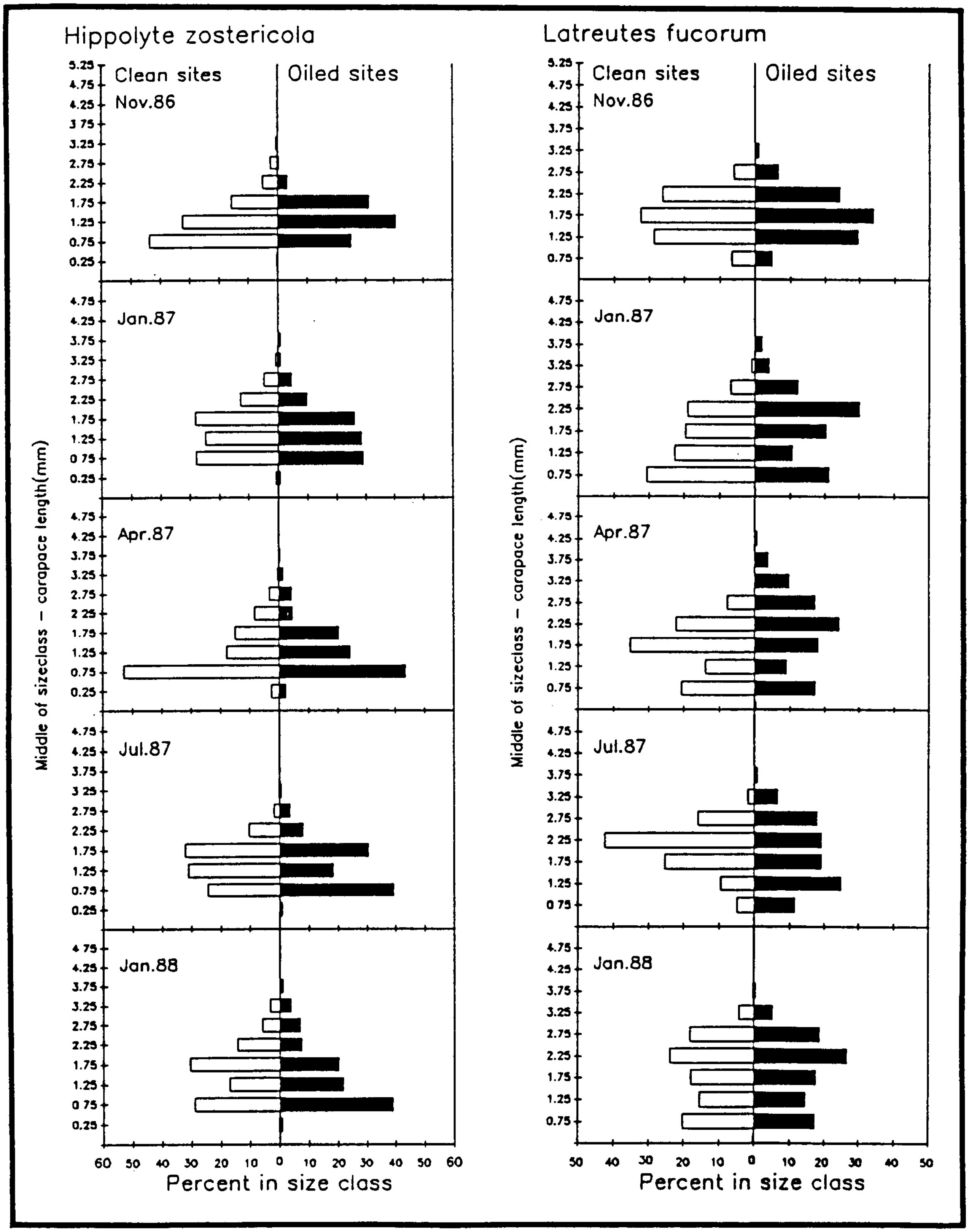

Figure 13.8. Population structures, in oiled and unoiled grassbeds, of two caridean shrimp.

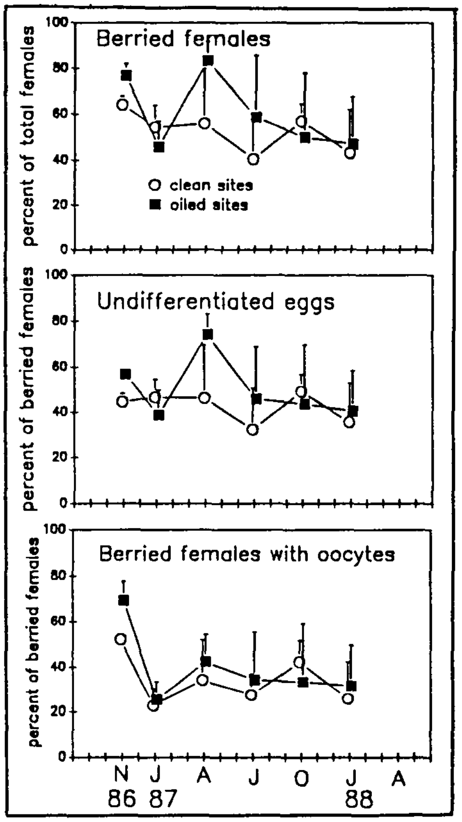

Figure 13.9. Reproductive processes of *Hippolyte zostericola* determined as described in the text.

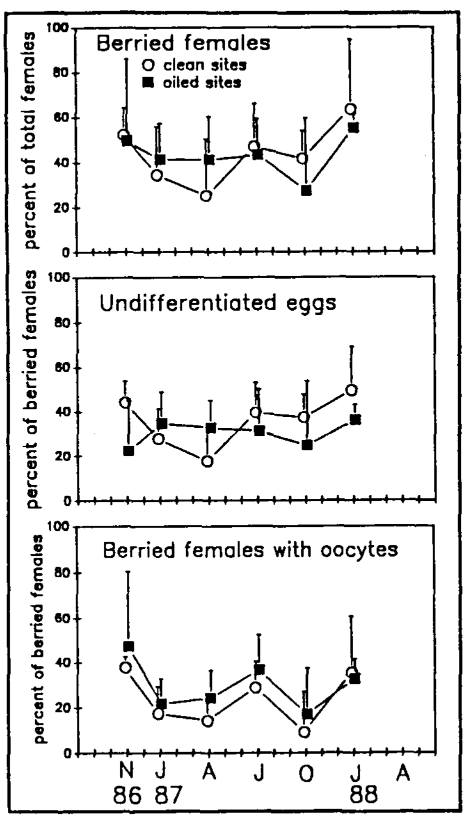

Figure 13.10. Reproductive processes of *Latreutes fucorum* determined as described in the text.

Table 13.5. Hydrocarbons in Seagrass Sediment Surface Scrapes (4a) and at Depths (4b) as Determined by Ultraviolet Fluorescence (UVF) and by Gas Chromatograph (GC-URE) Analysis. (Units are ug/g dry wt. Site categories, heavy, moderate, and unoiled are based on oiling levels based on knowledge of the spill path and on oil observed at each site. See Figure 13.1 for station locations.)

Station	1986		1987		1988	
	UVF	GC-URE	UVF	GC-URE	UVF	GC-URE
(4a)						
Heavily Oiled Sites:						
LREN	4020	2021	6683	203	658	60
LRS	792	111	1198	137	501	51
MINS/N	1499	151	957	75	607	52
PGN			211	19	188	11
Moderately Oiled Site:						
NARC	596	82			98	7
Unoiled Sites:						
DONT	0	0	6	0	0	0
PALN	0	0	1	0	0	0
LINE			102	14	4	0
BNV					6	0
(4b)						
Subsurface Oil:						
LREN						
0-2 cm	4020	2021	6683	203	391	19
8-10 cm					665	64
18-20 cm					553	39

description of the weathering rates of crude oil in tropical seagrass meadows. There are no other studies of this type in the literature.

Observations on temporal fluctuations in population structures suggested that juveniles of *Latreutes fucorum* were no more oil sensitive than were adults of this species. Density differences between oiled and unoiled grassbeds may have thus been due to a general toxic effect of oil on this species. *Hippolyte zostericola*, usually the most abundant shrimp in all grassbeds during this study, appeared unaffected by oil during the course of this study. Initial hydrocarbon analyses (by UVF techniques) demonstrated that there was still a lot of oil in surface sediments on the initial sampling date. These two hippolytid shrimp showed evidence of successful reproduction and recruitment in oiled seagrass meadows. Additional supporting hydrocarbon data, including complete characterization of the oil contained in surface sediments, would permit us to make a stronger statement on these effects.

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THE IMPACT AND LONG-TERM RECOVERY OF MANGROVE FORESTS FOLLOWING THE 1986 OIL SPILL IN PANAMA

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INTRODUCTION

During the past three years, the mangrove forests of Panama have been examined closely regarding the impacts of the 1986 oil spill and any subsequent recovery. This recovery is primarily based on the trees which make up the basic structure of all mangrove habitats, and, as such, the studies have focused on their growth and recruitment. Essentially, the fundamental questions behind this research relate to this ecosystem's ability to recover on its own, or whether some assistance might be beneficial, or essential. In the latter case, it is quite likely that oil spill damage may lead to irretrievable loss of habitat if nothing is done once trees are oiled. On the other hand, they may recover faster if left alone. This study of the Panama oil spill will answer some of these questions and provide the protocol and basis for future assessments of mangrove forests faced with this threat.

Clearly, large oil spills kill mangrove trees. It is most likely that oil coating the above-ground breathing roots causes suffocation, but there may also be a toxic effect, particularly when the oil is more fresh. There is also the question of whether oil has long-term effects on forest recovery, since oil is commonly observed in mangrove sediments five to six years after the spill. Presumably, this influences growth of both seedlings and surviving trees, although there has been no prior assessment of the longer term influence of oil on growth and recruitment. The problem is compounded further by a limited understanding of such processes in unoiled pristine mangroves.

This account does not propose to present a listing of all observations made during this study, preferring instead to present an outline of the entire program with just a few of the more important observations and conclusions.

METHODS

The methods developed during the project were chiefly based on prior experience (e.g., Duke *et al.* 1984), and in reference to other studies (e.g., Snedaker and Snedaker 1984; Tomlinson 1986). This entailed the scoring of a number of parameters ranging from measurements of seedlings and trees, such as height and girth, to salinity and the presence of oil. Measurements of oil content in the sediment were those taken by the hydrocarbon subproject (Burns, this proceedings).

A technique was developed to age seedlings quickly in the field without harming them (Duke and Pinzón in press). This now represents a major tool in this process-based study, providing the means to retrospectively assess demographic structure of growing seedling communities and reforestation. Such an evaluation was previously considered impossible.

Mapping of vegetation outlines was made from aerial photographs, based on detailed groundtruth and familiarity with all local mangrove plants. Mangrove areas are defined as tree vegetation growing in the intertidal zone. In the study area in Panama, this includes five species, *Rhizophora mangle, Laguncularia racemosa, Avicennia germinans, Conocarpus erectus* and *Pelliciera rhizophorae*. Only the latter species is not shared with the Gulf states of the United States. The present study focuses on *R. mangle* since it was the one chiefly affected by the 1986 spill.

Twenty-six study sites in the vicinity of the Panama oil spill (Caribbean coast) were chosen encompassing the range of mangrove habitats affected by the spill, including control areas. These were assessed for two years. Seasonality was gauged from monthly observations and longer term status from annual estimates and measurements. Canopy condition was measured as the total leaf biomass, a standard measure in plant commodity studies. This was estimated from litterfall and leafy shoot observations.

PRIMARY IMPACT

Following the 1986 spill, large areas died within several months of oiling, creating extensive patches of deforestation equalling approximately

75 hectares. Tree death and deforestation, therefore, represents the most outstanding and recognized impact of oil spills on mangroves (Teas 1989). But, this view is incomplete since the numbers surviving direct oiling were possibly much greater, suggesting that death represents only the extreme result of contact with oil. For example, a study in Puerto Rico showed leaf size was smaller for trees growing in chronically oiled sediment (Lugo *et al.* 1980), indicating the possibility of a more subtle, less obvious impact on survivors. These ideas must be considered more fully when assessing long-term impact of oil spills on mangroves.

The extent of the primary impact of deforestation was determined from a series of aerial photographs taken before and after the spill. This has revealed the precise nature and patterns which characterize oil spill deforestation. In fact, the recognition of these same patterns in older photos revealed for the first time that an earlier oil spill in the study area caused equally extensive deforestation. This spill was caused by the sinking of the tanker *Witwater* in 1968. While significant biological effect was reported (Rutzler and Sterrer 1970; Birkeland *et al.* 1976), observations of the mangrove forests were not included. This finding has important implications to the assessment of long-term recovery in the present study since this spill occurred 18 years earlier and recovery has been entirely unassisted. Several sites are being studied for comparison with the 1986 deforestation recovery thus providing a model of recovery over two decades.

LONG-TERM RECOVERY

There are three major components of oiled mangrove forests, including unoiled and oiled trees with the latter comprising survivors and deforested sites. Recovery of deforested areas involves recruitment and growth of seedlings to mature trees, while surviving trees need only persist until harmful conditions dissipate. This would be understandably quicker. Where seedlings are unable to become established, permanent loss of habitat is inevitable. The reasons for the failure of seedlings to become established depends on availability of propagules, their ability to take root and become established, post-establishment survival, and site erosion.

Furthermore, at all three stages, unoiled trees, survivors, and seedlings are all subject to secondary oiling. There is oil from the original spill which became absorbed into the sediment at low tides, achieving greater penetration by flowing down crab burrows and dead root castes. After five years, this residual oil is often observed resurfacing and forming new slicks after heavy rain, or when the substratum is disturbed. These secondary effects may entail further obvious site deterioration and they could add to the subtle retardation of recovery.

The study in Panama has tried to address most of these considerations in making an evaluation of long-term recovery. However, to complicate things further, growth of mangroves is dependent on habitat differences, seasonal growth, and longer term environmental change. Generally, deforestation was restricted to fringing forests in sheltered channel sites and exposed sites backing reef flats.

Condition of Surviving Mangrove Trees

Oiled survivors have apparently suffered canopy deterioration, showing lower levels of mean annual total leaf biomass ($r=0.54$, $P<0.01$) and leaf standing crop, leaves per shoot ($r=0.63$, $P<0.005$). In the presence of oil, there was a consistent 23-33 percent reduction in leaf weight, and leaf biomass, in the canopy.

This infers that oil has reduced the ability of these trees to support the prespill densities of canopy leaves. This is probably the result of an equivalent loss of feeding roots which cannot be replaced while oil remains in the substratum. In this scenario, the trees have shed leaves, ostensibly to compensate for the loss of roots, leading to a reduction of shoots. This is apparently continuing since wood litter fall was still significantly higher in oiled sites during 1990. It appears as though the trees are adjusting their process strategies, trying to economize on their total leaf area and carbon fixation, by varying leaf size, numbers of leaves per shoot, and numbers of shoots per unit area. The prognosis of long-term recovery does not look good, however, considering the data, for example, of standing crop leaves per shoot. These estimates are significantly lower in oiled sites in the first instance, and in the second, they show a continuing decline in the second year of this study, 1991. Such evidence suggests that these surviving trees remain under serious threat.

Recovery of Deforested Mangrove Areas

After five years, there is essentially prolific seedling growth and recovery in deforested, sheltered areas. Natural recruitment has occurred annually and appeared uninhibited by the presence of residual oil. Nevertheless, this study has also found that growth seems to be suppressed by oil, shown by seedlings in less oiled substrates having significantly greater height extension ($P < 0.05$). There was similar trend in exposed sites, but these had very low survivorship of seedlings. In fact, these are severely affected by erosion, with 1-2 cm of surface sediment lost over a one year period (1990-1991), compared to no significant loss in sheltered sites. Furthermore, this process appears to be accelerating in recent years, resulting directly from the latter stages of breakdown of trees and roots killed in the 1986 spill. Their structure had provided support and protection for the young seedlings, but now this is going fast. In exposed sites, there is a greater amount of wave action, but also there is the direct buffeting and scouring caused by numerous and large drift-logs. Established trees can withstand this, but clearly the seedlings take several years to attain sufficient size before they have a chance of survival under these circumstances.

The seedling recovery from the 1968 spill was entirely natural, notably unaided by planting, as was the 1986 spill. This point is particularly important since recovery from the latter was reportedly assisted by the massive planting effort of the Refinería Panamá (Teas *et al.* 1989). By contrast, this study of seedling demography has indicated that the planting effort was essentially unnecessary since natural regenerative processes were sufficient in most instances. In fact, there were significantly lower densities in planted sites, presumably caused by soil and root damage, and interference with natural recruits. Furthermore, the planting effort failed to assist recovery in the most vulnerable areas, notably the exposed sites behind reef flats. It is predicted that several of these forests may never recover because neither planted or natural seedlings were able to withstand strong buffeting by driftwood. Furthermore, the erosion has now removed the protective soil and root mat, exposing a hard rocky surface where future natural recruitment is considered virtually impossible. Such blown-out sites are evident from the earlier spill, as examples of what to expect for exposed sites deforested by the 1986 spill.

CONCLUSIONS

This study will provide a detailed assessment of the impact and long-term recovery of mangrove forests following the 1986 spill in Panama. Already, the evidence clearly identifies serious primary and long-term impacts, suggesting that where mangroves are valued, then responses must concentrate on keeping mangroves free of oil. However, when oiling of mangroves is unavoidable, these findings will also provide some strategies for minimizing the damage and long-term impact. For example, mangroves growing in exposed coastal sites should be given the greatest protection, particularly where decisionmakers face possible trade-offs in directing limited spill response resources. There are also strategies which can be suggested for action following oil contact with mangroves. One example includes active cleanup of individual trees, ostensibly concentrating on those protecting the mangrove fringe, in the first instance. Where this fails, and trees die, particularly in exposed sites, then a possible solution is to install protective barriers whilst seedlings recolonize the site. Furthermore, if natural recruitment is found to be inadequate, then planting may be required to supplement the natural processes. This action must be given very serious consideration, however, since misdirected assistance may add further to the deterioration of the particular mangrove forest. The decision of knowing how and when to act, if at all, clearly must come from studies like this one.

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THE PERSISTENCE OF OIL SPILLED IN MANGROVE ECOSYSTEMS

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INTRODUCTION

The key component in assessing the impact of a chemical spill in the marine environment is to relate the observed biological changes with the presence of the toxic chemicals. Oil is a complex mixture of many hundreds of chemicals, most of which are hydrocarbons of various configuration. Crude and refined oils have been documented to be toxic to all components of marine ecosystems exposed to catastrophic spills. The Bahía Las Minas oil spill of over eight million liters of medium weight crude oil onto the Caribbean coast of Panama was documented to cause massive mortality in mangrove, seagrass, and coral reef ecosystems (Jackson *et al.* 1989; Cubit *et al.* 1987). The long-term impact assessment was thus launched with major studies in all three types of tropical coastal ecosystems. The objectives of the hydrocarbon chemistry program are to interface with the extensive array of biological impact assessment studies to provide chemical evidence for exposure levels; to determine the variability of contaminating oil residues within habitats; and to study the diagenetic fate of the oil in terms of correlating the composition of residual fractions with the long-term impact and recovery studies. This presentation focuses on the unexpected persistence of the oil in mangrove sediments and the continued reoiling of the coastal habitats for over five years following the spill.

METHODS

A combination of chemical methods was used ranging from ultraviolet fluorescence spectroscopy (UVF) which is selectively sensitive to the aromatic hydrocarbons, through the more quantitative but less specific method of flame ionization gas chromatography (GC), to the extremely sensitive, selective technique of selected ion monitoring gas chromatography/mass spectrometry (SIM-GC/MS). Details of extraction and analysis procedures were published by IOC/UNESCO (1991). Estimates of oil content in mangrove sediments and organisms made by all three methods showed a highly significant level of correlation spanning four orders of magnitude. As space is limiting here, the UVF data will be used to describe relative oil concentrations and GC and GC/MS data will be used to describe compositional changes.

PERSISTENCE OF OIL IN THE MANGROVE ECOSYSTEMS

Sediment cores taken in the mangroves in oiled areas in 1986 during the initial impact survey showed that oil had penetrated sediments down to 20 cm in depth. Oil moved by tidal action, diffusion, down animal burrows, and (in later years) down channels created by the decaying roots of the dead mangrove trees. Only a few of the long-term sites had been sampled in the initial survey. After the biologists had selected their study sites for the long-term impact assessment, triplicate sets of cores were collected from each site in 1989 and in 1990 (years three and four post-spill).

The time series data show that oil concentrations remained high in mangrove surface sediments through at least year four and that more oil was transported to depth in the later years. Table 13.6 shows the Log of the $\mu g/g$ dry weight determinations for UVF and GC methods and the Log of the $\mu g/g$ dry weight determinations of the sum of individual polynuclear aromatic hydrocarbons (PAHs) determined by GC/MS. There is some year-to-year variability in the data, probably due to patchy distribution of oil residues within the sediment column and spatially within sites. An attempt was made to minimize sampling variability by combining the 0-2 cm, 8-10 cm, and 18-20 cm sections from three cores at each station. Drawings and photographs document the patchy distributions of oil in the cores.

Weathering processes of evaporation, dissolution, microbial degradation, and photochemical decomposition had dramatically altered the composition of oil residues in surface sediments after just six months. Only in heavily oiled sediments could the straight chain or branched chain alkanes from the oil be quantified. In most sediment samples, the hydrocarbon patterns determined by GC contained up to 99 percent unresolved components, indicating that microbial degradation had removed the resolved components. By contrast, reaching this stage of degradation in temperate salt marshes requires approximately two years (Burns and Teal 1979). Very few of the mangrove sediments in later years contained quantifiable levels of marker alkanes. However, residual pools of oil in mangrove sediments remained fluid enough to flow out of the sediments when cored or disturbed by storm erosion. Oil slicks have repeatedly been observed through year five to leach out of oiled mangroves and move along the coast, redistributing the oil even into previously unoiled sites.

Figure 13.11 shows gas chromatograms of the hydrocarbon fractions of the Venezuelan Mexican Isthmus Crude (VMIC) which was spilled, oil oozing from depth in a core hole from a heavily oiled channel site 3-1/2 years post spill, and oil recoating mangrove roots in a previously unoiled site 2-1/2 years after the spill. The chromatograms show the reservoirs of trapped oil still contained a significant fraction of low boiling hydrocarbons which could presumably still be toxic when leached into the coastal waters. Residues redeposited on solid surfaces were so highly modified that source identification would be impossible by GC without additional supporting chemical evidence. Figure 13.12 shows the conservation of the UVF spectra even in the highly modified oil residues. Subtle changes in the spectra due to the disappearance of the low molecular weight aromatics were evident in some samples. The majority of the fluorescence signal to this crude oil is contained in the high boiling residual aromatic hydrocarbons. Figure 13.13 shows the conservation of the pattern of triterpane biomarkers seen by GC/MS selected ion monitoring of m/z 191 and related ions. The triterpanes elute in the C26 to

Table 13.6. Ultraviolet Fluorescence Spectroscopy (UVF) and Gas Chromatography-Total Hydrocarbons (GC-THC) Oil Content as LOG (ug/g dry wt.) and Total Polynuclear Aromatic Hydrocarbons (PAHs) as LOG (ng/g dry wt.) in Mangrove Sediments.

A. River Sites

	P2-9/86			P3-5/89			P4-7/90		
RO1 LRRS	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				4.2	3.3	3.4	5.0	4.1	4.7
8-10 cm				3.7	2.6	3.2	4.9	4.1	4.7
18-20 cm				2.5	2.0	2.2	4.2	3.3	3.8

	P2-9/86			P3-5/89			P4-7/90		
RU1 HIDR	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				2.4	2.3	2.7	2.2	1.9	2.6
15-20 cm									

	P2-9/86			P3-5/89			P4-7/90		
RO2 PAYR	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				4.7	3.8	4.3	4.6	3.8	4.7
8-10 cm				5.1	4.4	5.1	4.6	3.8	4.6
18-20 cm				3.2	2.7	2.7	3.5	2.8	3.5

	P2-9/86			P3-5/89			P4-7/90		
RU2 UNR	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				2.1	1.7	2.6	2.3	2.6	2.4

	P2-9/86			P3-5/89			P4-7/90		
RO3 PMRE	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				4.7	3.9	4.5	4.5	3.5	4.0
8-10 cm				4.9	4.2	5.0	3.7	3.0	3.5
18-20 cm				3.2	2.9	4.0	2.3	2.0	4.2

	P2-9/86			P3-5/89			P4-7/90		
RU3 ALER	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				2.1	1.8	3.0	2.7	1.7	3.0

	P2-9/86			P3-5/89			P4-7/90		
RO4 PMRW	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				4.8	4.0	4.9	5.1	4.1	5.0
8-10 cm				3.3	2.6	3.6	4.6	3.9	4.7
18-20 cm				2.0	1.5	2.6	4.0	3.3	4.5

	P2-9/86			P3-5/89			P4-7/90		
RU4 MERR	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				1.7	1.5	1.8	2.3	1.9	2.2

Table 13.6. Ultraviolet Fluorescence Spectroscopy (UVF) and Gas Chromatography-Total Hydrocarbons (GC-THC) Oil Content as LOG (ug/g dry wt.) and Total Polynuclear Aromatic Hydrocarbons (PAHs) as LOG (ng/g dry wt.) in Mangrove Sediments (continued).

B. Channel Sites

	P2-9/86			P3-5/89			P4-7/90		
CO1 SBCE	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				5.5	4.8	6.3	4.7	3.5	3.8
8-10 cm				5.3	4.6	5.2	5.4	4.6	4.8
18-20 cm				4.0	2.7	3.6	5.4	4.7	5.3

	P2-9/86			P3-5/89			P4-7/90		
CU1 MACS	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm	2.4	2.1		2.1	1.4	2.4	2.5	1.5	2.4
18-20 cm	1.3	0.7							

	P2-9/86			P3-5/89			P4-7/90		
CO2 SBCS	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm	5.0	5.1	6.3	5.3	4.6	5.2	5.0	4.4	4.7
8-10 cm				4.6	3.9	4.6	4.6	4.2	4.5
18-20 cm	3.5	3.7	4.8	3.6	2.9	3.3	2.6	2.1	3.0

	P2-9/86			P3-5/89			P4-7/90		
CU2 MACN	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm	2.8	2.7		2.4	2.3	3.0	2.8	2.4	3.2
8-10 cm				2.9	2.5		3.1	2.4	
18-20 cm	3.2	4.0		2.8	2.2		2.8	2.7	3.2

	P2-9/86			P3-5/89			P4-7/90		
CO3 PCE	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				5.2	4.0	5.0	5.0	4.0	4.3
8-10 cm				3.5	2.6	2.2	4.6	3.8	4.3
18-20 cm				3.2	2.3	2.1	3.4	2.6	3.1

CU3/	P2-9/86			P3-5/89			P4-7/90		
CN3 HIDC	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm	1.6	1.5		1.9	1.6	1.5	3.3	2.3	2.9
8-10 cm				1.4	1.6	2.0	3.2	2.9	2.9
18-20 cm	1.6	1.6		1.3	1.3	0.8	2.6	1.9	2.7

	P2-9/86			P3-5/89			P4-7/90		
CO4 PCS	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				4.9	4.1	5.1	5.1	4.6	5.4
8-10 cm				5.3	4.5	5.5	5.0	4.4	5.7
18-20 cm				4.6	3.6	4.6	3.5	2.5	3.4

	P2-9/86			P3-5/89			P4-7/90		
CU4 SBCW	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				3.0	2.0	2.6	4.5	3.5	3.7
8-10 cm				2.6	1.9	2.7	3.1	2.1	2.8
18-20 cm				0.9	1.5	1.2	1.7	1.0	1.8

	P2-9/86			P3-5/89			P4-7/90		
CO5 LRCW	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				4.1	4.3	3.3	4.4	3.6	4.6
8-10 cm				3.5	2.4	3.2	3.0	1.7	2.9
18-20 cm				3.5	1.9	3.3	4.8	3.8	4.9

	P2-9/86			P3-5/89			P4-7/90		
CU5 LRCS	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				3.5	2.9	3.0	3.8	3.1	3.1
8-10 cm				3.4	3.2	3.6	3.0	2.4	2.8
18-20 cm				2.4	1.4	2.1	1.8	1.7	2.0

Table 13.6. Ultraviolet Fluorescence Spectroscopy (UVF) and Gas Chromatography-Total Hydrocarbons (GC-THC) Oil Content as LOG (ug/g dry wt.) and Total Polynuclear Aromatic Hydrocarbons (PAHs) as LOG (ng/g dry wt.) in Mangrove Sediments (continued).

C. Open Coast Sites

	P2-9/86			P3-5/89			P4-7/90		
OO1MINM	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				4.2	3.3	3.6	4.7	3.7	4.0
8-10 cm				3.1	2.0	2.2	3.5	2.7	3.3
18-20 cm				1.9	1.1	0.6	3.7	2.7	3.3

	P2-9/86			P3-5/89			P4-7/90		
OU1 MSM	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				0.0	0.0	0.0	0.8	0.6	1.6

	P2-9/86			P3-5/89			P4-7/90		
OO2 PGM	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				4.7	3.9	4.7	5.1	4.1	4.6
8-10 cm				4.4	3.2	4.2	4.9	3.6	4.1
18-20 cm				4.1	3.2	4.5	4.3	2.7	3.8

	P2-9/86			P3-5/89			P4-7/90		
OU2 PBM	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				0.6	0.2	0.6	1.6	0.8	1.9

	P2-9/86			P3-5/89			P4-7/90		
OO3 DROM	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm	4.2	3.2		4.7	3.6	4.7	4.8	3.6	4.3
8-10 cm				5.0	3.6	5.0	4.7	3.8	4.4
18-20 cm	3.0	2.1		3.6	2.4	3.4	3.5	2.5	3.4

	P2-9/86			P3-5/89			P4-7/90		
OU3 PADM	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				1.3	0.2	0.8	1.1	0.3	1.9

	P2-9/86			P3-5/89			P4-7/90		
OO4 PMM	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				4.0	3.2	2.3	5.4	4.3	5.1
8-10 cm				3.6	2.2	2.9	4.8	4.1	4.8
18-20 cm				2.8	1.6	2.1	4.2	3.4	4.1

	P2-9/86			P3-5/89			P4-7/90		
OU4 LINM	UVF	GC	PAH	UVF	GC	PAH	UVF	GC	PAH
0-2 cm				1.5	1.1	1.7	1.5	0.9	2.2

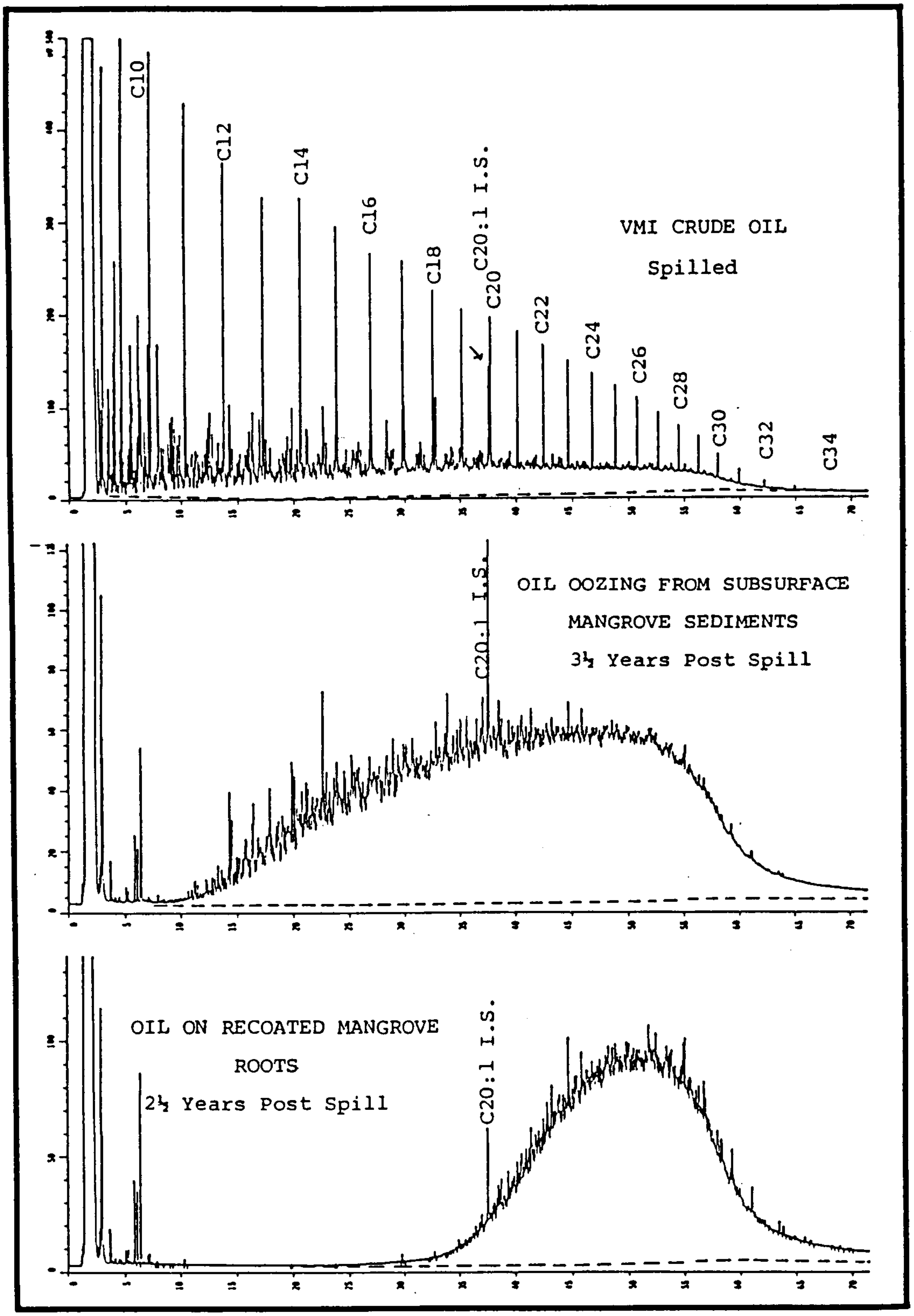

Figure 13.11. Gas chromatograms of spilled oil and oil oozing from sediments in subsequent years and the extensive alteration of patterns due to weathering of oil recoating mangrove roots. (C20:1 is an internal standard added for GC quantification.)

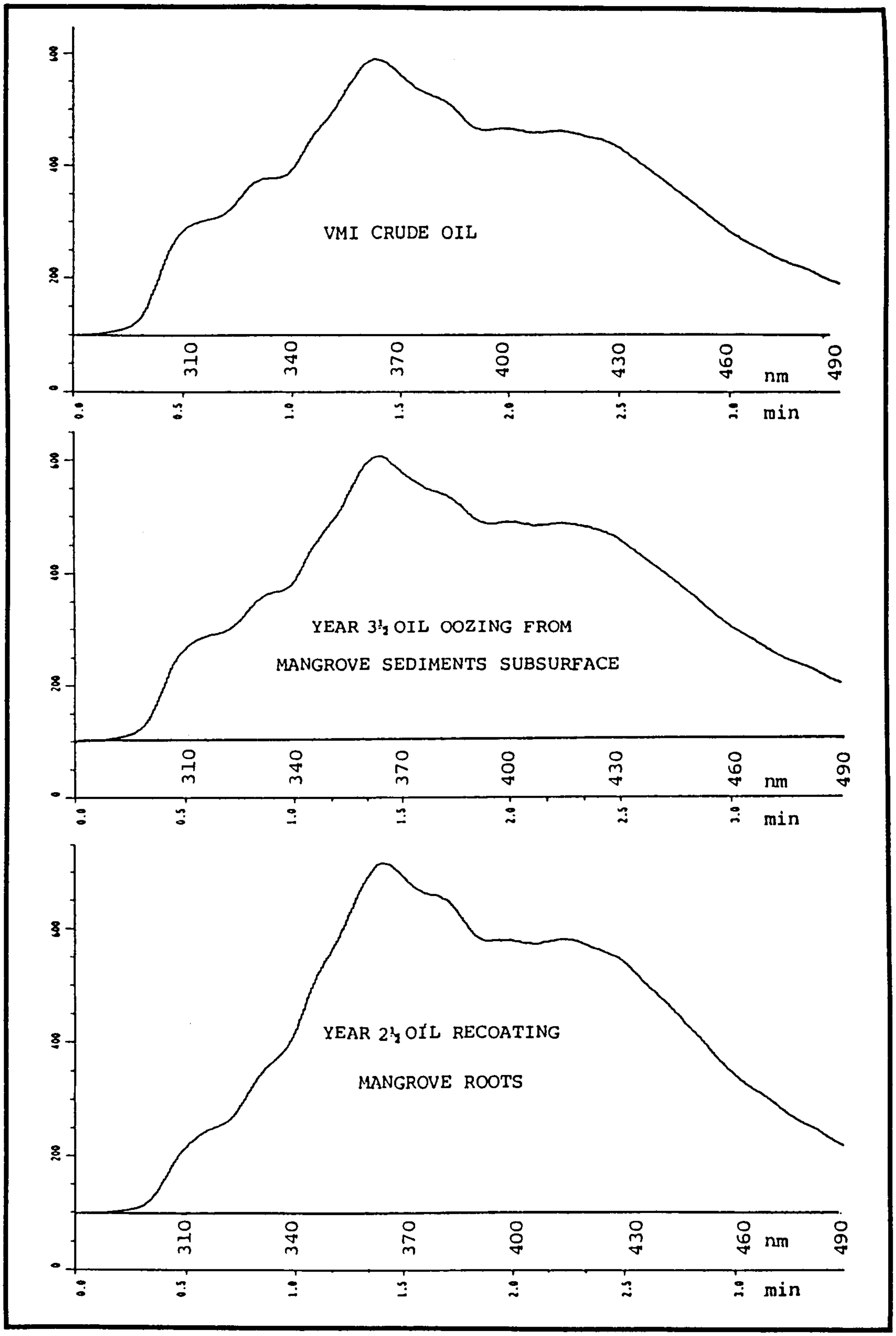

Figure 13.12. Synchronous excitation emission ultraviolet fluorescence spectra of oil spilled into mangrove ecosystem showing pattern retention even after extensive weathering of residual.

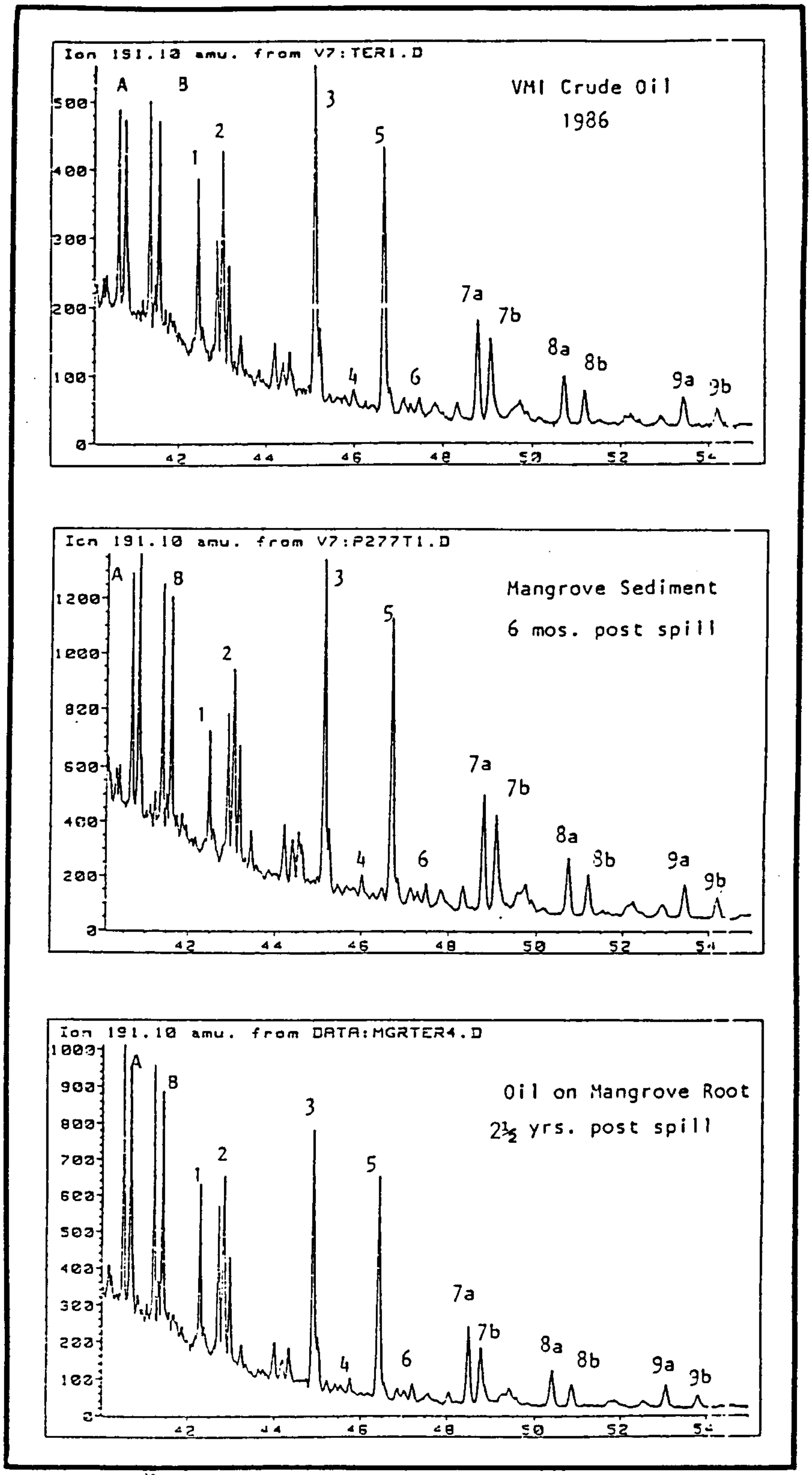

Figure 13.13. Selected ion monitoring gas chromatography/mass spectrometry (SIM GC/MS) trace of 191 m/z for triterpane biomarkers in the hopane series.

C30 boiling range. By use of these selective techniques, the source identity of even highly weathered residues can be verified.

In 1991, the sediments were again cored. In addition to saving sediment for analysis of dead/live roots, the oil oozing out of the core holes in a three minute time period was collected at each site. For cores showing no oozing oil (control sites) 20 ml of water refilling the hole was collected. Figure 13.14 shows the Log of the amounts of oil determined by GC and UVF methods. From this data, it is clear that significant amounts of oil leached out of disturbed sediments through to year five post-spill. Figure 13.15 shows the gas chromatograms of the oil from the river sites. In most cases the oil was highly degraded and similar to the residues seen in sediment extracts. However, RO4 contained a surprisingly fresh oil residue with the full suite of n-alkanes preserved. This is in sharp contrast to the oil in surface sediments. There is no evidence that this oil at depth is from a new source. Thus it must have been preserved relatively intact from the 1986 spill in an anoxic zone of sediment, perhaps inside a decayed mangrove root.

Further evidence that this oil oozing from deep sediments is residual from the spilled VMIC comes by examination of the individual PAH data. (Triterpane data is not yet available for the 1991 samples.) Figure 13.16 shows the distribution of parent and alkyl substituted PAH in the naphthalene (N), fluorene (F), dibenzothiophene (D), phenanthrene/anthracene (P), and chrysene/benzanthracene (C) series for VMIC, the ooze oil from RO3 in 1990, and the ooze oil from RO4 in 1991. Allowing for the loss of the most volatile naphthalenes, the patterns are quite similar. Table 13.7 shows the entire data set for PAHs in the 1991 ooze oil samples. It is apparent that significant levels of the low molecular weight aromatics were still leaching from disturbed sediment through year five.

Water soluble fractions of the crude oil were accumulated by bivalves over the entire study time. Figure 13.17 shows the concentrations of oil in oysters and mussels as averages of the samples from the replicate sites at each time period. Table 13.8 gives the data for each sample. The immediate impression is that oysters (*Crassostrea rhizophorae*) had only about one-half the amount of oil in their tissues compared to mussels (*Mytilopsis dominquensis*). At three of the river sites in 1988, both species were collected from the same sites. Mussels contained on average about twice the levels as oysters. Levels in both species at all oiled sites and at a few of the control sites subsequently oiled would be expected to cause at least sublethal stress responses in the bivalves (Widdows *et al.* 1990).

The disparity in the levels concentrated by these two species led us to conduct an uptake experiment. In May of 1991, oysters and mussels were collected from controls sites, packed in open mesh nylon bags, and placed at station RO1. Samples of each species were taken on days 0, 3, 6, 9, 12, 15, and 21. Figure 13.18 shows the GC and UVF results from these samples. The time course for uptake was as previously documented for other similar species (Burns and Smith 1981). However, the oysters showed only half the initial rate of uptake (Ri), half the average concentration (Cavg), and half the maximum concentration (Cmax) as the mussels. This experiment shows the difference in accumulation characteristics of the two species.

The field data can thus be interpreted to mean that similar amounts of soluble oil fractions were available for bioaccumulation at river and channel sites. This is in agreement with the sediment data. It shows that significant levels of potentially toxic hydrocarbons were bioavailable through year five. Barnacles (*Balanus improvisus*) from open coast sites were also tested for their usefulness as bioindicators. However, this species is so small that it was not possible to dissect it away from its shell as was possible for the bivalves. Thus the shells of the barnacles were included in the extractions. Levels of oil in these samples were extremely variable and the residues appeared to be high boiling residual tar type fractions, not the water soluble fractions accumulated by the bivalves. Figure 13.19 shows examples of the GCs of oil residues from the three species. It must be concluded that the barnacles were not a useful bioindicator species.

The water soluble fraction of the leaching crude oil bioaccumulated in the bivalves is further demonstrated by the UVF spectra shown in Figure 13.20. The bivalves contained the water soluble fraction in the 2 to 4 ringed series while the oozing oil was more enriched in the heavier and more

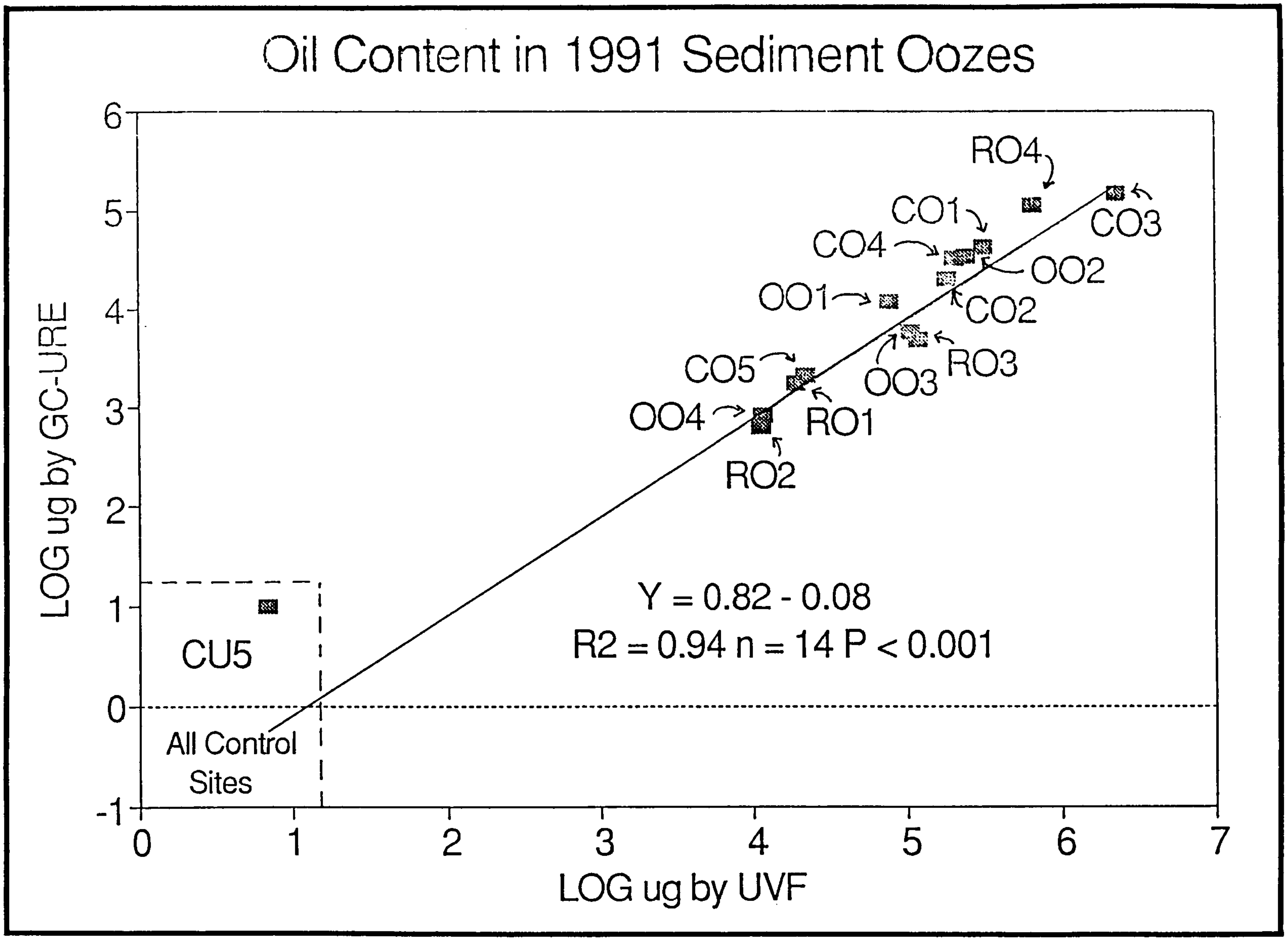

Figure 13.14. Ug of oil oozing out of core holes in mangrove sediments within 3 minutes in 1991. (Log of ug total oil determined by UVF and by GC.)

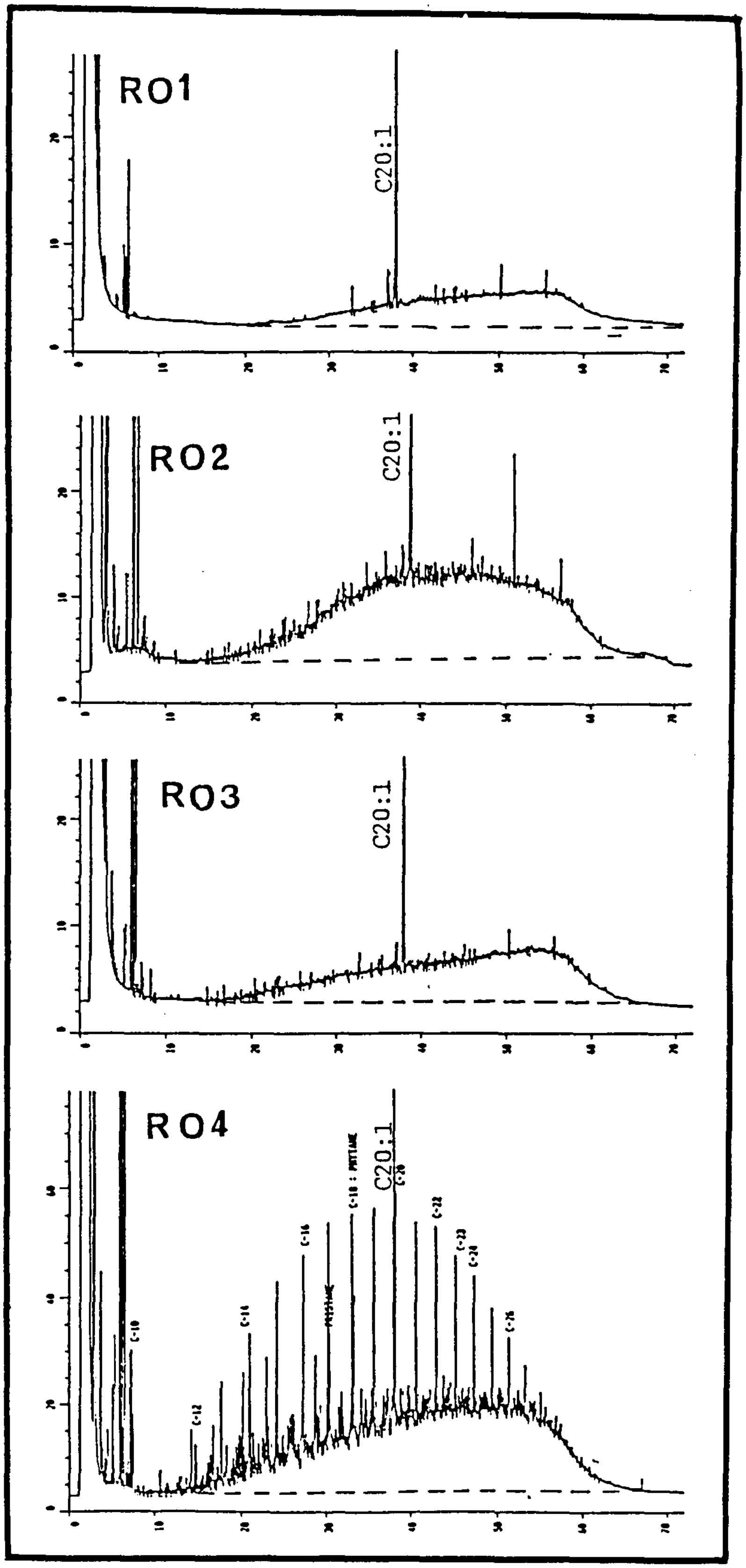

Figure 13.15. Gas chromatograms of oil oozing from core holes in mangrove sediments in May 1991 river sites. (C20:1 is an internal standard.)

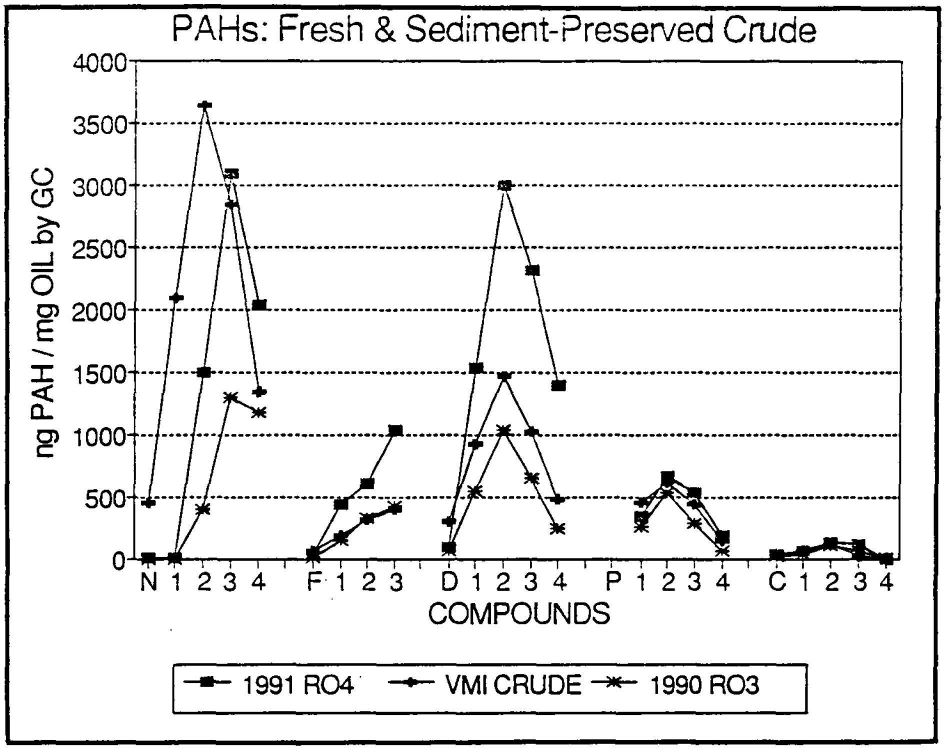

Figure 13.16. The distribution of parent and alkyl substituted PAH in the naphthalene (n), fluorene (F), dibenzothiophene (D), phenanthrene/anthracene (P), and chrysene/benzanthracene (C) series for VMI crude, the ooze oil from RO3 in 1990 and the ooze oil from RO4 in 1991.

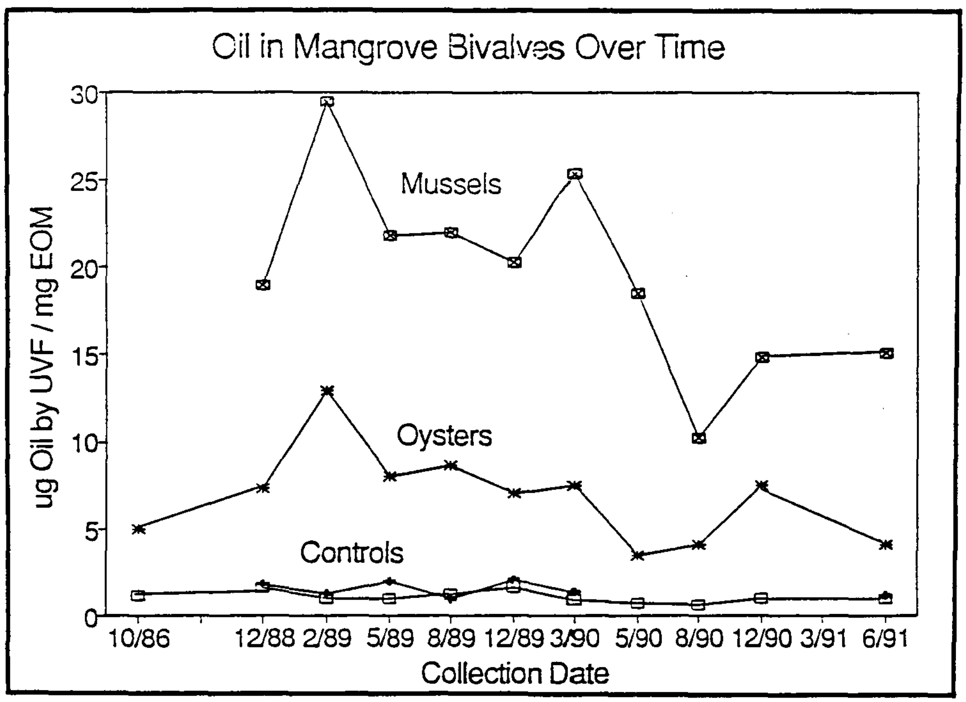

Figure 13.17. The UVF oil concentrations in bivalve tissues over time. (Points are the average value of replicate sites. Individual site data in Table 13.4.)

Table 13.7. The PAHs in 1991 Ooze Oils from Mangrove Sediments. (Units are ng PAH/mg total hydrocarbons determined by GC.)

COMPOUND	OO1	OO2	OO3	OO4	RO1	RO2	RO3	RO4	CO1	CO2	CO3	CO4	CO5	CU5
naphthalene	0	0	0	18	0	0	0	4	0	0	0	2	0	0
C-1 naphthalene	0	0	0	28	0	0	0	10	0	0	0	1	0	0
C-2 naphthalene	0	0	0	57	10	15	0	1500	103	0	0	21	6	0
C-3 naphthalene	164	18	87	68	64	72	0	3092	472	295	73	109	88	0
C-4 naphthalene	650	172	227	20	122	177	101	2041	500	839	651	470	11	0
fluorene	0	0	0	0	0	5	0	35	21	4	4	6	3	0
C-1 fluorene	26	24	37	23	19	24	0	441	109	66	29	55	14	0
C-2 fluorene	157	141	71	34	58	67	55	608	175	339	147	347	17	0
C-3 fluorene	692	789	735	338	0	670	598	1047	908	920	1233	1160	134	0
dibenzothiophene	26	7	13	4	7	14	4	90	18	24	19	17	2	0
C-1 DBT	30	19	52	11	51	21	13	1537	285	167	65	273	12	0
C-2 DBT	1330	743	658	294	522	897	873	2997	1093	1736	2022	2375	56	0
C-3 DBT	2290	2909	2438	1235	992	2188	1920	2327	1417	2170	3774	2730	433	0
C-4 DBT	1962	2466	3751	2003	1117	2243	1837	1399	1225	1578	3000	1865	936	0
C-1 phenanthrene/an.	5	0	48	25	13	27	1	346	20	4	6	20	13	141
C-2 phenanthrene/an.	147	80	268	66	58	109	53	670	119	214	201	166	26	0
C-3 phenanthrene/an.	427	278	819	260	145	373	254	536	122	394	591	398	65	0
C-4 phenanthrene/an.	199	205	920	250	138	288	246	194	104	176	309	200	90	0
fluoranthene	18	0	50	40	15	25	18	31	15	26	46	28	19	1
pyrene	17	0	76	118	17	69	73	56	75	65	134	73	49	2
C1-pyrene/fluoranth	366	550	465	600	0	435	328	325	414	338	793	406	246	0
C2-pyrene/fluoranth	507	734	674	882	174	627	556	359	527	351	961	461	360	0
chrysene/benzanthr.	96	44	83	39	20	46	50	35	47	40	97	45	20	0
C-1 chrysene/benzan.	86	38	163	75	0	99	94	62	87	66	161	90	51	0
C-2 chrysene/benzan.	302	139	493	269	0	268	146	143	206	158	341	222	130	0
C-3 chrysene/benzan.	284	121	473	29	0	200	109	115	153	130	265	195	109	0
C-4 chrysene/benzan.	117	71	213	101	0	45	0	0	0	0	74	97	0	0
benzopyrenes	6	7	17	10	4	9	5	4	6	4	10	7	5	0
perylene	20	24	65	32	6	23	0	17	17	17	43	22	10	0
dibenzanthracene	0	0	18	0	0	0	0	0	0	0	0	5	0	0
benzoperylene	301	297	743	475	218	418	0	182	188	216	462	273	205	0
TOTAL PAHS	10225	9876	13657	7404	3769	9452	7336	20202	8424	10339	15509	12140	3108	145

*Note: Phenanthrene and anthracene eluted outside the SIM acquisition window and were not quantified in this data set.

Table 13.8. Mangrove Organisms GC-URE Oil Content ug/mg lipid (EOM). (URE is the GC signal generated by the complex mixture of hydrocarbon residues which cannot be resolved into individual peaks. This is a conservative estimate of "petroleum" hydrocarbons in samples.)

Site	Dec 88	Feb 89	May 89	Aug 89	N/Dec 89	Mar 90	May 90	Aug 90	N/Dec 90	M/Jun 91
RO1 LRRS m	19.7	12.5	12.0		40.9	14.7	114.3	3.4	3.9	3.3
RO2 PAYR m	(13.7o) 28.3		8.1	10.1	6.6	1.6	12.2	8.3	7.1	4.2
RO3 PMRE m	(8.3o) 8.1				13.8	13.7	7.6	4.2	9.1	3.8
RO4 PMRW m	(4.3o) 9.0	11.4		11.1	9.2	8.7	5.8	3.6	5.9	5.2
RU1 HIDR m	3.5		1.3		1.5	0.0				0.6
RU2 UNR m	1.3	1.3			2.9					0.4
RU3 ALER m	1.8			3.4	1.7	0.0				1.0
RU4 MERR m	0.5	1.5	0.9	0.5	0.0	0.0				0.5
CO1 SBCE o	2.4, 5.2	8.9			7.8	3.8	2.2	6.4	1.5	2.8
CO2 SBCS o	7.3, 3.1			9.8	5.2	4.3	6.5	3.5	9.8	2.8
CO3 PCE o	3.1, 2.3			6.0	0.6	1.0	2.3	2.4	4.4	0.9
CO4 PCS o	8.2, 34.0	6.5	4.5		13.7	4.9	7.8	6.5	6.8	2.9
CO5 LRCN o	2.2		2.1		1.6	4.3	1.6	1.4	2.3	4.6
CU1 MCS o	7.1					Int				1.0
CU2 MCN o	4.1	2.0	1.7		0.4	1.6				3.2
CU3 HIDC o	0.7			0.0	1.1	0.9	0.0	0.4	2.9	0.7
CU4 SBCW o	2.7	lost	1.2	2.0	0.9	Int	0.3	0.5	3.0	1.1
CU5 LRCS o	1.0				0.0	1.5	0.3	0.9	1.5	0.7
OO1 MINM b	44.0	4.1			5.5				1.9, 3.1	
OO2 PGNM b	87.9		1.1	1.3	4.5				4.4, 2.9	
OO3 DROM b	18.2		6.4						4.8, 6.2	
OO4 PMM b	3.9	14.6		0.8					1.7, 0.7	
OU1 MSM b	2.0	0.0	0.0		0.0					
OU2 PBM b	0.5	3.3		0.0						
OU3 PADM b	1.5		3.0	0.0						
OU4 LINM b	1.8				0.5					

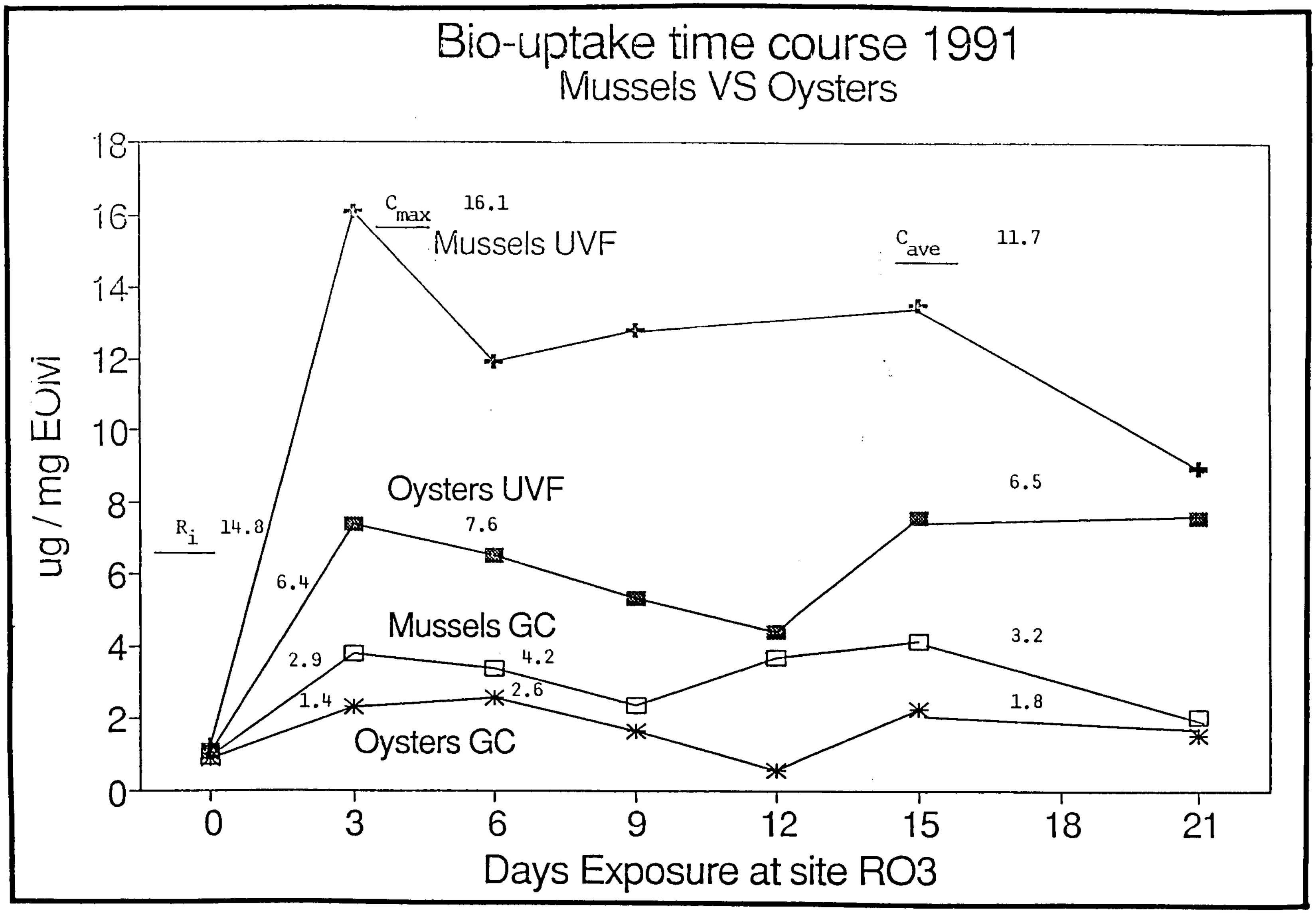

Figure 13.18. Concentrations of oil determined in both UVF and by GC-URE in bivalves transplanted from control to oiled site RO1 in May 1991.

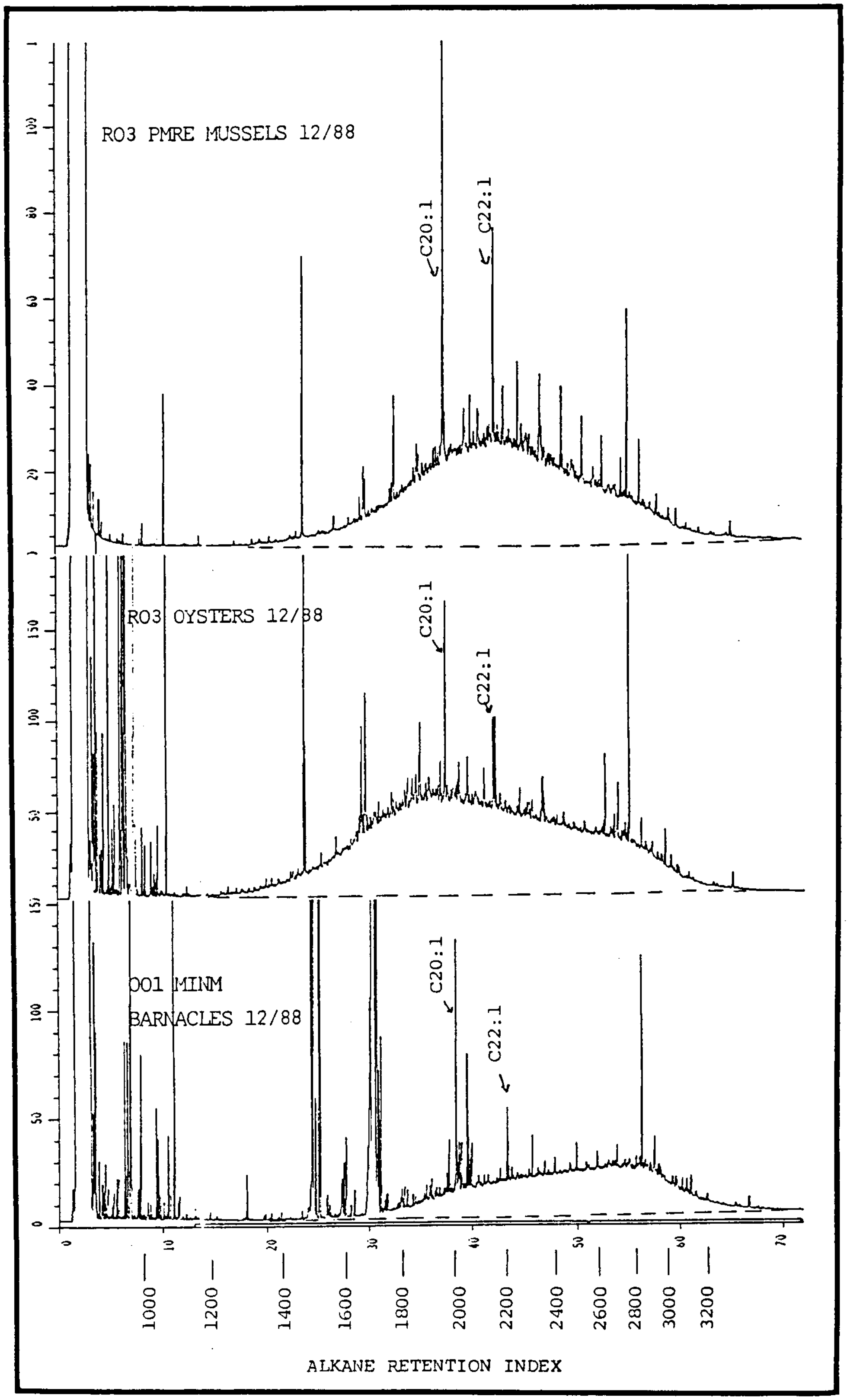

Figure 13.19. Gas chromatograms of saturated hydrocarbons in mangrove organisms, December 1988.

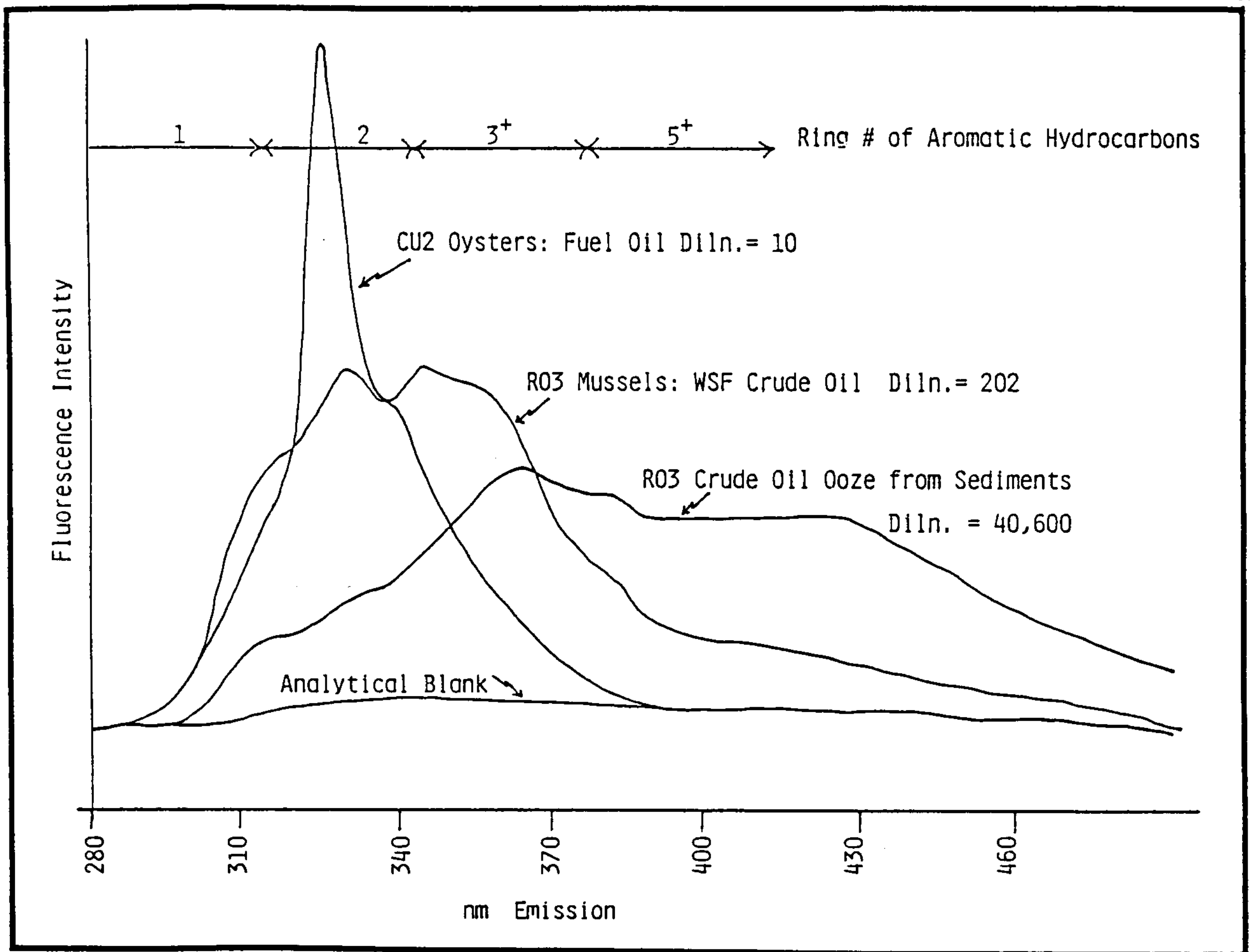

Figure 13.20. Synchronous excitation emission spectra 25 nm Δ.

fluorescent 4, 5, and higher ring series. The third trace is of a fuel oil residue in oysters from a control site which is easily distinguished both in quantity and quality from the crude oil residues.

CONCLUSIONS

The chemistry data confirm the long-term persistence of crude oil residues in the deep muds of the mangrove ecosystems. The originally fast rate of degradation of alkane fractions observed in 1986 was not maintained in degradation rate of the more residual aromatic hydrocarbons. Pools of trapped oil maintained surprising consistency in composition as seen by UVF, GC, and GC/MS analysis. This trapped oil was continually leached into coastal waters and was continually bioaccumulated by encrusting bivalves over the first five year period. The most residual aromatic fractions appear to be the dibenzothiophene and phenanthrene and higher series. The continued high concentrations of these relatively toxic fractions, even in sediment residues that appear highly weathered by GC, indicate their life span in the mangrove ecosystem is much longer than five years. Justification for further study with emphasis on the functional ecology of the mangrove systems is clear. The next five years is expected to be the critical period for studying both lethal and sublethal impacts (Teal *et al.* 1991; Farrington *et al.* 1991).

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(BBSR): K.A. Burns, D. Jorrisen, J. MacPherson, J. Tierney, L. Yelle, and many student assistants. Special collaboration with biologists S. Garrity and S. Levings in field work in the mangroves was essential. We thank these and all the collaborating biologists at Smithsonian Tropical Research Institute. This is Contribution No. 1306 of the BBSR.

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FRINGING MANGROVES AND THE EPIBIOTA OF THEIR ROOTS: EFFECTS OF THE BAHIA LAS MINAS OIL SPILL DURING THE FIRST FIVE YEARS AFTER THE SPILL

Dr. Sally C. Levings
and
Mr. Stephen D. Garrity
Smithsonian Tropical Research Institute

Mangrove forests dominate many tropical and subtropical shores. Red mangroves (*Rhizophora mangle* L.) in Panama form a major interface between land and water, and fringe a range of habitats from wave-exposed open coasts to calmer estuaries. As their prop roots extend into the water, they become covered with various organisms, including bivalve mollusks, algae, barnacles, sponges, tunicates, and hydroids. These fringing roots and their sessile epibiota serve as nurseries, refuges, and feeding areas for a diverse, mobile fauna, including commercially valuable species (Odum *et al.* 1982).

Virtually nothing is known about long-term effects and dynamics of recovery from tropical oil spills on such assemblages (NRC 1985). Because mangrove prop roots grow down through the intertidal zone into subtidal sediments, oil spills coming ashore in fringing mangrove forests will always strand upon prop roots and some portion of their associated epibiota (Vandermeulen and Gilfillan 1984).

Three different assemblages of sessile organisms occur on fringing mangrove roots on the Caribbean coast of Panama. The specific assemblage depends upon whether the mangroves inhabit wave-washed open shores, channels and lagoons, or interior drainage streams (Garrity and Levings 1991). This among-habitat diversity in prop root epibiotic communities provides an opportunity to examine a range of biological effects and responses to oiling over a small geographic scale. The variety of species present on roots allows comparative examination of damage and response for both ephemeral and long-lived species.

Research to date has compared (1) abundances of all epibiotic organisms and (2) aspects of the structure of the mangrove fringe in oiled versus unoiled sites. We have focused on community composition, community development, and recruitment of the epibiota and on the extent of structural alteration to the fringe. We have experimentally examined salinity tolerances of bivalve mollusks and barnacles, and examined factors affecting recruitment of the dominant epibiont in drainage streams. We here briefly summarize major findings to date (see also Cubit *et al.* 1987; Jackson *et al.* 1989; Garrity and Levings 1991).

EXTENT OF OILING

Oil initially coated virtually the entire surface of mangrove roots from above or at the high tide line at oiled sites (Garrity and Levings 1991). Five years after the spill, oil was found on 30-50 percent of roots on the open coast and in channels, but its percent cover had dropped to less than 10 percent. Most (greater than 80%) roots in drainage streams were still oiled, and mean percent cover was approximately 25 percent. The release of pulses of oil from sediments was tracked using artificial roots. Large washouts of oil occurred in the early and mid wet season on the open coast and in channels, and oil leached almost continuously from contaminated sediments in drainage streams. Thus, this point source spill has become a source of chronic contamination.

EFFECTS OF OILING ON MANGROVE ROOTS AND THE MANGROVE FRINGE

By June 1991 (five years after oiling), fringing mangroves at oiled sites occupied 36 percent, 51 percent, and 63 percent less shoreline than at unoiled sites on the open coast, in channels, and in drainage streams, respectively. Looking only at surviving mangroves, there were approximately a third fewer live roots/meter in the fringe at oiled than unoiled sites ($p<0.01$, ANOVA). Prop roots were 2-10 times as likely to be dead at oiled than unoiled sites in all habitats. Roots were significantly shorter in length at oiled than unoiled sites on the open coast and in drainage streams. This effectively reduced the amount of root area deep in the water column. Thus the amount of substrate (submerged roots) available for epibiotic production was significantly reduced in oiled areas, independent of any effects of oiling on the epibiota.

CHANGES IN THE ABUNDANCE OF EPIBIOTA ON MANGROVE ROOTS

The epibiota on prop roots had not recovered completely in any of the three fringing habitats by May 1991. On the open coast, some species had begun to recover based on comparisons with unoiled sites, although algae, sponges, and cnidarians were still rare at oiled sites. In channels within Bahía Las Minas, normally-dominant oysters were less abundant at oiled than unoiled sites and some less abundant species were still absent. The normal epibiotic community remained devastated in streams, with almost no recovery of populations of false mussels. The combined effects of damage to both the epibiotic assemblage and its substrate (the prop roots themselves) suggest that recovery will be a complex, prolonged process.

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Mr. Stephen Garrity is the scientist-in-charge of two subprojects (reef flat gastropod, epibiota of fringing mangroves) of the STRI/MMS Bahía Las Minas Oil Spill Project. A Vietnam veteran, he holds a B.A. from University of Massachusetts-Boston and did graduate work at University of Massachusetts-Amherst. He has investigated ecological, behavioral and environmental aspects of nearshore communities on both coasts of Panama since 1976, and first examined Caribbean gastropods and fringing mangroves while a STRI predoctoral fellow in 1981-1983.

TYING IT ALL TOGETHER: OPEN PANEL DISCUSSION – ALL PARTICIPANTS AND SCIENTIFIC REVIEW BOARD MEMBERS

Dr. James J. Kendall
Minerals Management Service
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This session consisted of presentations by the "Scientists-in-Charge" of each of the component sub-projects of the Minerals Management Service (MMS) *U.S. National Museum Oil Spill Recovery Study* commonly know as the *Panama Oil Spill Study*. Since this was the final year of the study and the participating scientists were spread world-wide, this Information Transfer Meeting (ITM) session was intended to function as the last forum prior to the final synthesis effort. Synthesis and analysis were intended to be the theme of this session.

While a number of sessions at any ITM include presentations by past and present MMS contractors, this session was unique in that the audience not only had the opportunity to hear presentations about an active MMS study, but also to participate in discussions concerning data analysis and synthesis. In some instances, speakers were presenting new data for the very first time and this sometimes lead to a re-evaluation of the data and of the conclusions of other sub-project researchers.

Because this session was intended as a working meeting for the individual scientists of the study as well as a "transfer of information" between the presenters and the audience, the members of the study's Scientific Review Board (SRB) were also invited to attend. The SRB provides scientific advice and criticism, and reviews experimental designs, data, and reports as the project progresses. As such, they have the opportunity to view the project in its entirety and are less likely "to miss the forest for the trees." The members of the SRB which participated in this open discussion included the SRB chairman, Dr. Robert Carney, Louisiana State University; Dr. Richard Dodge, Nova University, Florida; Dr. Yossi Loya, Tel Aviv University, Israel; and Dr. Donald Aurand, Marine Spill Response Corporation.

Adding much to the individual question and answer periods and the ensuing discussions were members of the audience who proceeded to take an active part in the dialogue. Notable among these were Dr. John Ogden of the Florida Institute of Oceanography; Dr. Paul Sammarco, Executive Director, Louisiana Universities Marine Consortium; Dr. Rezneat Darnell, Department of Oceanography, Texas A&M University; and Dr. Stephen Gittings, Manager, Flower Garden Banks National Marine Sanctuary.

As was previously noted by Dr. Carney (see Carney 1990; Kendall and Hill 1990), the study conducted in Panama covers all the major components of the ecosystem and is unique in its attempt to integrate the chemical effects of the spill with those of the biological components. The framework thus exists to effectively understand, biologically, ecologically, and chemically, the processes causing the observed changes.

Since each of the oil spill scientists had already summarized his or her finding in a formal presentation, most of this open panel discussion centered upon the use(s) of the information from this study. For example, once the study has been completed, the report published, and the individual scientists gone their separate ways, how can, and will, the "products" of this effort best be used for prevention and mitigation.

As expected, it was the consensus of the participants that prevention would always be preferable to mitigation. However, as has been noted previously (Carney 1990; Kendall and Hill 1990), before any of the results and lessons of this study can be applied to areas closer to home, the basis for comparison must first be made. That is, direct comparisons between the environments and the species of Panama with those of the Gulf of Mexico must be made with caution. While individual species and environmental parameters may be comparable on a one-to-one basis (under specific instances), ecosystems and habitats consist of multitudes of species and series of interconnected pathways and environmental parameters. Comparisons, even when made with great care, need to be made between the cumulative results of the individual elements and not merely between individual components.

Regarding the actual use of the information for prevention and mitigation, it must first be established how this very "scientific" information would be incorporated into actual, real-time decisions. For example, can the information and experience acquired from this study be used during decisions on how, when, and where a boom should be positioned should mangrove areas be threatened by a spill; based upon the results of this study, have our views regarding the use of dispersants been changed or modified; and should a spill occur, where, and under what conditions should clean-up operations not be initiated?

Finally, what then is the best mechanism for providing this information to decisionmakers which would increase the likelihood of its actual use in the decisionmaking process? It was agreed by all that while the peer-reviewed scientific literature is the best means to exchange information between scientists, it is probably not the way to provide this material to decisionmakers. What is needed is to work the opposite end of the system, that is, in basic, non-technical terms point out to these individuals the practical day-to-day value of those resources with the potential to be impacted. For example, if a coral reef could be threatened, then its value to the community should be demonstrated, preferably in terms of the economy. If wetlands are important, then emphasize their importance in terms of the revenues which they generated through commercial and recreational fishing rather than in terms of "productivity" and "nutrient cycling." Once these values are established, the necessary pre-planning for the protection of these resources will be requested, if not demanded, by the decision-makers themselves. It is these non-technical requests from the other end of the system which will expedite the use of the appropriate science at the other.

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Dr. James J. Kendall is a biologist with the Minerals Management Service's Gulf of Mexico OCS Region, Office of Leasing and Environment, Environmental Studies Section. His research interests include the effects of contaminants on the physiology of corals, the behavior of reef animals, and procedures for aquatic toxicity testing. Dr. Kendall's experience in the effects of contaminants on marine organisms and systems began when he developed an *in situ* procedure for testing the effects of offshore drilling muds on the calcification rate, protein content, and amino acid composition of corals. He has conducted research and monitoring programs in the Gulf of Mexico, Galveston Bay, the Florida Keys, and the Gulf of Eilat, Red Sea. Dr. Kendall received his B.S. in biology from Old Dominion University and his Ph.D. in oceanography from Texas A&M University.

DEEP-WATER ENVIRONMENTAL HAZARD ASSESSMENT

Session:	DEEP-WATER ENVIRONMENTAL HAZARD ASSESSMENT
Co-Chairs:	Dr. James P. Ray Dr. Robert M. Avent
Date:	November 7, 1991

Presentation	Author/Affiliation
Deep-water Environmental Hazard Assessment: Session Introduction	Dr. James P. Ray Shell Oil Company and Dr. Robert M. Avent Minerals Management Service Gulf of Mexico OCS Region
Deep-water Oil and Gas Operations	Mr. Carl Wickizer Shell Offshore, Inc.
A Review of Physical Oceanographic Processes on the Continental Slope and Deep Basin of the Gulf of Mexico	Dr. Peter Hamilton Science Applications International Corporation
Geologic Hazards of the Northern Gulf of Mexico Continental Slope: Implications to Resource Development	Dr. Harry H. Roberts Coastal Studies Institute Louisiana State University
Selected Aspects of the Ecology of the Deep-water Fauna of the Gulf of Mexico	Dr. Benny J. Gallaway LGL Ecological Research Associates, Inc.
Dispersion Modeling of Drilling and Production Discharges in Deep Water Using the Offshore Operators Committee Model	Dr. Robert C. Ayers, Jr. Exxon Production Research Company
Environmental Monitoring of the Gulf of Mexico Outer Continental Slope	Dr. Jerry M. Neff Marine Sciences Unit Arthur D. Little, Inc.

DEEP-WATER ENVIRONMENTAL HAZARD ASSESSMENT: SESSION INTRODUCTION

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INTRODUCTION

This session on Deep-water Hazard Assessment was organized to allow participating scientists to discuss the information needed to conduct effective deep water hazard assessments. As the petroleum industry explores, develops, and produces in increasingly deeper tracts of submerged land on the continental slope, costs increase dramatically. Hazard assessments (the determination of environmental impacts caused by anthropogenic activity) for deep waters require an understanding of the deep-water environment as well as the nature of activities conducted on deep-water facilities. It is important to determine which aspects or resources of the continental slope environment might be at risk, what data are and are not available, what types of information might be needed to fill critical data gaps, and where future research monies might be most profitably spent. This session reviewed the particular demands placed on deep-water physical structures, their routine operations, safety considerations, and the physical, ecological, and geological features of the slope which must be considered in the development of a deep hazard assessment. The session concluded with a panel discussion of the hazard assessment process for preparing environmental impact statements and designing future studies.

Dr. James P. Ray is Manager, Environmental Sciences, in the corporate Environmental Affairs Department of Shell Oil Company in Houston, Texas. He has worked in the environmental field related to offshore oil and gas since receiving his doctorate in biological oceanography in 1974. Dr. Ray has had extensive experience in the design and implementation of environmental monitoring programs related to the offshore fate and effects of petroleum industry discharges. He has served on several NAS panels, including those related to oil and drilling mud discharges in the marine environment. He has served two years as a member of the Minerals Management Service scientific advisory committee. He is currently managing several programs related to produced water radionuclides and serves as Shell's environmental technical advisor to their deepwater drilling projects.

Dr. Robert M. Avent received his Ph.D. in biological oceanography in 1973 from Florida State University. His main field of interest is marine physiological ecology. He has pursued investigations on the biological effects of hydrostatic pressure, animal zonation, and reef morphology. He is with The Environmental Studies Section of Minerals Management Service's Gulf of Mexico OCS Regional Office where he came in 1981 from the National Marine Fisheries Service.

DEEP-WATER OIL AND GAS OPERATIONS

Mr. Carl Wickizer
Shell Offshore, Inc.

Presentation summary text not submitted.

A REVIEW OF PHYSICAL OCEANOGRAPHIC PROCESSES ON THE CONTINENTAL SLOPE AND DEEP BASIN OF THE GULF OF MEXICO

Dr. Peter Hamilton
Science Applications
International Corporation

Knowledge of current characteristics in the deep waters of the Gulf of Mexico is important for rig design and operational safety considerations, but also for predicting the dispersion of discharges into the water column. Current regimes are inherently more variable with longer time scales and near-surface discharges will take longer to reach the sea bed, because of greater water depths, than in shelf environments.

Deep water circulations are dominated by eddies that have characteristic diameters ranging from about 50 to 400 km and surface speed of 30 to 200 cm/s. Important processes are discussed in terms of descending length scales beginning with the Loop Current and its associated large anticyclonic warm eddies, and following with secondary warm and cold eddies that are often found on the lower Texas and Louisiana slope. These secondary eddies are thought to be important influences on the upper slope and outer shelf exchange processes about which there is little quantitative information. Finally, strong winter storms and hurricanes can generate large oscillatory currents in their wakes that can persist for several days.

The Loop Current (LC) is a branch of the Gulf Stream system that enters through the Straits of Yucatan and exits through the Straits of Florida. Most of the flows are above 800 m, the depth of the Florida Straits sill, and the current boundary fluctuates to the north and northwest. When the LC is fully extended, a large anticyclonic (clockwise rotating) eddy detaches and begins to move off to the west or southwest. Satellite IR imagery and Ship-of-Opportunity expendable bathythermographs transects can be used to show that a LC eddy detaches, on average, at about 9 month intervals. However, the period between successive eddies may be as short as 6 months and as long as 20 months. Eddies that detach east of about 88°W sometimes reattach to the LC and then detach later further to the west. East of the Mississippi delta, the northern slope regions can be directly affected by strong currents from an extended LC or a recently formed eddy. West of the delta, the eddies generally remain south of the lower part of the slope (2,000 m isobath) and thus do not appear to be the direct cause of reported high currents in these upper slope regions.

The LC warm eddies propagate westward or south-westward into the western Gulf of Mexico at about 3 to 6 km/day. Eddy diameters range from 200 to 400 km with rotation periods of about 8 to 14 days. They are usually elliptical in shape and maximum near-surface speeds are typically about 75 cm/s but velocities of 175 to 200 cm/s have been measured in recently formed eddies. Figure 14.1 shows a recently detached eddy (Eddy B) and its position 3 months later in the western Gulf of Mexico. The typical bowl shaped depression of the upper level isotherms is indicated in this figure. This eddy begins to interact with the steep topography of the Mexican slope and by January 1986 has formed a cyclone-anticyclone pair of smaller eddies (Figure 14.2) that cause a strong eastward directed jet to be present between them at about 25.5°N. This is an apparently common occurrence because cold shelf water is often observed to be extracted from the shelf in a thin jet at about 25° to 26°N. The pair of eddies remained in the vicinity of the Mexican slope for next 3 to 5 months moving towards the south and eventually merging with an approaching LC eddy.

The interaction of westward propagating LC eddy with the Mexican slope shows one mechanism by which smaller cyclones and anticyclones can be formed. However, such eddies appear to remain close to the Mexican slope though there is some evidence that relic warm core eddies can migrate into the corner region of the slope off southwest Texas. There have been recent observations of relatively isolated 150 km diameter cyclones over the deep water of central basin. One such cyclone moved northwards onto the Louisiana slope as a large LC eddy propagated through the central basin. Once the cyclone was over the lower slope, it remained fairly stationary in position for a period that was longer than 6 months. This cyclone was difficult to detect in satellite imagery because of the lack of temperature gradients in the upper 100 m of the water column. Figure 14.3 shows a drifter being passed along a sequence of secondary anticyclones and cyclones that were present on the northern slope. Such eddy circulations over the lower slope help to explain the characteristics of the upper layer current meter measurements which have characteristic periods of several months, poor horizontal coherences, and similar amplitudes of cross-slope and along-slope fluctuations. These eddies range from about 50 to 150 km in diameter with near-surface speeds of 30 to 50 cm/s and similar rotation periods to LC warm eddies.

The upper slope and outer shelf regions are least understood. It is thought that cyclone-anticyclone

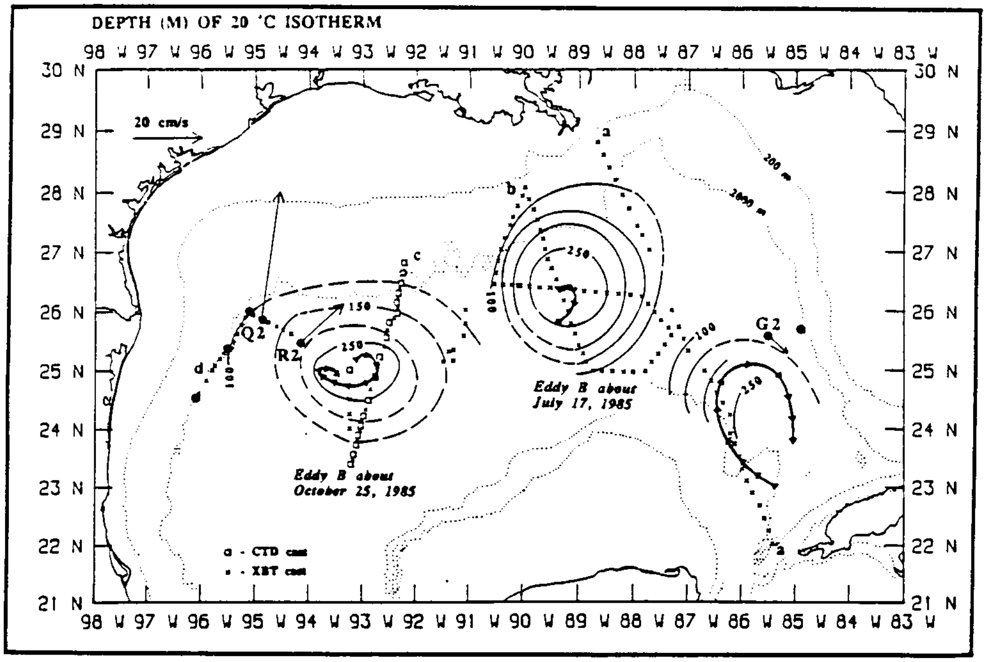

Figure 14.1. Two realizations of Eddy B from hydrography, Lagrangian drifters (heavy arrows at daily intervals), and upper layer current meters. (Moorings G, Q, and R are marked.)

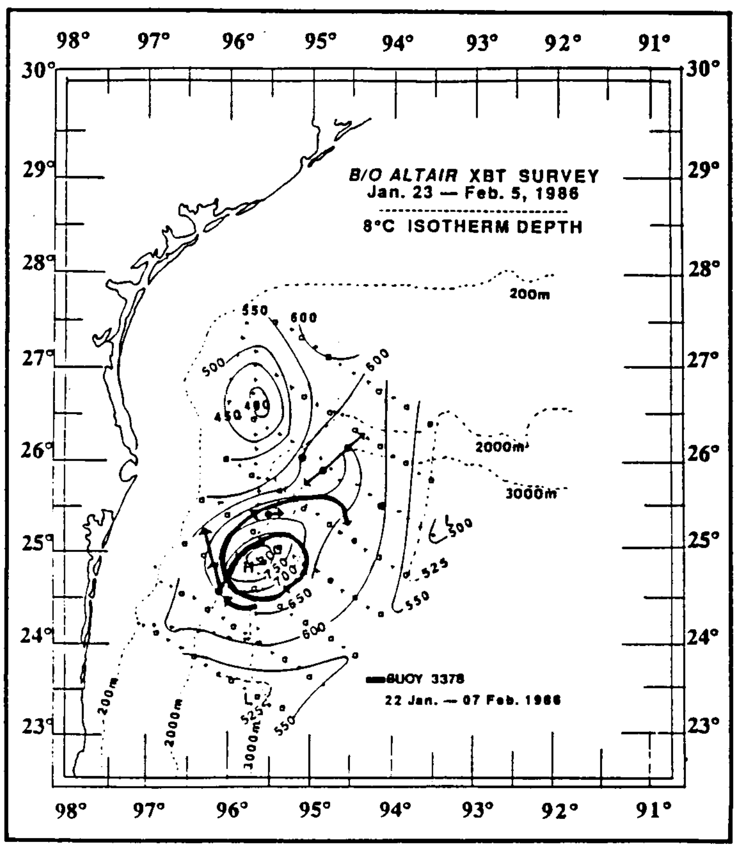

Figure 14.2. The cyclone-anticyclone pair that results from Eddy B interacting with the Mexican slope.

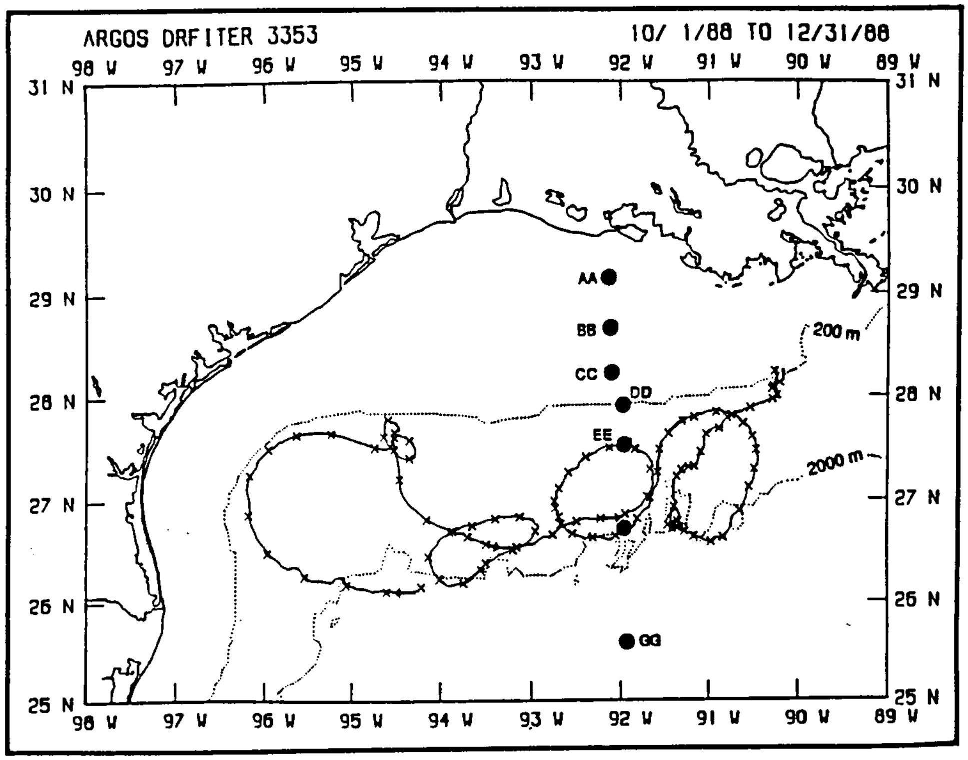

Figure 14.3. The ARGOS drifter track along the northern slope. (The positions are marked at daily intervals.)

pairs of lower slope secondary eddies can pull large volumes of shelf water off the shelf. This is seen in imagery but has not been directly observed. Most of the current measurements in the 200 to 500 m water depths off Louisiana have been made by industry and show complex layer structures in which the number of layers and relative directions of flow change with time. These changing layers are presumably caused by the interaction of wind-forced and buoyancy-forced flows on the outer shelf with the eddy circulations on the lower slope. The mechanisms for forcing such flows have not yet been described because of the paucity of data.

Eddy circulations dominate the upper 800 to 1,000 m of the water column. In the lower part of the water column in the deep basin, motions have typical periods of 15 to 35 days with amplitudes of 15 to 20 cm/s. The current fluctuations are in phase through the lower water column with slight bottom intensifications. These flows are attributed to topographic Rossby waves (TRWs) that are generated by the LC eddy shedding cycle and then propagate into the western Gulf at group velocities of 9 to 15 km/day. This is faster than the westward propagation of LC eddies and lower water column motions seem to be independent of upper layer eddies in the deep water basin. Figure 14.4 shows current records from below 1,000 m at Moorings G and Q (see Figure 14.1). The G4 record has been lagged by 106 days and shows moderate coherence with the Q4 record. These two moorings are separated by a distance of about 1,000 km.

Finally, a fast moving hurricane will generate an inertial wake where currents rotate with the inertial period (about 24-26 hours in the northern Gulf of Mexico) and are strongest to the right of the hurricane center. Near-surface speeds of near 100 cm/s have been observed in these wakes. Near inertial waves propagate horizontally and vertically generating large amplitude (~50 cm/s) oscillations at depth several days after the passage of the storm. This is quite different from the low-frequency storm-surge response of shallow shelf seas to hurricane winds.

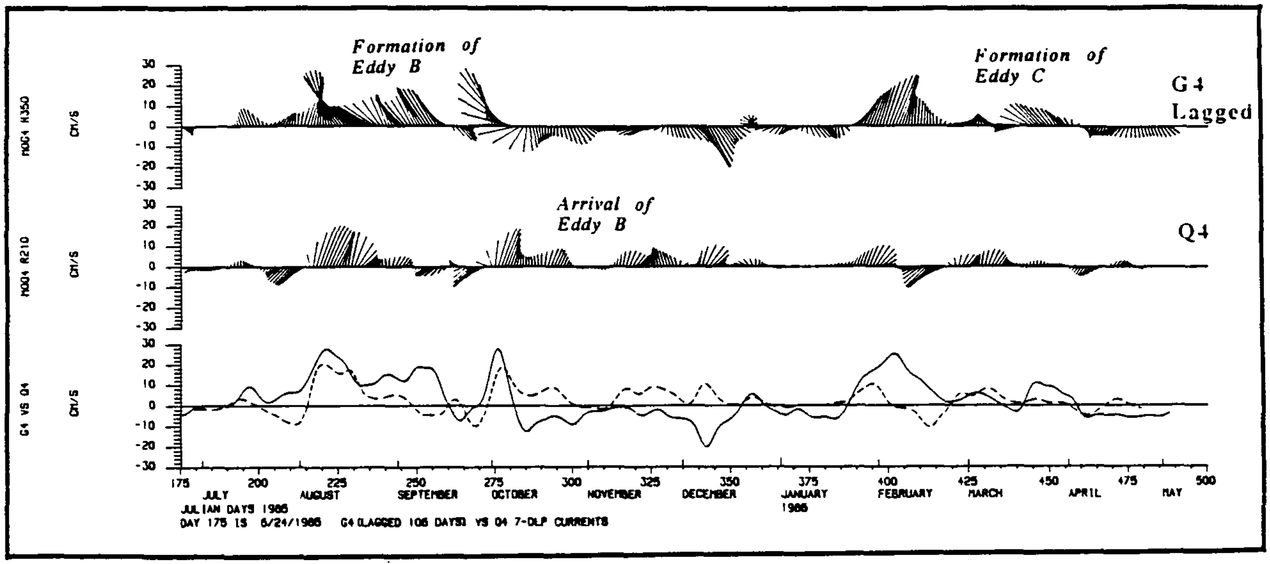

Figure 14.4. Seven day low-pass stick vectors and along-isobath velocity components for current measurements at G4 (1,560 m depth) lagged by 106 days (solid) and Q4 (1,500 m depth; dashed). (The formation [displaced by 106 days] and arrival of Eddy B at Q are indicated.)

This paper has presented a brief overview of the complex circulation processes associated with observed currents in the deep waters of the Gulf of Mexico. Important processes are the generation of large anticyclones by the LC, the existence and characteristics of smaller secondary cyclones and anticyclones on the lower northern slope, the generation of TRWs by the LC and their propagation into the western Gulf of Mexico, and event scale currents generated in the inertial wakes of hurricanes.

Dr. Peter Hamilton has been with Science Applications International Corporation (SAIC) in Raleigh, North Carolina, since 1977 where he has been Principal Investigator on several Minerals Management Service studies. He has considerable expertise in data analysis and in numerical modeling. Dr. Hamilton received his B.S. (1970, First Class Honor) from University of Sussex (Great Britain) and Ph.D (1973) from University of Liverpool (Great Britain). He was a Research Associate at University of Washington (1973-1977) and visiting scientist at Brookhaven National Laboratory (1975-1976).

Dr. Hamilton received a 1989 editor's citation for excellence in refereeing from the Journal of Geophysical Research and an SAIC award in 1990 for best technical publication for a paper in Journal of Geophysical Research on deep currents in the Gulf of Mexico. He is currently a member of the Environmental Protection Agency Modelling Evaluation Group of Long Island Sound Studies.

GEOLOGIC HAZARDS OF THE NORTHERN GULF OF MEXICO CONTINENTAL SLOPE: IMPLICATIONS TO RESOURCE DEVELOPMENT

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The continental shelf and slope of the northern Gulf of Mexico are sedimentary provinces that have been prograding Gulfward since Late Cretaceous times. The rapid southerly growth of these depositional features can be measured in hundreds of kilometers. Sediments have been derived from the Mississippi River and its ancestors. Rapid deposition has taken place over the thick Jurassic Louann Salt, a product of the early stages of opening of the Gulf of Mexico. These two factors, rapid and large-scale sediment input and coincident deformation of underlying salt, have made the continental slope and associated distal shelf areas of the northern Gulf perhaps the most complex in today's oceans. Some regions of the slope are constructed from a regular stratigraphy composed of alternating turbid flow deposits and hemipelagic sediments that have normally consolidated. Other slope regions are much more complex as a result of diapiric activity of salt and shale, faulting, and mass movement at various scales. Sediments associated with these regions vary from being over-consolidated to highly consolidated. Operating in this environmental setting requires a special understanding of the physical-biological-geological processes and their related response features. This understanding is incomplete and sometimes unusable in an operational context. This problem arises because we do not collect data sets that are detailed and coherent enough to make valid interpretations of the seafloor over more than local areas. Geohazards that have been identified in the distal shelf/slope province include active faults, local slumps and other mass movement features, steep slopes and hard bottom reefs-bioherms-hardgrounds associated with diapirs, gas/fluid escape features, gas hydrates, variable soils including sensitive soils, and chemosynthetic communities. Detection of these hazards is accomplished from a wide spectrum of data collection techniques that range from direct sampling (borings and corings, ROV surveys, submersible sampling) to remotely sensed acoustic data (high resolution seismic and side-scan sonar).

Faults on the continental slope are highly active and frequently have distinct offsets as well as associated hydrocarbon and/or fluid mud seeps. Most active faults appear to be related to the upward movement of salt or the flowage of salt at depth. Differential consolidation of buried submarine landslides and other rapidly deposited and highly unconsolidated sediments also forces faulting that affects the modern seafloor. The plan-view scale of active faults can be as small as a few hundred meters to several kilometers. Seafloor offsets can be in the tens of meters range. A record of movement is difficult to obtain, so even on faults with well defined scarps, timing is difficult to decipher. Geophysical and geological data provide response data concerning past faulting events. These data sets are helpful for predicting possible future impacts on the seafloor.

Mass movements occur on a variety of scales and they may manifest themselves as large submarine landslides, slumps, debris flows, turbid flows, and surface creep. These features can cover tens of km^2 and may involve many km^3 of sediment. Volume estimates of large shelf edge slumps suggest that up to 50 km^3 of sediment can be evacuated over a short period of time and transported to deep water environments of the slope and basin floor. Smaller instabilities on the oversteepened flanks of salt diapirs (up to 25°) involve significant but much smaller volumes of sediment. This smaller type of failure is more numerous and occurs more frequently. Also vast areas (several km^2) of distorted and remolded sediment have been observed on the modern seafloor downslope of fault scarps. Industry has found that it is prudent to consider these processes of mass movement when planning a man-made structure in deep water of the continental slope.

Carbonate mounds, hardgrounds, and local zones of seafloor and shallow subsurface cementation are common to the tops of salt diapirs and other areas of active hydrocarbon seepage. Recent submersible work has shown that significant buildups of carbonates occur over the full depth range of the slope. These authigenic carbonates have been determined to be by-products from the microbial breakdown of seep products, hydrocarbons, and hydrogen sulfide. At the shelf edge where shallow water (~150-200 m) allows light penetration to the seafloor, sedimentary organisms (some carbonate-producing) inhabit these hard substrates and in some cases produce a reef-like veneer. However, as water depths increase down the slope, the biologic veneer is lost and only the authigenic carbonates are left. The carbonate mounds and hardgrounds are extremely resistant, complex topographically (to 30 m relief), and spatially variable. Areas of seafloor characterized by carbonate buildups deserve special operational considerations because of the extremely variable soil conditions in and around the mounded areas which commonly exhibit extreme topography. In selecting platform sites and pipeline routes, experience shows that these areas are to be avoided.

Hydrocarbons, formation water, and fluid mud are transported to the sediment/water interface of the slope by way of complex fault networks. The surface manifestations of this transport are related to many factors including rate of flux, relative proportions of hydrocarbon-water-sediment, and depth of water (temperature and pressure regime). On the upper slope (water depths less than approximately 500 m), the above processes lead to the production of a spectrum of seafloor features from essentially flat-lying or slightly depressed gas vents to large volcano-like mud mounds up to about 1 km diameter with 50-100 m relief. These and a variety of intermediate forms are generally amorphous on high resolution seismic records and frequently display the signatures of escaping gas bubbles in the water column. Recent studies of natural hydrocarbon seepage indicate that mud volcanoes and associated seep features are associated with brine and crude oil flux to the seafloor as well as gas and fluid mud. Rates of buildup of large mud volcanoes and volume fluxes of various components (mud, brine, grade, and crude oil) are unknown. However, geomorphic (side-scan sonar data) and geologic (high resolution seismic) evidence suggests that huge volumes of fine-grained sediment can be extruded onto the seafloor over short periods of time. Mudflows and over steepened slopes associated with the buildup of mud cones are potential hazards to deep water operations. Collapsed sides of large mud cones have been observed on the northern Gulf of Mexico slope.

In water depths greater than about 500 m, mud volcanoes common to the upper slope are replaced by hydrate mounds. These mounds are formed from various proportions of mud, gas hydrates (ice-like solid forms of water and various hydrocarbon gases), and crude oil. Identification of prospective mound-like features on high resolution acoustic data and further verification with piston cores and direct observations/sampling from research submersibles suggests that hydrate mounds are relatively common features of the middle and lower slope province. However, the distribution of gas hydrates in the northern Gulf of Mexico is still an unknown due to large data gaps in both acoustic data and "ground truth" from piston cores and submersible observation/sampling. On high resolution seismic records, hydrate mounds correlate with zones of acoustic amorphism. These zones frequently relate to major vertical transport pathways (major faults or fault networks) from the subsurface. Hydrate mounds that have thus far received detailed study are frequently the sites of chemosynthetic communities and large volumes of authigenic carbonate. In addition to the various soil strengths associated with such a hydrate-carbonate complexes, submarine landslides have been linked to hydrates in some areas. The conditions under which hydrates become unstable are not well-defined. However, heat produced by production of hydrocarbons may be important in a local setting. Melting hydrates and the temperature-associated development of excess pore pressures within fine-grained sediments may change soil properties in favor of volume changes and strength reduction.

Man's operation in the deep water environments of the northern Gulf of Mexico must be accompanied by comprehensive and multidisciplinary studies utilizing the best technology available to assess the potential for geological hazards. A systematic and comprehensive approach is necessary because geologic conditions of the slope can be extremely complex. Evidence of seafloor instability is much more common than in adjacent shallow water environments of the continental shelf. Slope-depth investigations for geohazards sometimes require specialized equipment that is more difficult to deploy/operate and is technically complex. These factors translate into higher costs and longer times to acquire and analyze necessary data sets. However, the possible impacts of acquiring substandard data for planning billion dollar installations do not equate to the minimal investment required to adequately evaluate possible geological hazards.

Dr. Harry Roberts is a marine geologist and is currently serving as director of Coastal Studies Institute at Louisiana State University. He has conducted research in modern depositional environments both domestically and in foreign areas for over 20 years. He has published on both modern terrigenous clastic and carbonate depositional systems and played an active role in analyzing cores from the DSDP Leg 96 Mississippi Fan project. His research focus at present is on the marine geology of the northern Gulf of Mexico continental slope. Dr. Roberts has been active as a field trip leader for professional societies and private companies for many years and has taught and co-taught many continuing education courses.

SELECTED ASPECTS OF THE ECOLOGY OF THE DEEP-WATER FAUNA OF THE GULF OF MEXICO

Dr. Benny J. Gallaway
LGL Ecological Research Associates, Inc.

INTRODUCTION

The purpose of this paper is to provide a biological setting for discussion of the environmental hazards associated with oil and gas exploration and development on the continental slope of the northern Gulf of Mexico. The content of this paper is drawn from our studies of the slope ecosystem conducted by LGL Ecological Research Associates, Inc. (LGL) for the Minerals Management Service (MMS) during the period 1983 to 1988. A synthesis of the findings of these studies can be found in Gallaway (1988). Certain key aspects have been published in the peer-reviewed literature (Pequegnat *et al.* 1990). The goal of that investigation was to develop a basic level of understanding of the deep Gulf of Mexico fauna and their relationship with the environment. The findings are directly pertinent as background for evaluation of the potential for adverse effects resulting from oil and gas development in the slope ecosystem.

METHODS AND MATERIALS

LGL's sampling was conducted on five cruises in the years 1983 (Cruise I, fall), 1984 (Cruise II, spring; and Cruise III, fall), and Cruises IV and V in spring of 1985. A total of 59 stations was sampled along three down-slope transects (Cruises I, II, III) in the western, central, and eastern Gulf of Mexico (Figure 14.5), and isobathymetrically at three depths on the Eastern Transect (Cruise IV) and between the Western and Central Transects (WC on Figure 14.5) during Cruise V. Samples for analysis of meiofauna and macrofauna, as well as a suite of sediment characteristics and inclusions (e.g., texture, carbonate, total organic carbon [TOC] and hydrocarbons), were taken in a box corer that measured 24.5 x 24.5 x 44 cm. It was fitted with six metal coring tubes that measured 43.5 x 3.5 cm in internal diameter and were used for meiofaunal analyses. The megafauna was sampled with trawls, having gaps of 9 m (LGL) and 20 m (TerEco), with dredges, and with a benthic camera system. The latter is not discussed in this paper; suffice it to say that photos taken along trawling lines produced higher megafaunal densities than the trawl and in some cases revealed a holothurian species that was never brought up by trawls even though it was undoubtedly the most common species in its depth range. Sampling depths were not randomly spaced down the slope but were the approximate midpoint of previously defined biological zones with faunal assemblages (Pequegnat 1983): (1) the Shelf/Slope Transition Zone (118-475 m); (2) Horizon A of the Archibenthal Zone (500-775 m); (3) Horizon B of the Archibenthal Zone (800-975 m); the Upper Abyssal Zone (1,000-2,275 m); the Mesoabyssal Zone (2,300-3,225 m); and the Lower Abyssal Zone (3,250-3,850 m). The purpose of this strategy was to evaluate the predictive value of the Pequegnat zonation scheme.

During this study, 40 habitat variables were measured as potential factors affecting the distribution of the biota by region, depth, season, and years. To analyze this data set by inspection is difficult and time consuming; however, Principal Component Analysis (PCA) enables one to transform the set into smaller combinations that account for most of the variance of the larger set. The output of PCA permitted us to group stations in terms of their physical/chemical attributes and then to compare these with various biological classifications of the same stations (see under Megafauna).

RESULTS

In the meiofauna (retained by 63 μm screens) nematodes, harpacticoid copepods, nauplii, polychaetes, ostracods, and kinorynchs were numerically dominant, in that order, and together these groups made up 98 percent of the fauna. The macrofauna (retained by 0.3 mm screens) was dominated by polychaetes, ostracods, bivalves, tanaids, bryozoans, and isopods in that order, and together these made up 86 percent of the fauna.

Densities of both groups were highest on the Central Transect, and densities of both tended to decrease with depth. Between the depths of 300 m and 3,000 m there was a threefold decrease in

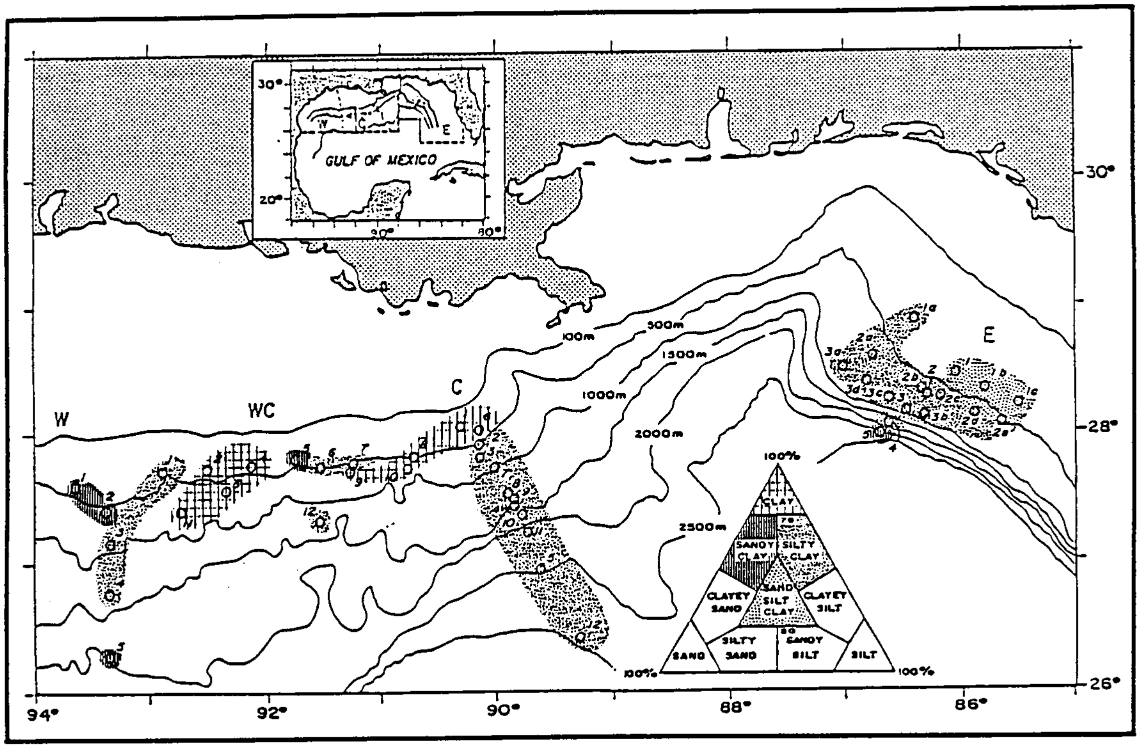

Figure 14.5. Distribution of sediment types on the continental slope as determined from samples at 59 stations (o).

meiofaunal and a twofold decrease in macrofaunal density.

Among the megafauna (collected by otter trawl), invertebrate densities, dominated by crustaceans, were four to five times as great as fish densities at all depths and on all transects. Densities were greatest on the Eastern and least on the Central Transect, and on all transects they decreased with depth. The megafauna of the northern and eastern Gulf of Mexico were confirmed to fall naturally into the depth distribution pattern suggested by Pequegnat (1983). The biological zones were remarkably concordant with physical and chemical differences in the environment.

On the slope off Louisiana and East Texas, in the depth range of 400-900 m, dense biological communities have been encountered at about 40 locations aggregated around oil and gas seeps. These organisms include clusters of large tube worms (vestimentiferans), vesicomyid clams, mussels, galatheid crabs, bresiliid shrimps, neogastropods, limpets, and fishes. This community is trophically dependent upon chemoautotrophic bacteria (which utilize hydrogen sulfide), although some mussels directly utilize methane as a carbon source. This community is closely related to that of the hydrothermal vent systems of the East Pacific Rise and to the Seep communities at the base of the Florida escarpment.

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Dr. Benny J. Gallaway has served as President of LGL Ecological Research Associates, Inc. since 1974. In addition to biological research duties with LGL, he serves on the graduate faculty of the Department of Wildlife and Fisheries Sciences, Texas A&M University. His general research interests focus on shelf and slope ecosystems and behavioral responses of organisms in these habitats to environmental gradients. In recent years, he has focused on the effects of environmental gradients on migrations of Arctic anadromous fish. Dr. Gallaway received his Ph.D. from Texas A&M in 1978.

DISPERSION MODELING OF DRILLING AND PRODUCTION DISCHARGES IN DEEP WATER USING THE OFFSHORE OPERATORS COMMITTEE MODEL

Dr. Robert C. Ayers, Jr.
Exxon Production Research Company

The Offshore Operators Committee (OOC) Dispersion Model has had extensive use by both government and industry since its release in 1983. It was developed by Brandsma Engineering and Exxon Production Research Company (EPR) with funding provided by the OOC and EPR. The model predicts the concentration of solid particulates and soluble components in the water column as a function of time and distance from the discharge point. The model also predicts the location on the seafloor where the solid particles initially settle. The OOC Model has been verified for mud discharges in the field and in laboratory tank tests. In recent years, the model's capability has been extended to handle produced water discharges. The extended version will be released in 1992.

The OOC Model was used to predict the fate of mud, cuttings, and produced water discharged from a hypothetical 48 well platform in 366 m (1,200 feet) of water. Mud and cuttings were discharged 116 m (380 feet) below the water surface. Solids concentrations in the water column during discharge were calculated for both mud and cuttings using a constant current of 17.5 cm/sec. Maximum mud solids concentrations fell below the lowest permitted 96 hour LC 50 concentration (30,000 parts per million [ppm] suspended particulate phase or 3,000 ppm whole mud) within 25 m of the discharge point. The transport time required to reach that distance in this simulation was about two minutes. Cuttings solids which were discharged at a much slower rate (5 bbl/hr as opposed to 1,000 bbl/hr for mud) and which have higher settling velocities than mud solids disappeared from the water column even faster. Pre-diluting the mud and cuttings with seawater prior to discharge was found to affect solids concentrations only in the immediate vicinity of the discharge point at these water depths.

The following approach was used to estimate the cuttings distribution on the seafloor. Four days of representative current data were selected from an extensive Minerals Management Service (MMS) data set measured in the Santa Barbara Channel. In the simulation, cuttings were discharged at a rate of 5 bbl/hr for four days and the distribution on the seafloor was calculated using the OOC Model and the MMS current data. During the four day period, about 12 percent of the cuttings from the well were discharged. The seafloor distribution was assumed to be representative of where the rest of the cuttings from the well would settle as well as all of the cuttings from the remaining 47 wells. This assumption, made to simplify the calculation, clearly restricts dispersion. Thus the cuttings solids on the seafloor in the affected grid blocks are higher in the calculation than they would be under actual conditions. In addition, it was assumed that no resuspension and bottom transport of cuttings solids occurred over the six years of drilling. The 61 m square (200 feet square) grid block immediately underneath the platform accumulated the most solids resulting in an average thickness of 72 cm (1.5 cm per well), under these near "worst case" conditions. Quantities in adjacent blocks contained fewer solids and the thickness decreased rapidly with distance from the well site.

A similar approach was used to estimate the distribution of mud solids on the seafloor. One thousand barrels of mud were discharged in one hour. The 1,000 barrel discharge represents about 11 percent of the mud solids discharged from a single well. After cessation of discharge, the solids were allowed to settle for one week. The four days of current data mentioned above were used in the first four days of the simulation and then currents from three of the four days were used again to complete the seven day simulation. The resulting seafloor distribution was assumed to be representative of where the rest of the mud solids from the well would settle as well as all the mud solids from the remaining 47 wells. Thus, as with the cuttings, the mud solids on the seafloor in the affected grid blocks are higher in the calculation then they would be under actual conditions. Also, as before, it was assumed that no seafloor erosion took place over the six years of drilling. During the one week time period allowed for settling, 63 percent of the mud solids reached the seafloor. A large grid block size, 3,049 m square (10,000 feet square), was used because at this water depth the solids are widely dispersed. Even with the approach used in the simulation which restricts dispersion, mud solids were spread over some 750 sq km (300 square miles). In this simulation the grid block containing the most solids was some four miles from the platform. The average thickness of mud solids accumulated in this block over the eight year period was 0.016 cm. The natural sedimentation rate on the slope is about 0.03 cm/yr or 0.2 cm over eight years.

Simulations of produced water discharges from a platform in 366 m of water were carried out for discharge rates of 5,000, 10,000 and 20,000 bbl/day using a constant current of 17.5 cm/sec. The produced water discharge pipe was 116 m below the surface. Produced water concentrations decreased rapidly with downcurrent distance and fell below 1.0 percent (a representative value for produced water 96 hr LC 50's) within 15 m (50 feet) of the discharge point in all cases. The transport time corresponding to this distance was about 2.5 minutes under the conditions used in the study. It was also shown that water column radium concentrations would fall well below the present 5 pCi/l drinking water standard within 100 m. This was true for all cases studied, including a 20,000 bbl/day produced water stream containing 1,000 pCi/l.

Produced water dilution rates can be very sensitive to the ambient density gradient. In this study, significantly higher dilution ratios were achieved by discharging beneath the strong gradient in the upper water column. This was demonstrated by comparing results from two simulations using ambient density data obtained from the Mississippi Canyon area where the only difference was the depth of the discharge pipe. Dilution ratios obtained in the case of the 116 m pipe depth were three times greater than those obtained in the case of the 15 m pipe depth at 100 m downcurrent of the discharge pipe. This increased dilution effect could benefit operators in deep water facing discharge regulations based on a limiting permissible concentration at the edge of a mixing zone.

The following conclusions may be drawn from the deep water discharge modeling exercise:

- Water column impacts from drilling and produced water discharges appear to be nil. Concentrations fall below 96 hr LC 50 values in minutes. Similarly, radionuclide levels fall below the present 5 pCi/l drinking water standard well within the 100 m mixing zone.

- Produced water dilution rates can be very sensitive to the ambient density gradient. In this study, significantly higher dilution was achieved by discharging produced water beneath the strong gradient in the upper water column.

- At these water depths, the rate of accumulation of mud solids on the seafloor is less than the natural sedimentation rate. In the near "worst case" scenario used in this study, the grid block with the most deposition had a mud solids accumulation rate an order of magnitude below the natural sedimentation rate.

- Cuttings can accumulate on the seafloor near the wellsite, even at these depths. In the near "worst case" scenario considered here which limits dispersion and ignores erosion, the thickness of the deposited material was about 72 cm in the block immediately beneath the platform. Quantities of cuttings solids in adjacent blocks were less and the thickness decreased rapidly with distance from the platform.

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ENVIRONMENTAL MONITORING OF THE GULF OF MEXICO OUTER CONTINENTAL SLOPE

Dr. Jerry M. Neff
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INTRODUCTION

The first offshore oil well in the world was drilled in 1898 from a wooden pier extending into the surf zone near Summerland, California. By 1990, more than 27,000 oil and gas wells had been drilled in U.S. coastal and outer continental shelf (OCS) waters. More than 10,000 of these wells are still producing oil and/or gas. These wells are located on nearly 4,000 platforms, most of them off Louisiana and Texas. The Environmental Protection Agency (EPA) has estimated that an additional 833 platforms will be installed in U.S. territorial waters before the turn of the century (EPA 1985). Between 1985 and 1990, 38.5 percent of the blocks leased in the Central Gulf of Mexico and 41.6 percent of the blocks leased in the Western Gulf of Mexico were in water depths greater than 200 m (Richardson and Gaudry 1990). Most of these deep water leases were in an oceanographic province called the continental slope (in the western Gulf of Mexico, the zone from about 120 to 2,800 m water depth).

Relatively little is known about the environmental effects of exploration, development, and production of oil and gas on the continental slope. The major environmental concern associated with most offshore oil and gas activities is that it may cause serious long-term damage to the marine environment and the natural resources it supports (Boesch *et al.* 1987).

IMPACT-CAUSING AGENTS

During drilling and production from an offshore platform, there are several possible discharges and physical alterations of the environment that may have adverse effects on the marine environment. The most important of these include drilling mud and cuttings discharges (about 1,900 metric tons/well), produced water discharges (usually in the range of 1 to 200,000 liters/day), physical disturbance of the sea floor by platform-related structures on the bottom, and accidental oil spills. Water-based drilling muds and cuttings and produced water are allowed by National Pollutant Discharge Elimination System (NPDES) permits to be discharged from offshore platforms on the OCS and slope of the central and western Gulf of Mexico. On the outer continental slope, physical structures on the bottom associated with drilling, development, and production include anchors and anchor chains, structures associated with the well head, and in some cases, the legs of permanent platform structures.

Drilling Muds and Drill Cuttings

Drilling muds are specially formulated mixtures of natural clays and/or polymers, weighting agents, and other materials suspended in water or a petroleum material. Water-based, but not oil-based, drilling muds may be permitted by NPDES permit to be discharged to the ocean. The five major ingredients in water-based drilling muds (barite, bentonite clay, lignosulfonate, lignite, and sodium hydroxide) account for over 90 percent of the total mass of additives in water-based drilling muds (National Research Council 1983). The other major ingredient is water. The remaining ingredients include a wide variety of specialty additives used to solve particular down-hole problems. The most important of these minor ingredients from an environmental perspective are diesel fuel or mineral oil, chromate salts, surfactants, and biocides. The ingredients in water-based drilling muds of greatest environmental concern are metals. The metals most likely to be present in drilling muds at concentrations significantly higher than their concentrations in uncontaminated marine sediments are barium, chromium, lead, and zinc. Nearly all water-based drilling muds are nontoxic or practically nontoxic (National Research Council 1983).

Drill cuttings are produced by the grinding action of the drill bit as it penetrates into the earth. They are composed of crushed rock and sediments characteristic of the geologic strata being penetrated by the drill. Drill cuttings usually are completely inert toxicologically but may cause localized damage by burying organisms living on the bottom. Drill cuttings from hydrocarbon-bearing strata will contain petroleum hydrocarbons. Oily cuttings could be toxic to marine organisms.

Cuttings, containing up to about 10 percent attached drilling mud solids, are discharged continuously during drilling, which takes place about 50 percent of the time the drilling rig is on location. Drilling mud may be discharged in bulk quantities of about 1,000 to 50,000 gallons at a time several times during drilling of a well. The largest discharge usually takes place after completion of the well. Each drilling mud discharge may take from a few minutes to an hour or more. A total of about 1,900 metric tons of drilling mud and cuttings may be discharged during drilling of a 10,000-foot well.

When discharged to the ocean, drilling muds and cuttings are diluted very rapidly by dispersion and fractionation, and most of the solids settle eventually to the bottom where they mix with natural sediments. The National Research Council (1983) concluded that any impact of drilling muds on marine organisms living in the water column is likely to be minimal and of short duration. However, drilling mud and cuttings solids could cause adverse impacts in bottom-living (benthic) biological communities wherever the mud or cuttings solids settle out and accumulate in large amounts. These impacts could be due to physical burial, changes in sediment texture making the habitat less suitable for some species, or chemical toxicity of some drilling mud ingredients. Several field studies have shown that effects on the deep-water benthos from drilling mud and cuttings discharges are minimal, localized, and of short duration.

Produced Water

A waste byproduct of oil and gas production is produced water. Produced water is fossil water that has been trapped in the reservoir with the fossil fuel, or water that has been pumped into the formation to aid in production of the oil or gas. The produced water is pumped to the surface with the oil and gas and must be separated from the hydrocarbons before the latter can be processed further. Some wells generate no produced water; others may generate 90 percent produced water and 10 percent fossil fuel. Over the life of most wells, approximately equal volumes of oil and water are produced. When allowed by NPDES permit, produced water from offshore production platforms is treated to remove dispersed oil and discharged to the ocean.

Produced water usually, but not always, is a saline brine with a total dissolved solids concentration (salinity) greater than that of seawater. Produced water may contain elevated concentrations of several metals and slightly soluble low molecular weight petroleum hydrocarbons. The metals most frequently present in produced water at concentrations substantially higher that their concentrations in clean natural seawater include barium, cadmium, chromium, copper, iron, lead, nickel, and zinc (Neff *et al.* 1987). The dominant hydrocarbons in produced water are low molecular weight aromatics (benzene, toluene, and xylene) and aliphatic hydrocarbons (butane through hexane). The more toxic two- and three-ring aromatics (Neff and Anderson 1981) and potentially carcinogenic polynuclear aromatic hydrocarbons (Neff 1979) are present at only trace concentrations in produced water.

Dilution of production water upon discharge to the ocean is very rapid, the actual rate depending upon such factors as rate of discharge, salinity of the produced water, current speed, degree of turbulent mixing of the water column, and water depth. In deep offshore waters containing low suspended sediment loads, it is probable that little or none of the metals and hydrocarbons discharged to the ocean in produced water reach the bottom. Impacts of produced water discharges on the benthic fauna are rarely seen around discharges from platforms in deeper offshore waters (Neff 1987).

Oil Spills

There is a slight risk of accidental oil spills associated with all phases of offshore oil and gas exploration, development, and production. Spills from the platform may result from leaks and blowouts during exploratory and development drilling. During production, oil spills may result from pipeline ruptures and chronic leaks. In deep-water areas, oil may be transported ashore by tanker or barge, increasing the risk of spills during transfer and shipment.

Large spills associated with oil and gas production on the U.S. OCS are rare. There have been only three spills over 1,000 barrels from offshore platforms since 1979 (U.S. Department of the Interior 1985). Of the five billion barrels (210 billion gallons) of oil produced from the U.S. OCS between 1970 and 1985, about 61,000 barrels (2.56 million gallons) were spilled (U.S. Department of the Interior 1987). This is 0.001 percent of production.

However, when large spills do occur, the potential for serious environmental damage is great. Large spills associated with offshore development in foreign waters, such as the *Ixtoc*-I blowout in the Bay of Campeche, Mexico, and major tanker accidents, such as the *Amoco Cadiz* spill off the coast of France, have caused serious long-term impacts in marine ecosystems (Teal and Howarth 1984; National Research Council 1985). Every effort should be made to avoid similar accidents in the future and to develop rapid and effective cleanup methods, should such spills occur.

Physical Structures on the Bottom

Structures on the bottom associated with drilling and production on the outer continental slope include anchors and anchor chains, well head structures, and sometimes platform legs. These structures may cause local scour of the bottom (Davis *et al.* 1982). They may also attract demersal predators that would affect local benthic faunal by predation. These effects are very minor and localized.

THE SLOPE ENVIRONMENT

The benthic environment of the outer continental slope is generally characterized by a more stable physical/chemical regime than shallower environments: uniform low temperatures, high salinity, and usually high dissolved oxygen concentrations. Generally, the slope fauna have a high species richness and diversity, but low biomass production, characterized by zoogeographic variation and small-scale patchiness (Jumars 1976). One of the most important factors regulating community structure in the slope benthos is the slow rain of organic nutrient particles from above. The particles are an important nutrition source of the benthos and could be an important route of introduction of anthropogenic pollutants to the slope benthos (Rowe *et al.* 1986). Because sediment deposition rates on most parts of the slope are very low, most benthic fauna of the slope are not well adapted to tolerate high sediment fluxes and deposition rates. The benthos could be sensitive to increased fluxes of particulate matter associated with drilling mud and cuttings discharges from offshore oil and gas exploration and development.

On the slope off Louisiana and Texas, there is a large number of hydrocarbon seeps that support unique biological communities (MacDonald *et al.* 1990). The communities are adapted to using low molecular weight petroleum hydrocarbons or sulfide associated with the seeps as a source of nutrition. These communities probably would not be sensitive to materials discharged at the surface from offshore drilling and production operations, but they could be damaged by physical disturbance from platform-related structures on the bottom.

MONITORING THE SLOPE ENVIRONMENT

As discussed above, the major components of environmental concern in permitted or accidental discharges during exploration for and development and production of petroleum resources on the continental slope of the Gulf of Mexico will be metals and petroleum hydrocarbons. Changes in the concentrations of these chemicals in different environmental compartments (sediments, biota, water) can be used as an indication of potential impacts of offshore oil and gas activities. Impacts are indicated if increases in the concentrations of these chemical tracers of discharges can be correlated with biological changes beyond the natural biological variability of the affected environment. In order to accomplish this monitoring goal, it is necessary to have information about the natural background concentrations of the chemicals of interest in different environmental compartments of the benthic environment of the slope. It is also necessary to know the composition of the biological communities and their natural variability in the study area.

In the deep sea, the rate of accumulation of discharged materials on the bottom and the area over which they are dispersed before deposition will depend on water current speeds and directions at different levels in the water column. The potential influence of this deposition on the benthos will depend on its rate relative to the natural flux of particles from the water column to the sediments.

Because of these considerations, offshore studies on the outer continental slope of the central and western Gulf of Mexico before, during, and after exploratory and development drilling should focus on physical, chemical, and biological features of the benthic environment. Activities should include the following:

- Sediments should be analyzed for a few target metals (barium, chromium, lead, and zinc) and petroleum hydrocarbons (naphthalenes, phenanthrenes, and dibenzo-thiophenes) most likely to accumulate on the bottom from platform discharges.

- Near hydrocarbon seeps, hydrocarbon fingerprinting methods will be needed to differentiate between seep hydrocarbons and hydrocarbons that might be discharged from platforms.

- Seasonal patterns of water currents should be studied at all depths, particularly near the bottom, to characterize dispersion of platform discharges and near-bottom turbidity currents and rates of bed resuspension and transport.

- Measure concentrations, compositions, and flux rates of particles from the water column to the bottom.

- Determine benthic community structure in different major slope habitat types: fine-grained sediments; topographic features; natural hydrocarbon seeps.

- Measure recruitment rates of benthic fauna to different natural substrates on the slope.

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Dr. Jerry M. Neff received his Ph.D. in zoology from Duke University. After eight years on the faculty of the Department of Biology at Texas A&M University, he moved to Battelle Ocean Sciences Laboratory. Recently, he joined the staff of the Marine Sciences Unit at Arthur D. Little, Inc. During the 20 years of his scientific career, he has performed many research projects dealing with the fate and biological effects of chemicals, particularly those related to offshore exploration for and production of oil, in the marine environment and has published more than 100 papers on this and related topics.

RESEARCH PLANS BY PRINCIPAL INVESTIGATORS: "MISSISSIPPI RIVER PLUME HYDROGRAPHY STUDY"

Session:	RESEARCH PLANS BY PRINCIPAL INVESTIGATORS: "MISSISSIPPI RIVER PLUME HYDROGRAPHY STUDY"
Co-Chairs:	Dr. Alexis Lugo-Fernández Dr. Stephen P. Murray
Date:	November 7, 1991

Presentation	Author/Affiliation
Research Plans by Principal Investigators: "Mississippi River Plume Hydrography Study": Session Introduction	Dr. Alexis Lugo-Fernández Minerals Management Service Gulf of Mexico OCS Region and Dr. Stephen P. Murray Coastal Studies Institute Louisiana State University
A Review of the Mississippi River Plume Hydrography Task of the LATEX Shelf Physical Oceanography Program	Dr. Stephen P. Murray Coastal Studies Institute Louisiana State University
Acoustic Doppler Surveys of Currents and Particles in the LATEX Coastal Boundary Layer	Dr. Curtis C. Ebbesmeyer Evans-Hamilton, Inc.
Pollutant Chemistry Element of the LATEX Plume Study	Dr. Jay C. Means Aquatic Toxicology Laboratory Louisiana State University
The Near Field Plume Survey	Dr. Lawrence J. Rouse, Jr. Coastal Studies Institute Louisiana State University
Benthic Boundary Layer Element of the LATEX Plume Study	Dr. L. Donelson Wright Virginia Institute of Marine Science College of William and Mary and Dr. Richard W. Sternberg Department of Oceanography University of Washington
Sediment Trap Element of the LATEX Plume Study	Dr. Wilford D. Gardner and Dr. Mary Jo Richardson Department of Oceanography Texas A&M University

(Continued)

Session: RESEARCH PLANS BY PRINCIPAL INVESTIGATORS: "MISSISSIPPI RIVER PLUME HYDROGRAPHY STUDY" (continued)

Presentation	Author/Affiliation
Biological Sampling in the Mississippi River Plume Hydrography, Task B of LATEX Study	Dr. R. Eugene Turner Department of Oceanography and Coastal Sciences Coastal Ecology Institute Louisiana State University and Dr. Quay F. Dortch Louisiana Universities Marine Consortium
Zooplankton Characterization Element of the LATEX Plume Study	Dr. Richard F. Shaw Coastal Fisheries Institute Center for Coastal Environmental and Energy Resources Louisiana State University
Hypoxia Component: Mississippi River Plume Hydrography LATEX Physical Oceanography Program	Dr. Nancy N. Rabalais Louisiana Universities Marine Consortium
Data Management and Information Transfer Element of the LATEX Plume Study	Ms. Mary L. White Coastal Ecology Laboratory Louisiana State University

RESEARCH PLANS BY PRINCIPAL INVESTIGATORS: "MISSISSIPPI RIVER PLUME HYDROGRAPHY STUDY": SESSION INTRODUCTION

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Gulf of Mexico OCS Region
and
Dr. Stephen P. Murray
Coastal Studies Institute
Louisiana State University

The Texas-Louisiana (LATEX) Physical Oceanography Program funded by Minerals Management Service (MMS) has just started. The research plans of the LATEX Program's three components will be presented at this Information Transfer Meeting (ITM). The ITM has three sessions dedicated to physical oceanography and LATEX. This session presents the research plans of the Mississippi River Plume Hydrography, Part B of LATEX. The objectives of these presentations are to

- inform the scientific community of the research plans;
- explore the coordination and cooperation with other scientific programs in the area;
- present methods, analysis, and types of data to be collected; and
- gather information that can improve the experimental design and the logistics.

The session contains 10 presentations describing the individual tasks of Part B. Each principal investigator presented his cruise plans, data to be collected, methods, and analysis of his task. The MMS hopes this session provides useful information to researchers and program managers interested in the physical oceanography of the Gulf of Mexico.

Dr. Alexis Lugo-Fernández is an oceanographer with the Minerals Management Service, Gulf of Mexico OCS Region. His primary interests are physical processes on coral reefs and circulation in the shelf. Dr. Lugo-Fernández obtained his B.S in physics and an M.S. in marine sciences from the University of Puerto Rico. In 1989, he received his Ph.D. in marine sciences (physical oceanography) from Louisiana State University.

Dr. Stephen P. Murray has 25 years of research experience in coastal and shelf waters. He is past Director of the Coastal Studies Institute at Louisiana State University where he is presently employed working on research projects on the physical oceanography of shelf, sea straits, and coastal waters. Dr. Murray received his Ph.D in dynamical oceanography from the Department of Geophysical Science, University of Chicago, in 1966.

A REVIEW OF THE MISSISSIPPI RIVER PLUME HYDROGRAPHY TASK OF THE LATEX SHELF PHYSICAL OCEANOGRAPHY PROGRAM

Dr. Stephen P. Murray
Coastal Studies Institute
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In this paper I will (1) present background material on the Mississippi River plume, showing why it is important to understand its spatial and temporal behavior; (2) cover the broad objectives of our study; (3) list our key technical and managerial personnel; (4) explain the basic thrust of our sampling plan; and (5) review the cruise tracks and sampling plans for the five cruises during which we study the extended plume. The single near field plume cruise is discussed in a separate paper.

The Mississippi River watershed drains almost 40 percent of the land area of the United States from the western slopes of the Appalachians to eastern slopes of the Rockies, from Canada to the Gulf of Mexico. It is the fifth longest river on the planet in terms of fresh water discharge, carrying 600 million cubic meters of water per year into the Gulf of Mexico. This massive amount of water carries with it 230 million tons of sediment per year.

The pollutant loading of the river is also of considerable significance but is only now under investigation by a U.S. Geological Survey led project.

We are interested in the alterations and eventual fate of the sediments and pollutant-charged waters when they are injected into the Gulf of Mexico. Every introductory oceanography and geology textbook shows a photo illustrating the riverine buoyant plume injected into the deep water off the major passes of the modern Mississippi delta. These plumes are highly influenced by the local winds and often are injected onto the outer shelf. The contribution of the plumes from the modern Mississippi delta to the extended, low salinity, and turbid plume that characteristically dominates the coastal waters along central, and western Louisiana, and the North Texas coast, appears to be intermittent and remains an outstanding question.

The Atchafalaya River system captures as much as one-third of the Mississippi discharge in central Louisiana and diverts it through a shallow rapidly building deltaic complex into the very shallow waters seaward of Atchafalaya Bay. The depths of waters where the Atchafalaya discharge enters the Gulf are only 2-3 m, in marked contrast to the 200-300 m off the main passes of the Mississippi delta. It is this extended plume from the Atchafalaya discharge, augmented intermittently by Mississippi River outflow, extending along the coast for 900-1000 km (even as far as the Mexican border) that is the focus of this study program.

The broad objectives of this task are to: (1) dynamically characterize the plume along its length and determine the volume and fresh water flux along this extended plume at high, mid, and low river stages, employing both hydrographic and acoustic doppler velocity profiling techniques; (2) evaluate variations in Mississippi River outflow contributions to the extended plume (EXPLUME); (3) document effects of "northers" in the disruption of the EXPLUME with respect to velocity structure, biological assemblages, and chemical pollutants; (4) determine the role of convergence zones in altering and dissipating the EXPLUME, especially near 94°W; (5) determine critical chemical pollutants and their flux fate, and phase partitioning along the EXPLUME; (6) measure flux of nutrients and particulates along the EXPLUME; (7) characterize zooplankton and phytoplankton assemblages along the EXPLUME; (8) determine relationships between hypoxic conditions on the shelf and the physical, chemical, and biological characteristics of the EXPLUME; (9) characterize the sediment transport regime with respect to water column and bottom boundary layer (BBL) particulate flux; (10) conduct a high resolution survey of the dynamics, or biological and chemical interrelationships of the near field plumes at the Mississippi River mouth passes; (11) physically, chemically, and biologically characterize the buoyant plumes injected into the EXPLUME from the large bays along the Texas-Louisiana (LATEX) coast, e.g., Sabine and Calcasieu Lakes and Galveston Bay; (12) use satellite remote sensing to provide a continuous and real time history of the evolving behavior of the EXPLUME and its fronts and meanders, the shelf waters, and the eddies and squirts on the LATEX shelf and slope.

Individual subtask leaders are Stephen P. Murray (Louisiana State University, LSU) in hydrography; Curt Ebbesmeyer (Evans-Hamilton, Inc.) in acoustic doppler surveys; Don Wright (Virginia Institute of Marine Sciences) in BBL studies; Wilf Gardner and Mary Jo Richardson (Texas A&M University) in vertical sediment flux; Gene Turner (LSU) in biology and nutrients, Quay Dortch (Louisiana Universities Marine Consortium, LUMCON) in phytoplankton; Rick Shaw (LSU) in zooplankton, Nancy Rabalais (LUMCON) in hypoxia studies; Larry Rouse (LSU) in the single near-field plume survey, Jay Means (LSU) in pollutant chemistry, and Larry Rouse, Oscar Huh, and Nan Walker in the remote sensing task. This is a highly qualified team, each with 15-25 years experience on their specialties in the study area.

The management team consists of Steve Murray - Program Manager, Curt Ebbesmeyer - at sea logistics manager, Jami Donley - Administrative Assistant and Information Transfer, Rod Fredericks - Project Engineer, Instrumentation and Moorings, and Mary White - Data Management.

There are five cruises scheduled to study the EXPLUME and one cruise to study the near field plumes at the Mississippi River mouth. Our basic strategy on the extended plume is to study three important regimes; (a) high river stage in April when the plume is fully developed and extends into south Texas; (b) the time of intense biological activity in July when hypoxic conditions are maximally developed; and (c) the time of minimal discharge in the plume, which is also the time of strong wind and wave mixing in October. Our cross-shore sampling spacing should be close to the internal Rossby radius (10-15 km). The long shore sampling should be about the wavelength of barocline meanders (60-90 km).

Our cruise plans are designed to accomplish the objectives and resolve the time varying features associated with the EXPLUME. Cruise 1, April 21-30, 1992, will cover about 2,500 km (Figure 15.1) obtain 134 conductivity/temperature/depth (CTD) stations, 33 biological stations, and result in 230 chemical analyses of water and bottom sediment. This cruise begins (a) with a series of Doppler velocity control boxes to study along plume changes in velocity and transport, (b) three cruciform sample patterns in front of the major bays for chemical analysis of bottom sediments, (c) an extension of the survey into south Texas, and (d) a BBL tripod deployment. Underway measurements in surface waters include temperature, salinity, dissolved oxygen, fluorescence, transmissivity, optical backscatter, irradiance, and selected biological and chemical parameters.

Each of the five hydrographic cruises has a common backbone known as the CORE SURVEY consisting of eight transects and carefully selected tie lines (Figure 15.2). Acoustic doppler survey tracks with CTD stations delineate five control volume boxes focused on the Atchafalaya outflow: (1) an upstream box which will gauge the input from the Mississippi outflow farther to the east; (2) a source box which captures the Atchafalaya inflow; (3) near field; (4) far field boxes; and (5) another volume flux control box near Galveston Bay in the zone where the plume has historically abruptly narrowed. We have designed five to eight CTD stations on cross-shore transects and tie lines will have two to three CTD stations to help interpret property distributions between transects. The BBL tripod deployment is located on Transect 3 between two Task A current meter moorings. Biology and pollutant chemistry stations are discussed in other papers by Sub-Task Leaders.

I emphasize that our cruises have been designed on the modal locations of the extended plume based on longterm satellite imagery. Just prior to each survey, imagery input will guide the final layout of the survey and will be continually updated during the cruise from the imagery analysis at the Earth Scan Laboratory at LSU.

A south Texas leg of the survey will be executed on Cruise I and Cruise IV down to Corpus Christi. It includes continuous doppler velocity coverage of the narrow turbid plume in this region plus 24 CTD stations, four biology and four pollutant chemistry stations.

On Cruise II in July 1992, we, again, execute the core survey and include the West Delta leg for hypoxia studies, to be discussed by Nancy Rabalais; a front survey to be discussed by Curt Ebbesmeyer; and a convergence study. About this time of the year, strong southerly winds along the south Texas coast slow and then reverse the plume current. Convergence zones can be seen on satellite imagery and the low salinity plume water is depleted onto the mid and even outer shelf.

We have designed a generic convergence survey to characterize these zones but recognize that their spatial and time scales are quite variable and we will respond to the imagery analysis at sea with a modified survey.

On Cruise III in October-November 1992, after a cold front passage, we plan on studying the Atchafalaya plume in its offshore deflected state and execute a survey of one of the major estuarine discharge plumes.

The convergence process is well described in Cochrane and Kelly (1986) who illustrate how the intense southerly winds off south Texas in summer force a convergence in the surface layer which can fill the outer shelf with low salinity water. To study this phenomena we have designed a generic sampling plan flexible enough for rapid updating based on concurrent satellite image analyses. This plan will be executed when the satellite and shipboard sensors indicate the presence of a large convergence zone. It will consist of continuous acoustic doppler velocity coverage, 25 CTD stations, and six biology stations. A grid is also prepared for the estuarine plume studies, consisting of acoustic doppler current profiler lines, 26 CTD stations, and seven biology stations.

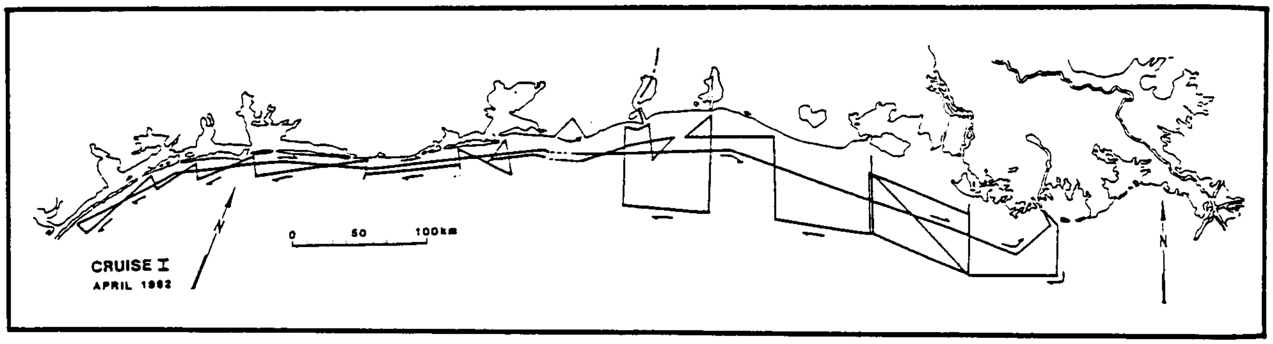

Figure 15.1. Ship track for Cruise I scheduled for April 21-30, 1992. (The Texas-Louisiana coast was straightened in this illustration for purposes of depiction only.)

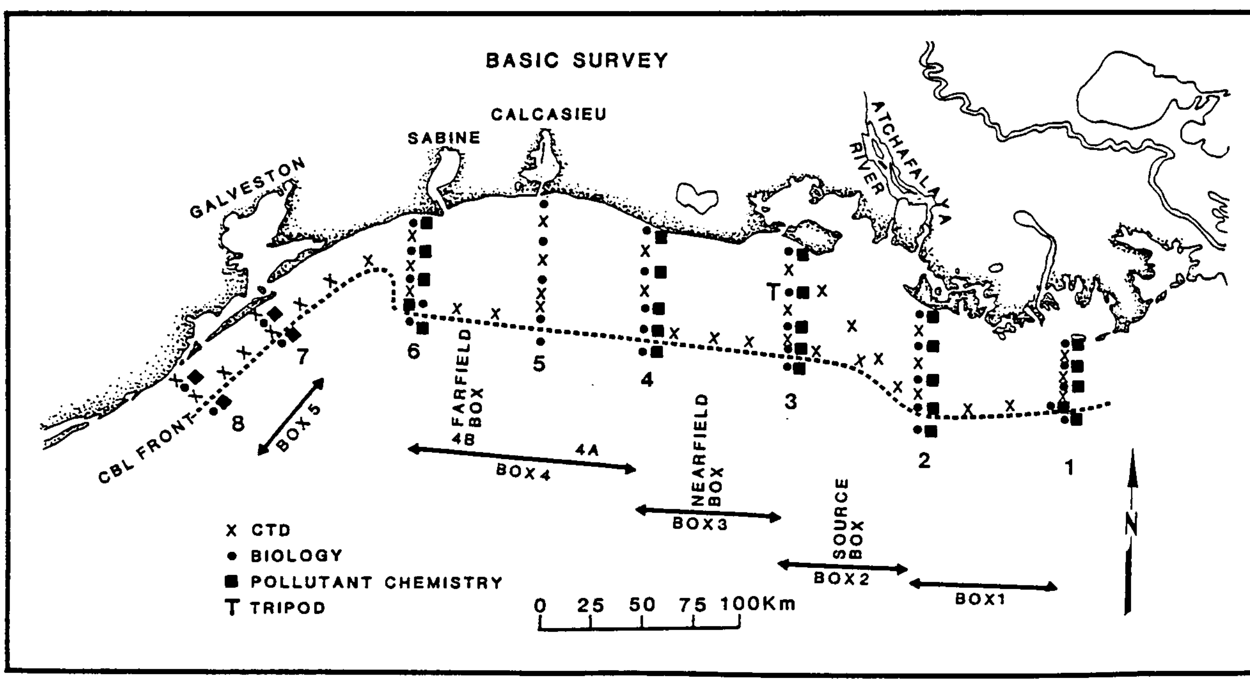

Figure 15.2. Location and types of information to be collected at each station along the eight transects of the proposed CORE SURVEY.

The deflected Atchafalaya plume study is far more complex. Our plan is to begin after a cold front passage when the northern wind begins to drop out. We will execute three visualizations of the velocity and density structure of the plume as it rotates back into its coherent longshore flow mode.

Cruise IV in February 1993 includes the core survey, the south Texas leg, another convergence study (which we anticipate to be along the mid-Texas coast in February), and a BBL tripod study. This winter deployment should allow the measurement of stronger wind and wave resuspension events.

Cruise V in July 1993 will include the core survey, the West Delta hypoxia leg, a convergence study, and the third BBL tripod study. Sediment traps will be deployed during the BBL tripod deployments. Details of individual subtasks are discussed in accompanying papers in this volume.

In summary, this program will determine for the first time fundamental aspects of the velocity structure and volume and sediment flux in the Mississippi-Atchafalaya plume. Of great significance is that we will simultaneously observe the flux and behavior of chemical pollutants in the plume, and delineate the relationships between indigenous phytoplankton and zooplankton assemblage and the dynamics of the plume itself. An unprecedented understanding of this major world river discharge plume and its influence on the shelf will emerge in technical reports and journal papers over the next 5 years.

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Dr. Stephen P. Murray has 25 years of research experience in coastal and shelf waters. He is past Director of the Coastal Studies Institute at Louisiana State University where he is presently employed working on research projects on the physical oceanography of shelf, sea straits, and coastal waters. Dr. Murray received his Ph.D in dynamical oceanography from the Department of Geophysical Science, University of Chicago, in 1966.

ACOUSTIC DOPPLER SURVEYS OF CURRENTS AND PARTICLES IN THE LATEX COASTAL BOUNDARY LAYER

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INTRODUCTION

The Acoustic Doppler Current Profiler (ADCP) has had a significant impact on oceanography. Although the concept was patented decades ago, it was only in the 1970's that an ADCP was used to obtain measurements of ocean currents. In the 1980's RD Instruments, Inc. introduced an ADCP now used widely. For example, investigators at Brookhaven National Laboratory found that the acoustic echoes (backscatter) recorded by an ADCP were correlated with zooplankton concentrations. Subsequently, investigators from the Waterways Experiment Station (Vicksburg) used an ADCP (aboard the R/V *Pelican*) to observe fine materials remaining in the water column off Mobile, Alabama, shortly after releases of dredged materials from barges. A correlation was found between the concentration of fine material captured with water bottles in the water column and that recorded by the ADCP (Figure 15.3).

Briefly, the ADCP on the R/V *Pelican* operates by transmitting short acoustic pulses from the vessel's transducer (Figure 15.4). Sound backscattered from plankton, particles, and inhomogeneities in the water is received by the transducer with a Doppler frequency shift proportional to the relative velocity between the scatterers and the transducer. A time series of measurements of the Doppler frequency shift after sound transmission produces a depth segmented picture (or profile) of the water flow velocity. Because the bottom is within the sonar range (bottom tracking mode) for these cruises, the Doppler frequency and the time delay of the bottom backscatter echo are also measured, providing accurate measurements of vessel velocity.

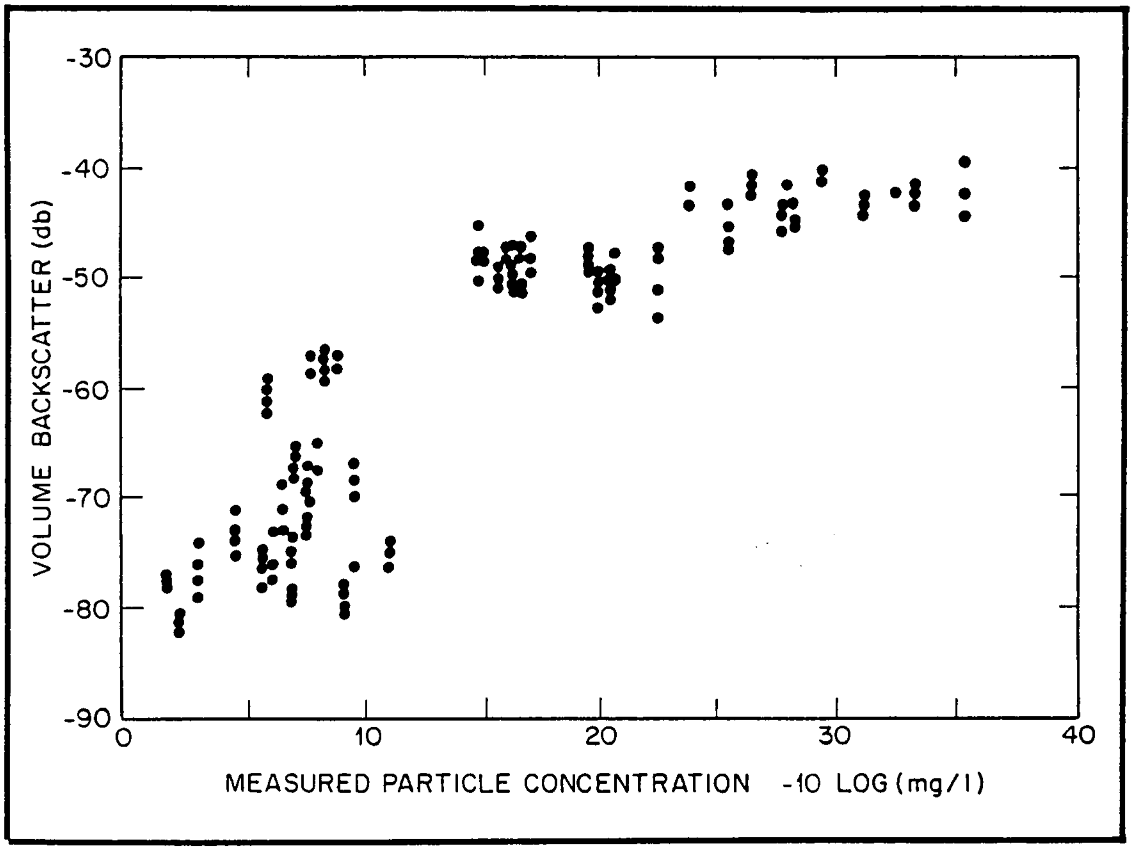

Figure 15.3. Scatter plot between measured particle concentration and ADCP backscatter for surveys of fine sediment released from barges (from Kraus 1991).

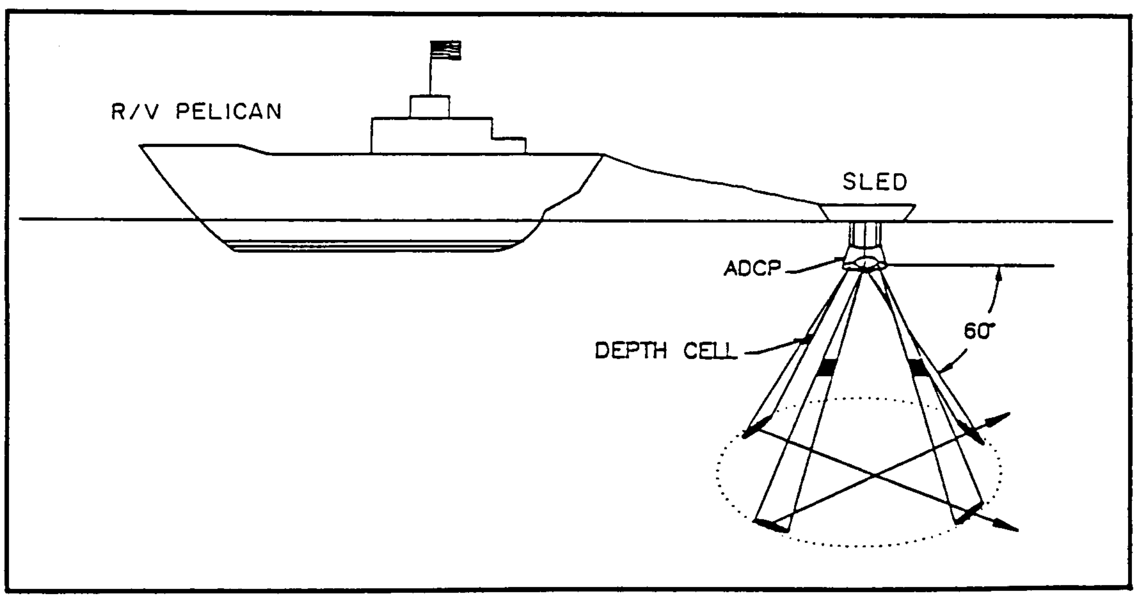

Figure 15.4. Schematic of the R/V *Pelican's* ADCP.

Since velocity and backscatter profiles are available in real-time while the R/V *Pelican* is underway, they provide an effective means with which to observe the coastal boundary layer thereby taking advantage of valuable ship time (Figure 15.5). This is particularly important during summer when satellite imagery often does not resolve the plumes comprising the coastal boundary layer. Moreover, while satellite imagery senses very near the sea surface, the ADCP resolves layers of the water column deeper than a few meters. The satellite and ADCP data nicely complement each other. Therefore, ADCP velocity and backscatter have been made integral parts of the coastal boundary layer surveys.

SAMPLING PLAN AND RATIONALE

The plumes of sediment-laden fresh water comprising plumes of the Mississippi and Atchafalaya Rivers evolve rapidly along the Texas-Louisiana (LATEX) coast; consequently it is necessary to carefully consider rates of sampling. Because the ADCP can rapidly obtain profiles of currents and backscatter, approximately once per second, an optimal approach is to sample while the R/V *Pelican* is underway with the ADCP serving as an observational tool. During the LATEX Task B plume cruises the R/V *Pelican* will be underway approximately 70 percent of the total cruise duration; good use of this considerable time will be made with the ADCP observing both currents and backscatter.

In designing the LATEX sampling plan, the following parameters were considered: water depth, vertical sampling interval, sampling rate (number of acoustic pings in a specified time averaging interval), the angle of the acoustic cone emanating from the transducer, frequency of the

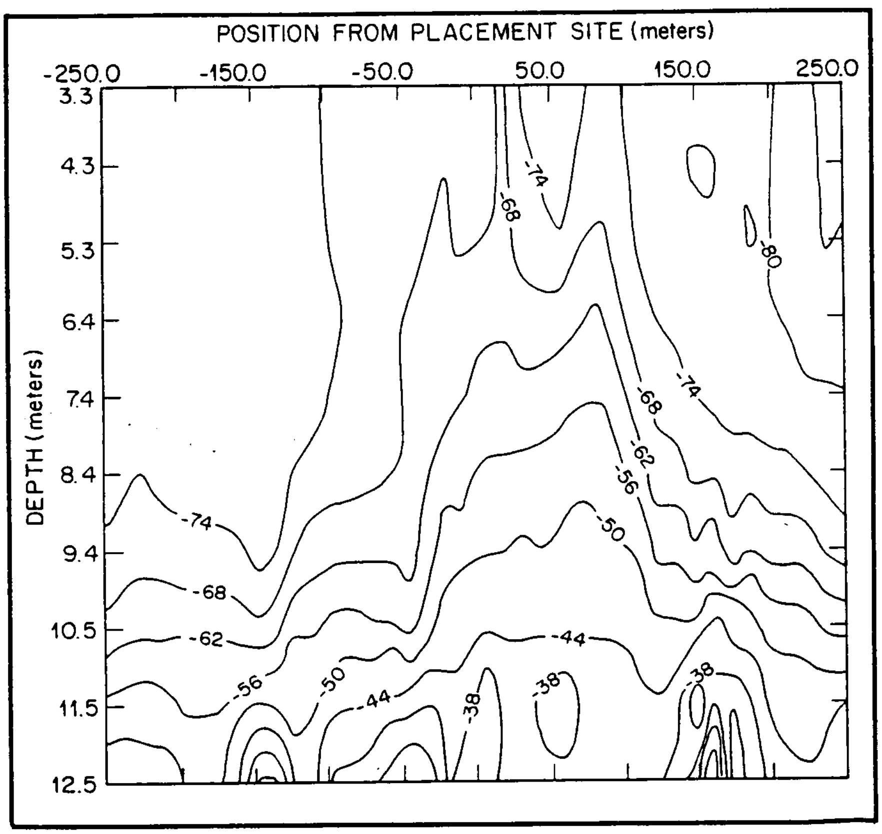

Figure 15.5. Example of real-time ADCP current profiles to be collected aboard the R/V *Pelican* during the LATEX Task B plume surveys.

transducer, and the number of acceptable pings (percent good data). These parameters are interrelated in an equation expressing the random error of the estimated current speed within a given vertical depth interval (called a bin; see Kraus 1991 for ADCP description). From intercomparisons with moored current meters, it has been found that constraining the random error below approximately 2 cm/s does not appreciably improve ADCP signal quality; therefore, this value was selected as the random velocity error, a parameter strongly constraining ADCP configuration.

The ADCP can interpret acoustical signals from a range of the water column, extending from a number of meters beneath the sea surface, to a number of meters above the sea floor. As it is well known that plumes tend to be concentrated near the sea surface, with significant variations occurring in the upper few meters, one important consideration is obtaining reliable data as close as possible to the sea surface. During the 1989 experiments off Mobile, Alabama, the ADCP was mounted over the side on a 4-inch diameter pipe. Reliable information on backscatter was obtained at depths as shallow as 3.3 m. With the ADCP transducers mounted on a sled towed behind the R/V *Pelican* this depth may be decreased to less than 3 m, but probably not less than 2 m.

Consider next, water depth and the ability of the ADCP to penetrate to the sea floor. Generally, the higher the frequency of the ADCP transducers the less penetration that can be obtained through the water column. Higher frequencies are desirable for two reasons: they lead to greater vertical resolution and they are sensitive to smaller sizes of suspended particles. The highest frequency commercially available is 1200 kHz which penetrates to a water depth of approximately 40 m. Since the coastal plumes are mostly found in depths less than 40 m, the 1200 kHz ADCP transducer is best suited to the coastal boundary layer cruises.

If plumes should be found in deeper water, lower ADCP frequencies may be required. Three frequencies are available on the R/V *Pelican's* ADCP: 300, 600, and 1200 kHz. The 300 and 600 kHz transducers are mounted in sea chests midship and near the center line of the R/V *Pelican*, whereas the 1200 kHz transducer is mounted on a towed sled. For water deeper than 40 m, the 300 and 600 kHz frequencies may be utilized.

With 2 cm/s as the random error and 1 m as the vertical resolution, the remaining ADCP parameter is the time averaging distance along the cruise track. As the ADCP transducer emits about one ping per second, it is obvious that more pings lead to smaller errors in the estimated speed but require a longer distance thereby degrading the horizontal resolution. At the R/V *Pelican*'s cruising speed of 9 knots, one and two minutes correspond to horizontal distances of 278 and 556 m, respectively. With the 30° cones of the R/V *Pelican*'s ADCP, the errors are 1.5 and 1.6 cm/s for these averaging periods. As a compromise a two-minute averaging interval has been chosen yielding data at approximately half kilometer intervals.

The coastal boundary layer includes fronts and convergence zones which are often defined by sharp horizontal transitions measuring tens of meters. As the ADCP will average information over a distance of approximately 500 m, considerable resolution would be lost if the vessel were to simply proceed across one of these transitions. Therefore, the cruise tracks actually carried out will include the following detail. In the vicinity of sharp transitions short tracks parallel to the transition will be executed. These will span a distance of 1 km or a time interval of four minutes equivalent to two ADCP averaging intervals. These 1-km segments will be parallel to, and as close as possible to transitions. Where transitions have a particularly complex horizontal configurations (e.g., corners, waves, etc.), additional 1-km segments will be executed within the time constraints of the surveys. These detailed maneuvers can be readily executed because the ADCP software continuously displays the ship track.

METHODOLOGY AND TECHNIQUES

The ADCP system will be operated continuously from the R/V *Pelican* during the surveys. Profiles will be obtained only when the ADCP system is bottom tracking so that corrections for ship's velocity will not be dependent on conventional navigation information (e.g., Loran, global positioning system). The measured ADCP profiles will be output from one personal computer to a second personal computer which will remove the ship's velocity from the measured raw profile data and display and record the resulting profiles. The recorded velocity and backscatter data will be displayed using standard software and color monitors so that scientists aboard the R/V *Pelican* may view the data in real-time, thereby optimally configuring the cruise plan.

During each of the 10-day surveys, with an averaging interval of two minutes, 5,040 profiles will be obtained while underway (7 days x 24 hours x 60 minutes/2 minute averaging interval). For each linear segment of the cruise track, it is anticipated that contours of the north-south and east-west speed components, as well as backscatter, will be produced. For the remaining 30 percent of each cruise, while the R/V *Pelican* is on station, ADCP measurements will be averaged. One average profile of currents and backscatter will be produced for comparison with parameters measured with other oceanographic techniques. For example during a conductivity/temperature/depth (CTD) cast, an ADCP profile will be obtained. This average will begin at the start of the down cast and will end when the CTD is brought aboard. Vertical profiles of the average speed components and backscatter will be produced for each CTD station. From these data, intercomparisons similar to that shown in Figure 15.3 are anticipated.

To calibrate the ADCP at the beginning of each cruise, the R/V *Pelican* will be run over a known measured course in two directions. The course will be run in both directions so any current velocity abnormalities can be eliminated. The bottom tracking and current velocity information obtained by the ADCP and the ship's velocity measured by time and distance will be analyzed to verify the ADCPs accuracy and to determine the ADCP's heading offset.

When the R/V *Pelican* is in the vicinity of LATEX A moorings located in the plume extension, additional calibration information will be obtained. In these situations the R/V *Pelican* will proceed as close as possible to moorings. This comparison will enhance the compatibility of the Task A and B data sets.

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POLLUTANT CHEMISTRY ELEMENT OF THE LATEX PLUME STUDY

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OBJECTIVES

The objectives of Subtask B-3, with respect to pollutant chemistry are:

- To measure a suite of chemical and/or physical pollutants known to be present focusing on the Mississippi-Atchafalaya plume, or Coastal Boundary Layer (CBL), from the Mississippi River to the south Texas coast, with special attention given to the area from the Atchafalaya River to the north Texas coast. These measurements will be acquired at selected stations and selected depths.

- To use these measurements to characterize the plume in the study area.

- To trace the movement and mixing of particular water masses within the plume in conjunction with the data from the other parts of the study, particularly the remote sensing and current data.

- To assist in the interpretation of the importance of changes in water mass characteristics within the plume and offshore.

- To identify and trace specific chemical pollutants as they enter into, end mix, and advect through the plume.

The overall goals of Task B-4 are:

- To develop a historical and contemporary understanding of pollutant loadings to the CBL.

- To analyze the distribution of chemical species within the waters of the CBL between dissolved, colloidal, and particulate phases.

- To characterize the fluxes and transformations of pollutants within the CBL.

- To develop a descriptive model of pollutant fluxes/transport within the various regions of the CBL which includes both spatial and time variability of cross-shore and alongshore fluxes of selected chemical species in the dissolved, colloidal, and particulate phases and which is able to discriminate between buoyant plume and bottom transport (resuspension).

The objective of our field program then is to obtain sufficient samples to allow us to define pollutant concentrations in a three-phase analysis scheme and to subsequently be able to develop spatial and depth resolved contour maps of pollutant concentrations that can be incorporated into a spatial and depth resolved semi-quantitative model.

METHODOLOGY

In estuarine and marine systems, many pollutants associate with particles or colloidal phases. Using loading estimates from historical data sets of our own measurements of loading factors we can estimate the pollutant inputs to the five boxes which encompass the Texas-Louisiana (LATEX) CBL as well as the near-field Mississippi plume. Modelling of the subsequent pollutant fluxes within those boxes requires detailed information on a variety of physical and chemodynamic processes. First, a clear understanding of the movement of water masses in both cross-shore and alongshore vectors is required along with estimates of dilution from either marine water or additional freshwater inputs. Second, accurate information on the fluxes of sorptive particles and colloidal phases as well as characterization of the sorptive capacities of these phases must be available. These must include horizontal transport (advection), downward vertical fluxes (settling), and upward vertical fluxes (resuspension) (Figure 15.6). Third, field verification of the assumptions of local partitioning equilibrium between the three phases and the identification of conservative and non-conservative behavior of individual chemicals must be obtained. Fourth, estimates of other fluxes (such as volatilization rates) or transformations (e.g., degradation reaction rates) for pollutants which might alter pollutant concentrations within a box must be obtained (derived primarily from thermodynamic models and literature). Finally, other physical factors which might alter pollutant behavior such as changes in salinity (e.g., flocculation of colloids), hypoxia (e.g., changes in redox state of certain elements), or local biological production (e.g., algal blooms) must be evaluated as potential modifying variables affecting pollutant fluxes.

Field Collections

During each of the five core surveys, a series of samples will be collected along five cross-shelf transects, each consisting of five stations with selection based upon satellite positioning information relative to the dimensions of the CBL. Samples will be collected at two discrete depths (1 m below the surface and 1 m above the bottom) at each station. Each sample will consist of a particulate phase, a colloidal phase, and a dissolved phase sub-sample. In addition, during each south Texas leg, four additional stations will be sampled at two depths. Priority will be given to the analysis of the membrane filter (particulate phase) and the ultrafilter (colloidal phase), with analysis of the dissolved organics phase based on findings from the former two phases.

In order to provide contemporary information on pollutant loadings to the CBL, a sample of the Mississippi River discharge water will be collected three weeks prior to each cruise. Samples of the

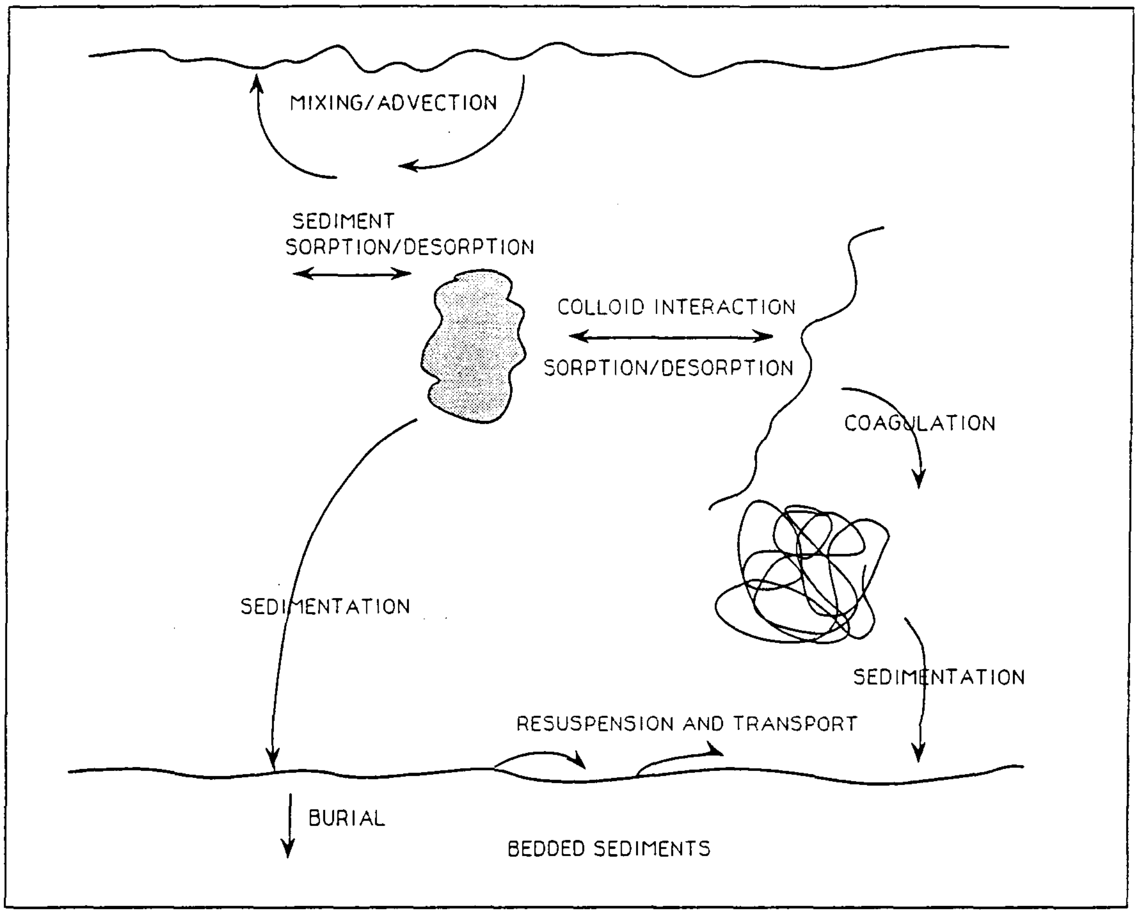

Figure 15.6. Diagram showing various physical/chemical processes affecting pollutant transport in LATEX CBL.

discharge will also be collected from within the mouths of the Atchafalaya, Calcasieu, Sabine, and Galveston estuaries waters during each cruise. These water samples will be subjected to the three-phase chemical analysis described above. In addition, during the first cruise (April 1991), we also plan to collect a series of bottom sediment samples at the mouths of four principal estuaries in the LATEX study area (Atchafalaya, Calcasieu, Sabine, and Galveston).

Water samples will be collected at two depths, 1 m from bottom and 1 m below the sea surface. The rationale for the use of multiple depths is to: (1) provide a depth-integrated measure for each contaminant selected for inclusion in a simple transport model; (2) distinguish between plume sediments and resuspended material near the bottom; and (3) examine pollutant distribution as function of depth and density stratification, especially in events associated with hypoxia. As mentioned earlier, water samples will also be acquired before and during each of the cruises in the Mississippi River and near the mouths of each of the remaining four major sources of freshwater and pollutants entering the study area. These samples will be surface water (1 m below the surface) taken on an outgoing tide in the fresh water portion of each estuary. The proposed sites for the samples other than the Mississippi River will be Venice, Louisiana, Morgan City, Louisiana, Cameron, Louisiana, and Galveston, Texas.

Upon reaching the surface, the water samples will immediately be filtered through pretreated 0.4 μm Nucleopore filters in a stainless steel filter apparatus (145 mm filter diameter). The filter will be transferred to a precleaned glass ampule and frozen until analyzed. The filtrate will be preserved with sodium azide (0.5%), and refrigerated until ultrafiltered in the laboratory ashore. Ultrafiltration will be performed using a high volume ultrafiltration unit (Amicon H-10). The retentate of the ultrafiltration process (~1 l) containing the colloidal-sized fraction of the sample will be passed through a membrane ultrafilter (UM-02) and the membrane frozen in a glass jar until analyzed. An aliquot of the ultrafiltrate (15 l) will be refrigerated until extracted and analyzed.

Samples of sediments (top 5 cm) at the Atchafalaya basin will be collected using a box corer at 20 points spaced at 10 km intervals forming a trapezoid with an internal diagonal around the broad area of basin discharge. The remaining three estuaries, characterized by narrow mouths opening into the Gulf, will be sampled at six positions (0.5, 1, 2, 3, 5, and 10 km) along a transect positioned over the discharge jet. Another transect, approximately perpendicular to the jet, and aligned with the direction of CBL flow, will be sampled at four locations, two on either side of the jet.

Analyses of 12 sediment subsamples from the first mooring deployments under Task B-5 will be analyzed in a similar manner, providing needed information regarding pollutant loading from the particle plume of the Mississippi River. The data collected from these bedded sediments will be used to focus the analytical effort for water column samples, thus providing some economies of effort.

Analytical Approach

The primary analytical tools to be employed in these studies for pollutant chemistry will be an inductively coupled argon plasma/mass spectrometer (ICP/MS) system for major and trace elements and a gas chromatograph/mass spectrometer (GC/MS) system for organic analyses. Both of these instrument systems have the advantage that multiple elements or compounds may be quantified simultaneously on a single sample. Repetitive analyses are not required. This means, in the case of the ICP-MS system, that data on as many as 55 elements can be obtained for approximately the same cost as only a few elements determined by atomic absorption spectrometry or conventional ICP techniques. In addition, data can be obtained on multiple isotopes of certain elements such as lead, beryllium or rare earths, and the information used to understand various geochemical processes occurring in the plume during transport and deposition, as well as during resuspension events.

Likewise, the use of multiple selected ion mass spectrometry on extracts of the three phases of interest in this system will allow the quantification, at ppb levels, of several classes of pollutants in a single analysis without extensive sample fractionation or cleanup techniques. Thus, both pyrogenic and petrogenic polynuclear aromatic hydrocarbons (PAHs), total hydrocarbons, polychlorinated biphenyls (PCBs), chlorinated pesticides, and a selected suite of herbicides may be analyzed simultaneously. In ongoing studies of the fate and transport of produced water hydrocarbons in progress under funding, our research group has been able to use these techniques to follow the chemical signature of a discharge for up to 5 km.

Table 15.1 lists the major groups of analytes that will be used in the quantitative evaluation. The specific compounds were carefully selected for quantitative evaluation ("primary ion") and for confirmation of identity ("confirming ion"). Each of these analytes has been selected from a much more extensive list (over 300 potential analytes) based upon the availability of loading information into the CBL based upon our review of historical and ongoing research in the Mississippi River and/or one of the other estuaries included in the study area. It must further be emphasized that the isomer specific analyses of the PAHs (59 of the total 89 organic pollutants) are included because it provides an unusual degree of resolution in the "fingerprinting" of hydrocarbon sources and fates. In addition, each of the pollutants selected has documented implications for the ecological health of coastal marine ecosystems and also potential human health implications through foodwebs leading to man which exist in these ecosystems. Retention order of the alkylated PAH isomers has been determined in our laboratory by analysis of individual components and is based on hundreds of routine analyses performed to date using the proposed methodologies.

Table 15.1. Organic and Inorganic Pollutants Selected for MMS-CBL Study.

Analyte	
Polynuclear Aromatic Hydrocarbons (PAHs)	52 (compounds)
Polychlorinated Biphenols (PCBs)	7 (compounds)
Chlorinated Pesticides	19 (compounds)
Herbicides	4 (compounds)
Trace Elements	41 (elements)

RATIONALE FOR THREE-PHASE SAMPLING AND ANALYSIS OF POLLUTANTS

Chemical pollutants may exist in the dissolved phase or the particulate phase within river discharges. Typically the distribution of any such pollutant has been described as a simple partition coefficient, or Kd. Recent research has identified a third, or colloidal, phase which may mediate the partitioning processes occurring between truly dissolved and particle-sorbed contaminants. The potential for estuarine and marine colloidal phases to sorb contaminants, including both trace and rare earth elements and a variety of neutral hydrophobic contaminants, has been investigated and reviewed recently by Sigleo and Means (1990). Since the colloidal phase has been demonstrated to be able to compete successfully with particulate phases for a variety of contaminants, thus decreasing the partition coefficients, and because this third phase is typically more mobile than the particulate phase, estimates of "dissolved fluxes" of various contaminants may be underestimated if they are based on two-phase partitioning models (Sigleo and Means 1990). The challenge of this study will be to develop a transport model for pollutants which takes into account the partitioning that may occur in such a three-phase system (Figure 15.7) as the freshwater discharge plume enters estuaries and finally the coastal boundary layer. While it is recognized that terrigenous colloids may be flocculating out of the system at relatively low salinities, recent studies carried out in other large river estuaries suggests that this allochthonous material is quickly replaced with autochthonous colloids generated in association with the high primary productivity of estuaries (Sigleo and Means 1990, and references therein).

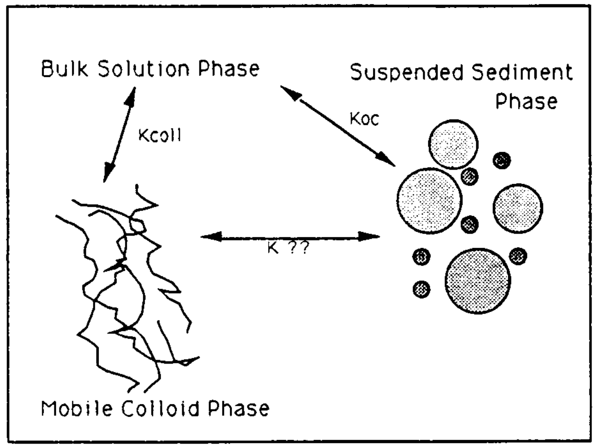

Figure 15.7. Three phase partitioning model.

Both inorganics and organics may be found in association with colloidal phases. For several elements of concern in the LATEX region, such as barium and zinc, associations with colloidal phases may be a significant component in the transport processes.

In a series of papers by Means and co-workers and summarized in Sigleo and Means (1990), it has been shown that estuarine and marine colloidal materials have the ability to sorb numerous neutral hydrophobic organic contaminants such as PAHs and various agricultural chemicals such as atrazine. This work has now been extended by other research groups to include PCBs and chlorinated pesticides (Brownawell and Farrington 1985, 1986; Kile and Chiou 1989). In their recent work on the Mississippi River, Periera *et al.* (1989) have found that a significant portion of the atrazine and other herbicides which they are following down the river is found in association with colloidal phases.

The scientific rationale for sampling the estuarine areas is to identify the presence of pollutants, to determine the range of nutrient and pollutant concentration being diluted in the study area, and to determine if the measured variables, for example, act conservatively as they are mixed. Silicate exhibits partially conservative behavior, for example, in contrast to the chemical behavior of pollutants bound to clays. If pollutants are not present in the river water during the field trip, then analytical approaches may be redirected to analyze for higher priority parameters. Further, the mixing behavior of these elements may be different in the CBL and in the region immediately offshore of the CBL or underneath during stratified conditions. This has bearing on the transport of materials in the study region.

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THE NEAR FIELD PLUME SURVEY

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The objective of this task is to characterize the near-field plume of the Mississippi River in terms of its physical, biological, and chemical parameters. The transport and mixing processes in the plumes of the individual passes, as well as the combined plume, will be described.

BACKGROUND

The interaction of the river plume with the Gulf of Mexico waters is complex. The strong vertical stratification of the water column near the mouths effectively isolates surface water masses from the deeper waters and reduces mixing. The fresher surface waters are also moved about very readily by changes in the wind stress. Further away from the mouths the stratification weakens, cross interface mixing is increased, and the response to shifts in the wind is not as dramatic. The diffusion of the freshwater also varies with changes in the meteorological forcing.

In spite of its importance, the Mississippi River plume has been the focus of only a few studies. Only five sets of physical oceanographic data with a broad spatial extent are known to exist for the proposed study area at present. The oldest data are from the study commissioned by the Louisiana Offshore Oil Port, Inc. during the early 1970's (Wiseman *et al.* 1976). Salinity and temperature fields of the bight west of the delta were mapped on eight occasions between July 1973 and April 1974, at a station spacing of approximately 9 km. Not all stations were sampled each cruise because of bad weather. A second data set from a series of cruises from March 1975 to May 1977 has been compiled by Allen and Turner (1977). These data were acquired over a wide area on both sides of the Mississippi Delta and do not represent repeated stations. The other three data sets are of more recent vintage. Since 1987, a research effort focusing on the biological responses to inputs from the Mississippi River (Dagg *et al.* 1988) has been sponsored by the Louisiana Stimulus for Excellence in Research (LaSER). This effort has carried out four cruises in the region to the west of the Mississippi Delta and at least two more cruises are planned. These cruises had no systematic sampling plan, but rather samples were taken opportunistically at fronts associated with the Southwest Pass plume and in waters of varying salinities out to the higher salinity water of the open Gulf. Most of the stations were within 35 km of the mouth of the pass, though some stations were as far away as 70 km. The fourth data set has been acquired on a series of cruises, begun in 1985, by Rabalais and her co-workers as part of investigation of the extent and causes of hypoxic conditions on the Louisiana shelf. Each of these cruises, which extended to the upper Texas shelf, had 4-12 transects in the region of this proposed study. A fifth data set is that being collected by Nutrient Enhancement Coastal Ocean Productivity (NECOP) investigators. The primary goals of NECOP revolve around processes in the region to the west of the delta. Several cruises have taken place and another cruise is scheduled for April 1992.

The single cruise to sample the near-field plume of the Mississippi River is currently scheduled for April 1993 (Figure 15.8). April was chosen because it generally encompasses the peak river discharge and somewhat stable weather conditions. The high river discharge contributes the maximum amount of organic and inorganic material to the shelf environment. The number of cold front passages has declined and the chances for clear skies and, hence, satellite images of the plume are very good. This timing will also complement the NECOP cruise presently scheduled for April 1992, by providing a second sampling of the Mississippi River plume under high river flow conditions.

CRUISE SAMPLING PLAN

A single cruise with a duration of approximately 12 days is dedicated to investigate the transport and dispersion properties of the near-field plume of the Mississippi River. Long-term observations of the discharge of the Mississippi River using satellite and aircraft imagery have demonstrated that the plume is a very dynamic entity, undergoing large displacements in relatively short times (Rouse and Coleman 1976). The single cruise will consist of three phases designed to survey both the spatial and short-term temporal variability of the plume at a variety of scales. The first and third phases will each consist of grids of more than 90 stations at which the required suite of continuous vertical measurements will be taken. If the weather and sea state permit, the data set acquired in these two phases will be the first at this synoptic scale of the Mississippi River plume. The first and third phases will investigate the dynamical spatial and temporal variability of the composite Mississippi River plume. The second phase of the cruise will focus on the smaller scale processes associated with the individual discharge plumes emanating from Southwest Pass, South Pass, and Pass a Loutre. The purpose of this phase of the cruise is to observe the character of the individual plumes, focusing on similarities and differences both between the individual surface plumes and within each.

At each station occupied on the cruise, a cast will be made with the enhanced conductivity/temperature/depth (CTD) to acquire profiles of the required parameters. Surface water samples will also be acquired at each station and analyzed for nutrients and suspended sediment concentration. Whenever the ship is underway, data will be collected by Multiple Interface Data Acquisition System (MIDAS) to produce continuous horizontal surface profiles. Continuous underway measurements will also be acquired by the acoustic doppler current profiler (ADCP) system. Water samples at a number of depths will be acquired for direct determination of water chemistry and biological activity at the first four stations in the first phase and at selected stations on the third phase. All stations in the second phase will acquire similar water samples. Pollutant chemistry water samples will be acquired on the third phase. The actual transect pattern for the cruise will be modified at the time of the cruise departure based on the latest available satellite imagery. As an example, the seaward extent of each of the transects in Phases I and II may reach further into the Gulf of Mexico if the satellite imagery shows that the

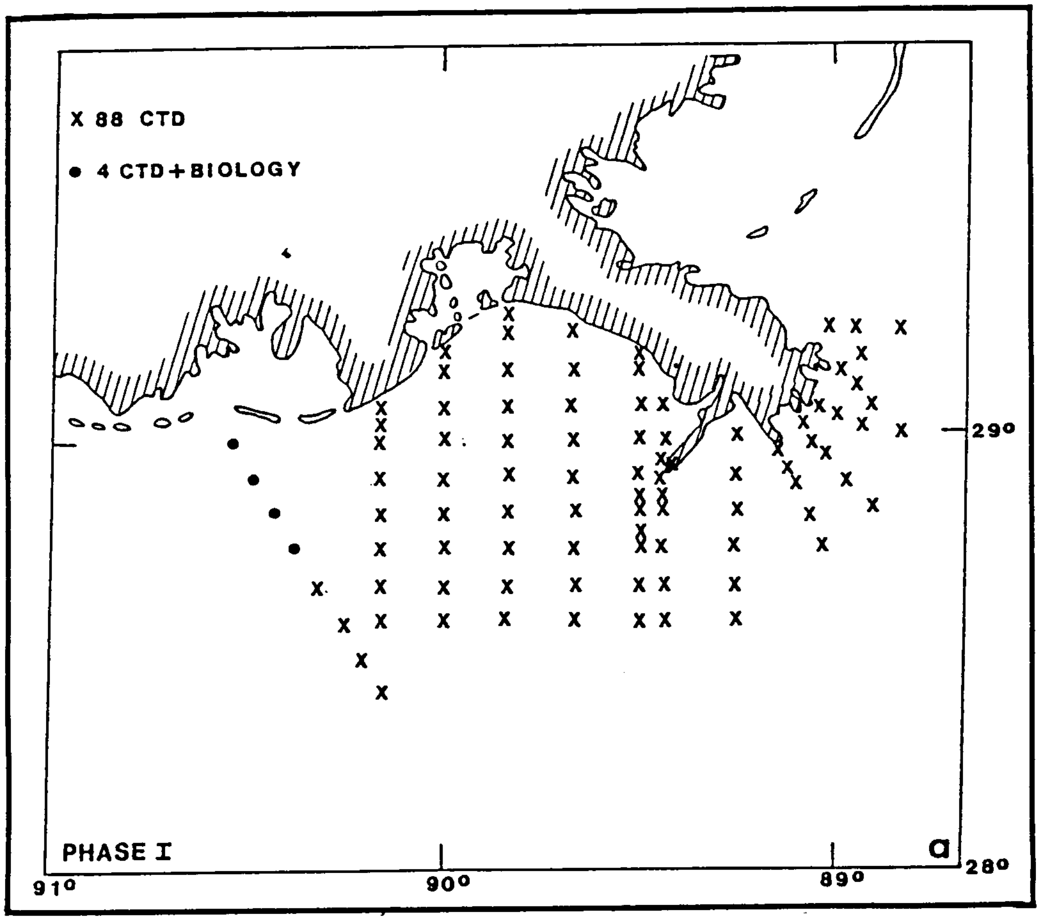

Figure 15.8. Locations of stations for the Near Field Plume Survey scheduled for April 1993.

Mississippi River plume extends beyond the proposed stations. Updated transmissions of analyzed advanced very high resolution radiometer products to the research vessel will be used to make further cruise track modifications, as necessary, at sea. The actual locations of the transects and sampling stations for Phase II of the cruise will be selected with the assistance of the images transmitted to the research vessel. Of course, if cloud cover prevents appropriate imaging of the sea surface, the research vessel will have to search for the discharge plumes using surface observations alone. The effectiveness of this cruise in sampling the Mississippi River plume will be enhanced by the availability of the satellite imagery which will be transmitted to the research vessel by Task B-1 of this project.

Phase I Synoptic Scale (#1)

The first phase of the cruise will acquire a "snapshot" of the three dimensional structure of the Louisiana shelf from Timbalier Bay to just east of the Mississippi Delta. Transects will be ten minutes of longitude apart in the along shelf direction and five minutes of latitude in the cross-shelf direction. In the vicinity of the delta, the transects are arranged, more or less, radially with station separation remaining about 9 km. This first phase should take approximately 75 hours to complete if the sea state permits optimal operations. A total of 92 stations will be occupied. Of these stations, only the first four will be complete biological stations, each of which will include a zooplankton tow.

Phase II Individual Discharge Plumes and Fronts

The second phase will focus on the character of the plumes from the three major passes of the delta. For the first part of this phase (Phase IIa) a continuous zigzag pattern will be run in each of the plumes. The sensors for this effort will be only the flow-through system and the ADCP. At the beginning of the pattern, in the mouth of the pass, a CTD cast will be made and water samples at selected depths and a zooplankton tow will be collected for analysis of biological and chemical parameters. A similar data set will be acquired at the end of the pattern again in the plume interior. The extent and orientation of the pattern will be guided by the latest satellite imagery and by continuous monitoring of the data gathered by the underway instrumentation.

After each pattern, a CTD and water sample cast plus a zooplankton tow will be made outside the plume for comparison. At the beginning of the pattern at Southwest Pass, the ARGOS drifter will be launched directly into the discharge plume. Since Southwest Pass is the outlet for more water than any other pass, the drifter will provide an indication of the trajectory for a large fraction of the total discharge. A total of nine stations will be occupied on this phase of the cruise.

The second part of this phase (Phase IIb) will investigate the distribution of material at a sharp front between the Southwest Pass plume and the adjacent shelf waters. Two locations on the plume front will be sampled. One will be very near to the mouth of the pass (~5 km). The other will be further away (25-50 km). The same station pattern will be occupied at both these sites. The front will be approached from the plume side acquiring the underway data. Beginning at 1 km seaward of the front, a line of CTD and water bottle casts will be made perpendicular to the front. Stations on the seaward side of the front will be 1 km and 100 m from the front. On the plume side, stations will be at 100 m, 400 m, and 1 km. On the plume side of the front, a radar reflecting buoy, drogued to flow with the surface water, will be launched. The drogue will serve as a point of reference for the second transect. Upon completion of the first set of five stations, the ship will steam toward a position estimated to be approximately 1 km downstream from the first station on the seaward side of the front and a second line of stations will be occupied. The exact position of this second line of stations will be determined by the position of the frontal drogue. A total of 20 stations will be occupied. At each of the stations a CTD cast will be made and water samples will be collected at selected depths for analysis of biological and chemical parameters. Zooplankton tows taken parallel to the convergence zone will be made at all stations within the plume but at only one station per transect on the seaward side of the front.

Phase III Synoptic Scale (#2)

The final phase of the cruise will be a repeat of the first phase. This time the cruise track will be from the east to the west. An additional line of stations will be occupied along 89° 35' W. This line of stations will enhance the information gathered about the Southwest Pass plume. As a result of this addition, the line of stations running to the southeast out of Terrebonne Bay will be modified. It is on this third phase of the cruise that the pollutant chemistry samples and the majority of the biological samples will be gathered. An additional 24 zooplankton collections will be made (four of which will be repeat stations from Phase I) bringing the plume survey total up to 53. Water samples from the Mississippi River near Venice will be collected during the cruise for subsequent biological and chemical analysis. The analysis of the information gathered on the cruise will be made in conjunction with river discharge data and offshore weather data gathered from the C-MAN and Meteorological and Oceanographic Measurement System (MOMS) stations in the study area.

As a part of this phase we propose to collect and analyze a total of 174 discrete samples for trace metals and trace organics. (Details of the pollutant analyses are given in the presentation by Dr. J. Means). We propose to collect water samples 1 m below the surface and 1 m above the bottom at 29 stations surrounding the Mississippi River delta. The spacing of the stations along the transects will be determined by satellite imagery showing the size and configuration of the plume. Data obtained in this study will be used to compare with existing and future-released data from the U.S. Geological Survey Mississippi River study on metals and organics as well as be used to develop portions of the pollutant flux/transport model in Task B-4.

The collection of continuous ADCP data between stations will be important to the analysis of the physical and biological profile data which we will acquire in Phases I and III of the cruise. The underway ADCP data will provide the connection between stations that will enable us to more accurately determine the vertical structure throughout the study area. The ADCP data will be most useful in Phase II where it will provide the vertical dimension to complement and supplement the measurements made by MIDAS in the surface waters. An ADCP transect acquired by C. Ebbesmeyer (pers. comm.) across the Mississippi River plume has demonstrated that the system is able to discern details of the vertical structure in this area. In order to take maximum advantage of this capability and to overcome some of the feature smearing which results from the one to two minute integration time of the ADCP, we will alter the plume front crossing track for one crossing at each of the individual plumes sampled in Phase IIa. The research vessel will steam parallel to the front for two to four minutes, cross the front, and steam parallel to the front (on the second side) for another two to four minutes. In this manner we will acquire integrated data along a short transect where we expect the vertical structure to change slowly. This method should provide us with the best sampling of the details of the vertical structure across the front.

A summary of the cruise is provided in Table 15.2.

Table 15.2. Cruise Data Collection Summary.

No. CTD Stations	224
No. Biology Stations	71
No. Phytoplankton Samples	129
No. Zooplankton Samples	40
No. Pollutant Chemistry Stations	29
Estimated Cruise Duration- All Phases	11.5 days
Estimated Cruise Length	2925.0 km

RATIONALE

The rationale for a plume survey is that it is important to characterize the near-field discharge and mixing dynamics of a major contributor to the LATEX coastal boundary layer (CBL). The proposed cruise will be able to provide information about the synoptic distribution of such discharge associated parameters as temperature, salinity, suspended sediment, nutrients, and pollutants. This will be accomplished by the closely spaced pattern of transects and stations (Phases I and III) at which the required suite of measurements will be acquired. Specific questions to be answered include:

- What is the synoptic distribution of freshwater, sediment, nutrients, and pollutants delivered to the shelf by the Mississippi River?
- What is the variability of this synoptic distribution at short time scales (five to ten days)? How is this variability related to changes in the wind stress?
- Do the plumes of the major passes of the Mississippi River contribute directly to the CBL or only to a general freshening of the shelf?
- What is the form of the CBL in the Louisiana Bight (the area west of the Delta)?
- What are the changes in the character and distribution of the properties of the discharge waters as they are transported away from their source?

Questions about the nature of the discharge plumes of the individual major passes can also be addressed. The character of each of the three major passes (Pass a Loutre, South Pass, and Southwest Pass) is different. For example, each of these passes has a different sill depth. Pass a Loutre is not dredged so it is in a more or less natural state. South Pass and Southwest Pass are dredged to project depths of 5.2 m and 12.2 m, respectively. In addition, each pass debouches a different percentage of the total discharge. These variations should contribute to different characteristics of mixing, and this affects plume surface layer dimensions and interaction with the bottom. In turn, the different mixing characteristics should produce differences in biological communities and pollutant chemistry. Measurements in the discharge plumes of the three passes (Phase II) will provide information to answer the following questions:

- What are the relationships between the shape and dimensions of the major passes and the physical, chemical, and biological characteristics of their plumes?
- How is suspended matter distributed at the frontal edges of the direct discharge plume? Is the distribution uniform? If the distribution is not uniform, is the material trapped in the vertical circulation cell at the front or is it trapped at the pycnocline by convergence and density differences?
- What is the short term temporal variability of measured parameters at the plume frontal convergence zone? How are these changes related to growth or decay of the front?

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Dr. Lawrence J. Rouse, Jr. has been at Louisiana State University for over 19 years. He is presently an Associate Professor in the Coastal Studies Institute and the Department of Oceanography and Coastal Sciences. He is also Associate Director of the Earth Scan Laboratory, the National Oceanic and Atmospheric Administration environmental satellite earth station at Louisiana State University. His research interests are shelf and estuarine transport processes and analysis of these processes using remotely sensed data. Dr. Rouse received his B.S. in physics from Loyola University and his Ph.D. in physics from Louisiana State University.

BENTHIC BOUNDARY LAYER ELEMENT OF THE LATEX PLUME STUDY

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INTRODUCTION AND RATIONALE

The inner shelf is a friction-dominated environment in which bottom and seasurface boundary layers may overlap and occupy the entire water column. Hence, boundary-layer and more general inner-shelf research questions are closely intertwined. Benthic boundary layer processes influence particle fluxes in several ways: (a) they determine the bottom drag sensed by mean flows; (b) they determine the skin friction shear stresses sensed by sediment particles and, hence, frequencies and rates at which particles are dislodged from the bed and placed in suspension; (c) they determine the vertical diffusivity of sediment near the bottom and hence control near-bottom suspended sediment concentration

*As presented by Dr. Wilford D. Gardner

profiles; and (d) they determine the detailed vertical structure of cross-shelf and isobath parallel flows in the near bed region where suspended sediment concentrations are highest.

Interaction among currents, waves, rippled-bed morphology, and sediment characterize the inner shelf bottom boundary layer and cause enhanced hydraulic roughness and drag. In the shallow water of the inner shelf the wave-current interactions are intense, prevail for much of the time, and are often enhanced by the presence of sharp-crested wave-induced ripples. It follows that the along-shelf currents and momentum balance on the inner shelf, which depends very strongly on bottom drag, requires accurate estimates of bottom shear stresses. The Coastal Physical Oceanography working group meetings on "Inner-Shelf Exchange" and the "Benthic Role in Cross-Shore Transport" both identified wave-current dynamics in the bottom boundary layer as a critical element in understanding biological, physical, and geological processes on the inner shelf. Our planned observations will record the wave-current field, and the associated bottom stresses, suspended sediment concentrations, and changes in bottom level at an inner shelf site.

OBJECTIVES

The immediate objectives of the bottom boundary layer facet of the Texas-Louisiana Plume Study are

- to determine the bed stresses felt by cross-shelf and isobath-parallel mean currents;
- to determine the frequency and rate of sediment resuspension from the seabed into the water column; and
- to determine the rates of cross-shelf and isobath-parallel sediment fluxes near the bed and to identify the mechanisms responsible for those fluxes. The above objectives are considered intermediate steps leading to the broader goals of elucidating the space and time variability of cross-shelf and along-shelf sediment flux and sediment deposition and evaluating the relative contributions of surface plume transport versus bottom boundary layer transport.

FIELD METHODOLOGY

The main instrumentation for the boundary-layer field experiments will be one Virginia Institute of Marine Science (VIMS) comprehensive bottom boundary layer instrumented system. This system, as it has been configured in our earlier studies, has consisted of a tubular aluminum frame 2.0 m in height with a 3.0 m triangular base and 25 kilogram lead disks attached to each leg. Diver observations have shown that this tripod produces negligible scour. However, to further minimize flow disturbance we are presently constructing a new tetrapod frame made of thinner stainless steel tubing and having a greater elevation and wider base. As in our previous deployments, this tetrapod frame will support a current profiling system with four 2-axis electromagnetic Marsh-McBirney current sensors (3.8 cm probe diameter), a Datasonics sonar altimeter which operates at 300 kHz, and a Downing Optical Back Scatterance array with five infrared sensors used to obtain point measures of suspended sediment concentration at approximately 5, 10, 25, 50, and 100 cm above the bed. A sample of the suspended material is collected *in situ* for calibration purposes via a sediment trap.

The tetrapod has four current sensors mounted in a vertical array above the bed (10, 40, 70, and 100 cm). The Marsh-McBirney current sensors are individually calibrated in steady flows before each field deployment using the VIMS 18 m recirculating flume. Each axis of the spherical flow sensor is calibrated separately in both positive and negative flow directions. Calibrations of the optical backscatterance sensors using native sediment from the field site, collected during deployments via sediment traps mounted on the tripod at different elevations, show excellent linear fit throughout the concentration range from 0 g/l to 15 g/l.

All Sea Data and Onset data loggers on the tetrapod will be synchronized and programmed for burst-mode sampling. The interval between bursts will be two hours, burst duration will be 17 minutes, and the sampling interval within a burst will be 1.0 s. The meter at 40 cm elevation will be sampled at 5 Hz to permit application of the dissipation method for estimating bed shear stress.

DATA PRODUCTS

Data tapes and solid state memories will be transferred to disks following retrieval of the tetrapod. Three disk copies will be produced. One set of disks will reside at Louisiana State University, one set will be returned to VIMS for processing, and one set will be sent to Dr. Sternberg at the University of Washington for parallel processing. Upon return to VIMS, data will be archived on hard disk in the VIMS Prime 9955 mainframe and two additional disk copies will be made as backup. Data will be pre-processed and converted to engineering units with spikes removed.

ANALYSES

Two methods will be used to estimate bed shear stress and drag coefficients. Using the profiles of burst-averaged u and v values from the four levels of horizontal current measurement, we may apply the law of the wall to estimate friction velocity, and the roughness length experienced by mean flows. We also plan to sample one current sensor at 5 Hz and apply the inertial dissipation method (Kolmogorov spectrum law) to estimate bed shear stress. We will use a modified version of the technique which applies to the specific situation of combined wave-current boundary layers. We plan to use this method and, as a check on its reliability, to compare the results to results obtained from the "law of the wall." For comparisons, we will apply data on wave orbital velocities, mean flow velocities, and bed roughness to the Grant and Madsen wave-current boundary layer model. From a knowledge of grain size frequency distributions and settling velocities of bed material and material trapped at different elevations and of the friction velocity, the Rouse number will be calculated for several relevant size classes. A suspended sediment concentration model will be applied and compared to observed vertical concentration distributions. The total depth integrated suspended sediment flux can then be calculated once the vertical velocity and concentration distributions are known.

Dr. L. Donelson Wright is a Professor of Marine Science at the Virginia Institute of Marine Science, College of William and Mary, and specializes in geological oceanography. He received his Ph.D. degree from Louisiana State University, through the Coastal Studies Institute, in 1970; dissertation research focused on the dynamics of the Mississippi plume. His ongoing research is concerned with bottom boundary layer dynamics, sediment transport, and continental shelf morphodynamics.

Dr. Richard W. Sternberg is a Professor of Oceanography at the University of Washington. He received his Ph.D. degree in 1965 from the University of Washington; his dissertation dealt with bottom boundary layer dynamics. His current research is focused on nearshore dynamics, boundary layer processes, and sediment transport processes.

SEDIMENT TRAP ELEMENT OF THE LATEX PLUME STUDY

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INTRODUCTION

Current meters and particle sensors can be used to quantify the horizontal transport of suspended sediment. The purpose of deploying sediment traps is to measure the rate at which particles are settling to the seafloor from the advective flow plus the rate at which resuspended particles return to the seafloor. They also provide samples for compositional and size analysis of the settling material. These data can then be used to compare predictions of sediment resuspension from boundary-layer measurements.

OBJECTIVES

- To determine the fluxes of sediment to the seabed at several sites across the shelf.
- To determine the flux of material from the surface plume that may also contribute to the flux to the seabed.
- To obtain samples of settling material for analysis of particle size and chemical pollutants

for incorporation into calculations of sediment transport.

FIELD APPROACH

At the site of boundary layer studies, traps will be placed at three depths on an independent mooring in the vicinity of the tetrapod. Traps will be (1) just above the base of the plume, where present, but no closer than 3 m from the surface, to sample particles in the plume; (2) centered between the seafloor and base of the plume; and (3) one meter above the seafloor to collect both resuspended and plume particles. These fluxes are needed to compare with the predicted resuspension rates from the tripod to compare the sediment fluxes from the river plume versus resuspension of bottom sediments. To obtain a better view of the descriptive features of sediment transport and its relations to pollutant transport/redistribution and biological community impacts, we will add sediment traps to current meter moorings 14, 15, and 16 along 92° W and 17, 18 and 19 along 90.5° W during the first year of deployments (Figure 15.9). On the moorings at the 10 m contour (moorings 16 and 17) there will be two traps per mooring while the other four moorings will have three traps per mooring. Samples will be returned to Texas A&M University (TAMU) for analysis.

It is important to note some caveats in the use of sediment traps in shelf environments. Studies suggest that traps are unbiased collectors in currents where Reynolds' numbers (R = r.v.D/u, where r is water density, u is the velocity past the trap opening with diameter D, and u is viscosity) are less than 30,000 with a cylindrical trap aspect ratio (A = trap height to diameter ratio) of 8 (Baker *et al.* 1988). This would allow unbiased collections of particles in flows up to 40 cm/s for the 7.3 cm diameter cylinders we plan to use. Flows may occasionally exceed 40 cm/s on the shelf, but the work of Baker *et al.* (1988) may help correct for those times. All traps will have baffles at the top to decrease turbulence and to exclude organisms larger than 1 cm (see discussion in U.S. GOFS Report No. 10, 1989).

Another caveat in using traps in shelf environments is the overlap of the surface and bottom boundary layers. Turbulent planetary boundary layers have turbulent diffusion and secondary flow that can circulate particles through the boundary layer, (on the shelf, this can be the entire water column depending on stratification and current velocities) more than once before they settle to the layer below or to the seafloor. Therefore, trap measurements will likely yield overestimates of vertical flux in boundary layers. If our measurements cannot be used as measures of flux, we will still be able to use the samples collected to calculate relative fluxes, and to do compositional and size analyses in different segments of the boundary layer.

RESULTING DATA AND ANALYSIS

Samples will be analyzed for total mass fluxes, particle size distribution and percent organic carbon at TAMU. Fluxes will be compared to the predicted resuspension rates obtained from the tetrapod data. Data from adjacent current meters will be used to interpret and correct calculated fluxes. Portions of selected samples will be shipped to Louisiana State University for analysis of a suite of chemical pollutants as described in other portions of the Texas-Louisiana study. Samples at the tetrapod site will be integrations of conditions over the time of tetrapod deployment, while samples on moorings across the shelf will provide integrated samples over a much longer time, and will provide spatial coverage over different shelf regimes relative to the plume.

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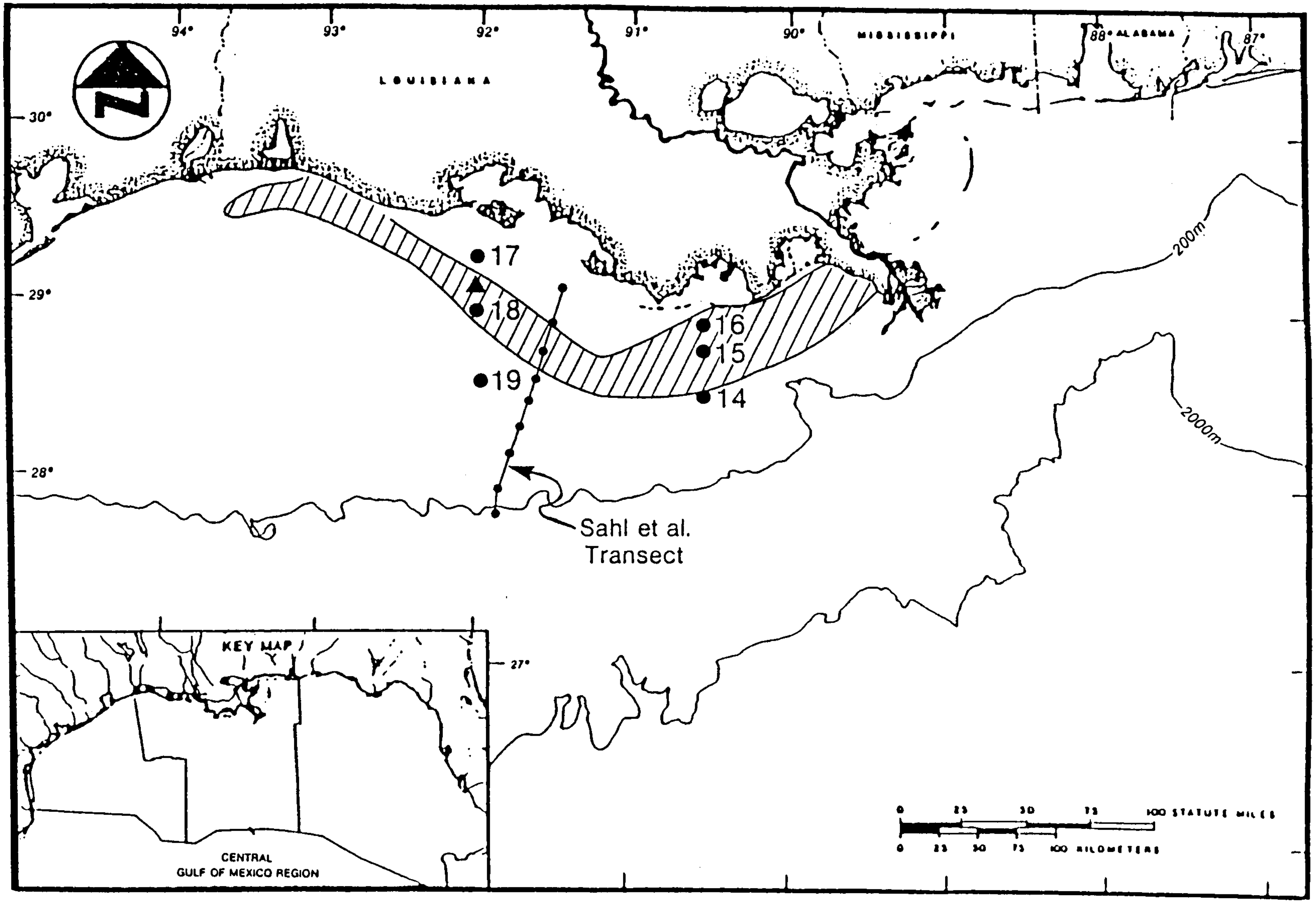

Figure 15.9. Proposed locations of the sediment traps.

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Dr. Mary Jo Richardson is an Associate Professor in the Departments of Oceanography and Geology at Texas A&M University where she has worked for the last seven years. Her research has centered on water column particle dynamics using sediment traps and particle sensors. Dr. Richardson received her B.S. in geology from Smith College and her Ph.D. in oceanography from the Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program in Oceanography. She is the recent recipient of National Science Foundation's new Faculty Awards for Women, a five-year award granted to only ten women nation-wide in earth sciences this year.

BIOLOGICAL SAMPLING IN THE MISSISSIPPI RIVER PLUME HYDROGRAPHY, TASK B OF LATEX STUDY

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The sampling on this subtask of the Mississippi River Plume Hydrography, Task B of the Texas-Louisiana (LATEX) research project is primarily concerned with the water column biology and chemistry. The general project objectives, cruise schedule, and station locations are discussed elsewhere in this session (see S.P. Murray in this volume). The parameters to be sampled in this part of the project include general water column chemistry (nitrate, nitrite, phosphate, silicate, and ammonia), indicators of phytoplankton community characteristics and species assemblages, and the light field (Table 15.3). The anticipated usefulness of these data collections includes the characterization of various water masses, calculation of mass transport, and an ecological analysis of how the biologic, physical, and chemical components are related.

Previous studies have focused primarily on regions near the Mississippi River delta. Less is known about the phytoplankton community and its milieu towards the west of that river, in the coastal boundary layer, or of other river plumes, especially the Atchafalaya River. River plumes contain characteristic assemblages of phytoplankton, which are markers for freshwater input and high, nutrient-induced productivity (Dortch 1991). These organisms are usually distinctly different from those found in offshore, less productive waters. This is particularly true of the Mississippi River which contributes large amounts of nutrients to the otherwise oligotrophic Gulf of Mexico. Data from cruises over the last three years in the near-field Mississippi River plume indicate four distinct phytoplankton groups (Table 15.4) that are associated with waters of different productivity (Dortch, unpublished). In addition, the occurrence of hypoxic bottom waters may be directly related to the sinking of diatoms produced *in situ* (Dortch *et al.* 1991; Rabalais *et al.* 1991; Turner and Rabalais 1991).

Descriptive analyses include the development of photosynthesis–irradiance (PI) curves, which include both alpha and Pmax values; and an examination of photosynthetic pigments, PI ratios, and nutrient ratios (DIN:Si:Ortho-P) within various water masses (x, y, and z), along salinity gradients, and temporally between sampling cruises and from other existing data sets. Integration of descriptive relationships with other program elements (zooplankton, phytoplankton, and hypoxia) will also be conducted.

*As presented by Dr. Nancy Rabalais

Table 15.3. Data Collection Efforts.

Examples of Data to be Collected	Method Used
natural fluorescence	handheld fluorometer
simulated *in situ* primary production	light boxes, *in situ* meter
attenuation coefficients	from light profiles
pigments (Rabalais)	spectrophotometric/fluorometric
nutrients	autoanalyzer
suspended particles (all)	filtration/gravimetric
phytoplankton species	size-fractioned; epifluorescence microscopy
bacteria	epifluorescence microscopy

Table 15.4. Associations of Phytoplankton Typical of Specific Zones of Productivity in the Mississippi River Plume.

- Freshwater input - transported from origin
  Phycocynanin containing small (1-2 μm) cynanobacteria
  Typical freshwater algae including diatoms and chlorophytes
  e.g., *Asterionella formosa*
  Scenedesmus sp.
  Pediastrum sp.

- Highly productive/intermediate salinity - transported from origin
  Moderately to heavily silicified diatoms
  e.g., *Thalassionema nitszchioides*
  Skeletonema costatum
  Nitszchia pungens

- Moderate productivity/intermediate salinity - not transported
  Lightly silicified diatoms
  e.g., *Ceratulina pelagica*
  Rhizosolenia fragilissima
  Rhizosolenia alata
  Rhizosolenia deliculata

- Low productivity/high salinity - not transported
  Small (<8 μm) autotrophic flagellates
  Large (>8 μm) heterotrophic dinoflagellates
  Phycoerythrin-containing small (1-2 μm) cyanobacteria

Interpretive data analyses include a spatial and temporal examination of nutrient relationships, especially with regards to results derived from phytoplankton nutrient limitation experiments developed from other programs and from atomic ratios. Empirical and statistical interpretations of water masses will be made using all program elements, especially from the phytoplankton species composition. The influence of fronts on water column chemistry and biology within and along the coastal boundary layer will also be examined.

Besides providing specific information to the Minerals Management Service program, this data will greatly extend both the spatial and temporal coverage provided by the Louisiana Board of Regents Louisiana Stimulus for Excellence in Research (LaSER) and Nutrient Enhancement Coastal Ocean Program (NOAA) programs. We are looking forward to the large-scale integration of the efforts of all discipline interests in the project and expect it to greatly expand our knowledge of these coastal waters from both process-oriented and descriptive points of view.

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Dr. Quay F. Dortch has been at Louisiana Universities Marine Consortium since 1986. She is currently an Associate Professor. Her research interests include the effects of nutrient inputs on algal species composition, eutrophication, and hypoxia. She received her Ph.D. in oceanography in 1980 from the University of Washington.

ZOOPLANKTON CHARACTERIZATION ELEMENT OF THE LATEX PLUME STUDY

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Louisiana State University

INTRODUCTION

An organizational and methodological plan for the zooplankton component of Task B from the Minerals Management Service (MMS) Texas-Louisiana (LATEX) Physical Oceanography Program was presented and discussed. The objective of this component is to respond to the request to conduct a limited-scaled survey of the zooplankton with the intent to support the other disciplines in their characterization of water masses and the gross identification of operative processes in the Mississippi/Atchafalaya extended plume which is sometimes called the LATEX coastal boundary layer (CBL).

BACKGROUND

Although the major thrust of this recently awarded (October 1990) program is physical oceanography, the Mississippi-Atchafalaya extended plume is extremely interesting and important from the biological perspective as well. The physical structure of this zone (Figure 15.10) often plays a major role in the distribution and abundance of the planktonic stages of a number of commercially important invertebrate and vertebrate species (Figures 15.11-15.13).

METHODS

A maximum of 250 zooplankton stations (samples) will be taken over the entire field effort (197 in Task B-3 and 53 in Task 8) which consists of six 10-day cruises.

We will conduct a general workup for the invertebrate zooplankton from every other station (i.e., down to the family level) with some selective instances of more detailed work on those species which show characteristic responses to the CBL and also have pertinency to upper level trophic dynamics (e.g., *Acartia tonsa*). Additional invertebrate zooplankton information will be provided by mapping estimates of size fractionated biomass using displacement volumes (Yentsch and Hebard 1957) or dry weights from plankton nets of the appropriate mesh sizes. Half splits (Van Guelden *et al.* 1982) of all zooplankton samples will be archived and be made available to future MMS shelf community/ecosystem studies.

Zooplankton sampling will consist of oblique tows involving a 60-cm bongo net fitted with a flow meter and 153 and 333 μm mesh plankton nets and an attached 20-cm ring fitted with a 63 μm net. Plankton tow duration is obviously limited by the filtration efficiency of 63 μm mesh net. All zooplankton collections will be split in half with a Folsom plankton splitter. One half sample from each net will undergo zooplankton biomass estimation (zooplankton displacement and/or dry weights). The remaining half sample from the 63 μm net (for every other stations this half split will be minus the recorded subfraction used in taxonomic workup) and the 153 μm net will be archived for any future zooplankton enumeration or ecosystem studies. The second half of the 333 μm net will have its larval fish identified to the lowest taxonomic level feasible.

Zooplankton samples will be field fixed in either 10 percent buffered formalin or 90 percent ethanol and changed over to 70 percent ethanol within 24 hours for long-term storage, a preservation methodology suitable for later larval fish otolith analyses under supplemental or complementary studies. Once the zooplankton samples have been picked, sorted, identified, and enumerated, the data will be entered into an IBM personal computer and quality proofed for subsequent analyses.

Some consideration of the vertebrate component of the zooplankton is timely and will maximize synergistic interaction with other national initiatives on line or coming on line for the southeast United States and the Gulf of Mexico, e.g., National Oceanic and Atmospheric Administration's Southeast Atlantic Bight Recruitment Experiment (SABRE) and CRESCENT, and will also complement a MMS fisheries initiative entitled "Study of Platform Associated Fisheries Resources" earmarked for the Central and Western Gulf and outlined in Outer Continental Shelf Report MMS 90-003. Our proposed data collection will also directly complement and supplement a substantial ichthyoplankton data collection undertaken by Dr. Shaw in and around the Mississippi River plume during the five-year LaSER Program.

This approach is valuable on several different levels: (1) the historical data base on ichthyoplankton is large (see Ditty *et al.* 1988 for review) with a number of shelf transport, CBL, and shelf-estuarine exchange studies (Shaw *et al.* 1982, 1985a,b, 1988a,b; Cowan 1988; Cowan and Shaw 1988, 1990; Cowan *et al.* 1989; Holt *et al.* 1989; Wiseman *et al.* 1986; Dagg 1988 for pertinent CBL/biological interactions); (2) the vertebrate zooplankton can show distinct across-shelf distributions (Shaw and Drullinger 1990a,b) often having distinct affinities for water masses especially around or within gyres, eddies, plumes, and fronts (Bakun and Parrish 1981; Richardson 1981; Atkinson and Targett 1983; Govoni *et al.* 1983; Townsend 1983; Cote *et al.* 1986; Sakamoto and Tanaka 1986; Govoni *et al.* 1989; Shaw and Drullinger 1990 a,b); and (3) by utilizing otolith methodology, larval fish can be reliably aged (daily), birth dates determined, and if spawning areas are well delineated (e.g., along a particular

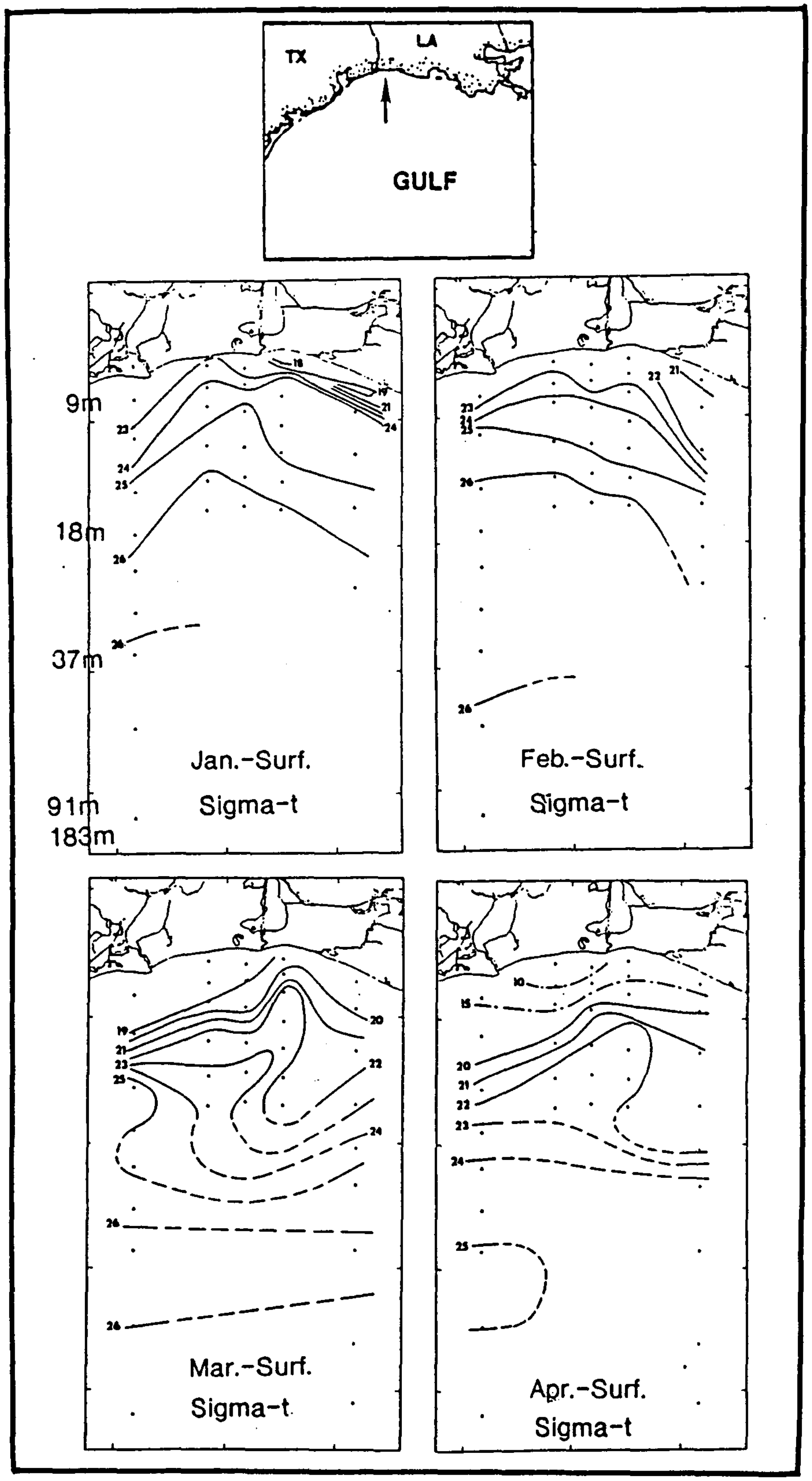

Figure 15.10. Patterns of surface sigma-t from transects taken off the Texas-Louisiana border during January through April 1982.

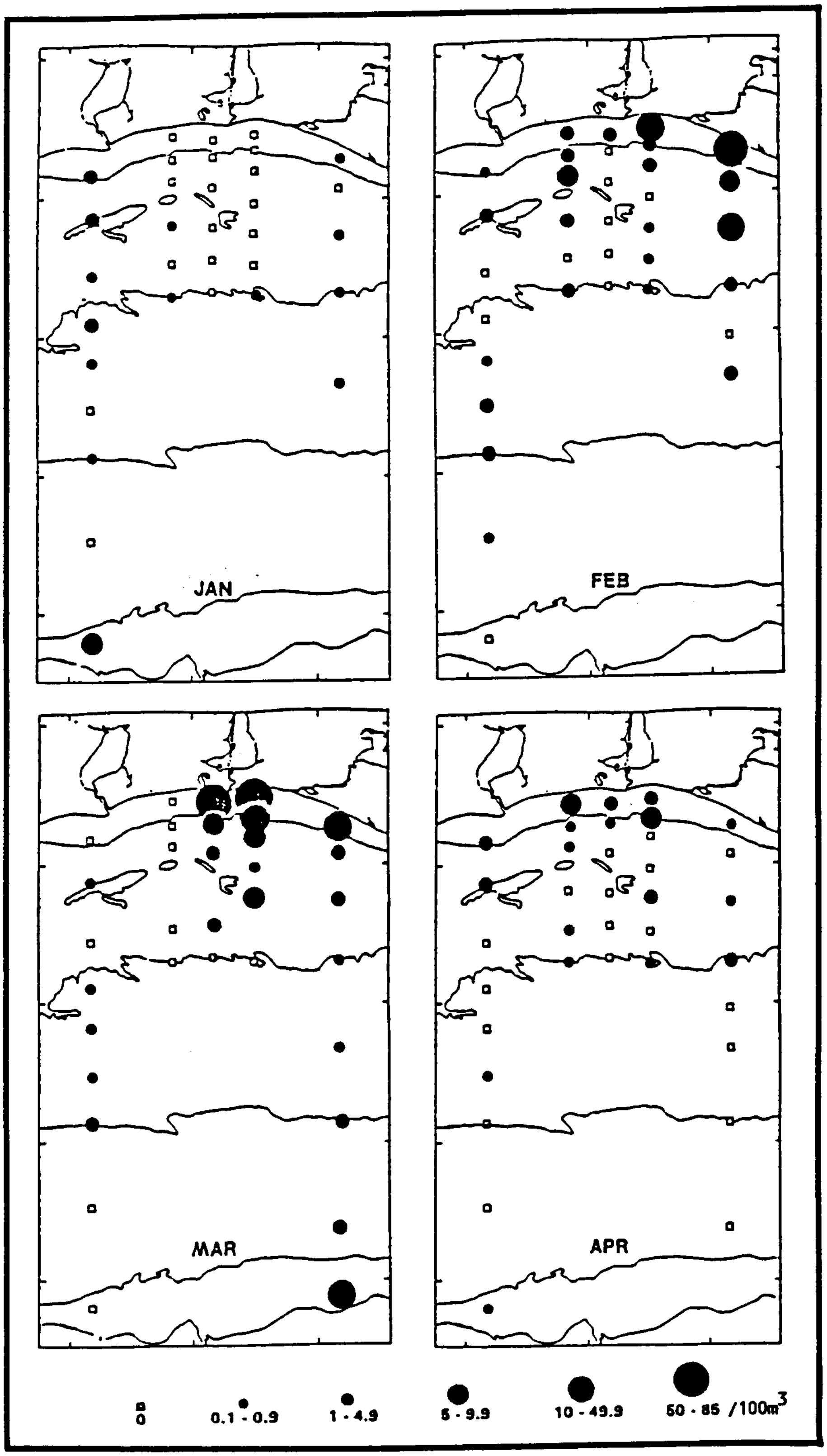

Figure 15.11. Sampling grid showing offshore station locations and transects A-E off the Texas-Louisiana border during January through April 1982. (Shown are *Penaeus aztecus* [brown shrimp].)

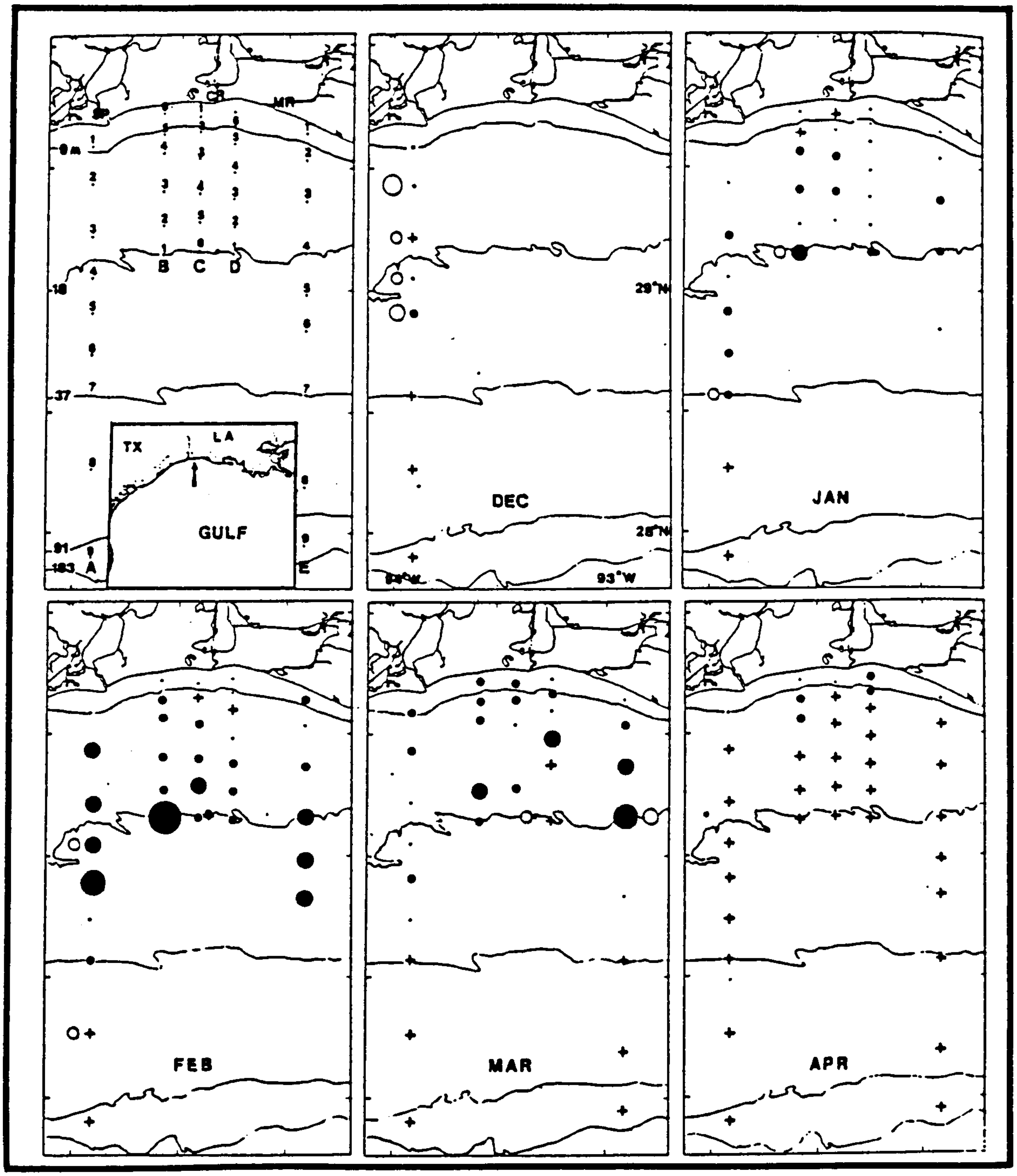

Figure 15.12. Sampling grid showing station locations (SP, Sabine Pass, Teas; CR, Calcasieu River, Louisiana; MR, Mermentau River) and *Brevoortia* egg and larval densities per 100 m³ from December 1981 to April 1982. (Larval densities [closed circles] are as follows: + = 0, • = 1-10, = 11-100, = 101-500, = 501-1,000, = > 1,000. Egg densities [open circles]: = 1-25, = 25-100, = 100-200. All other station egg values are zero.)

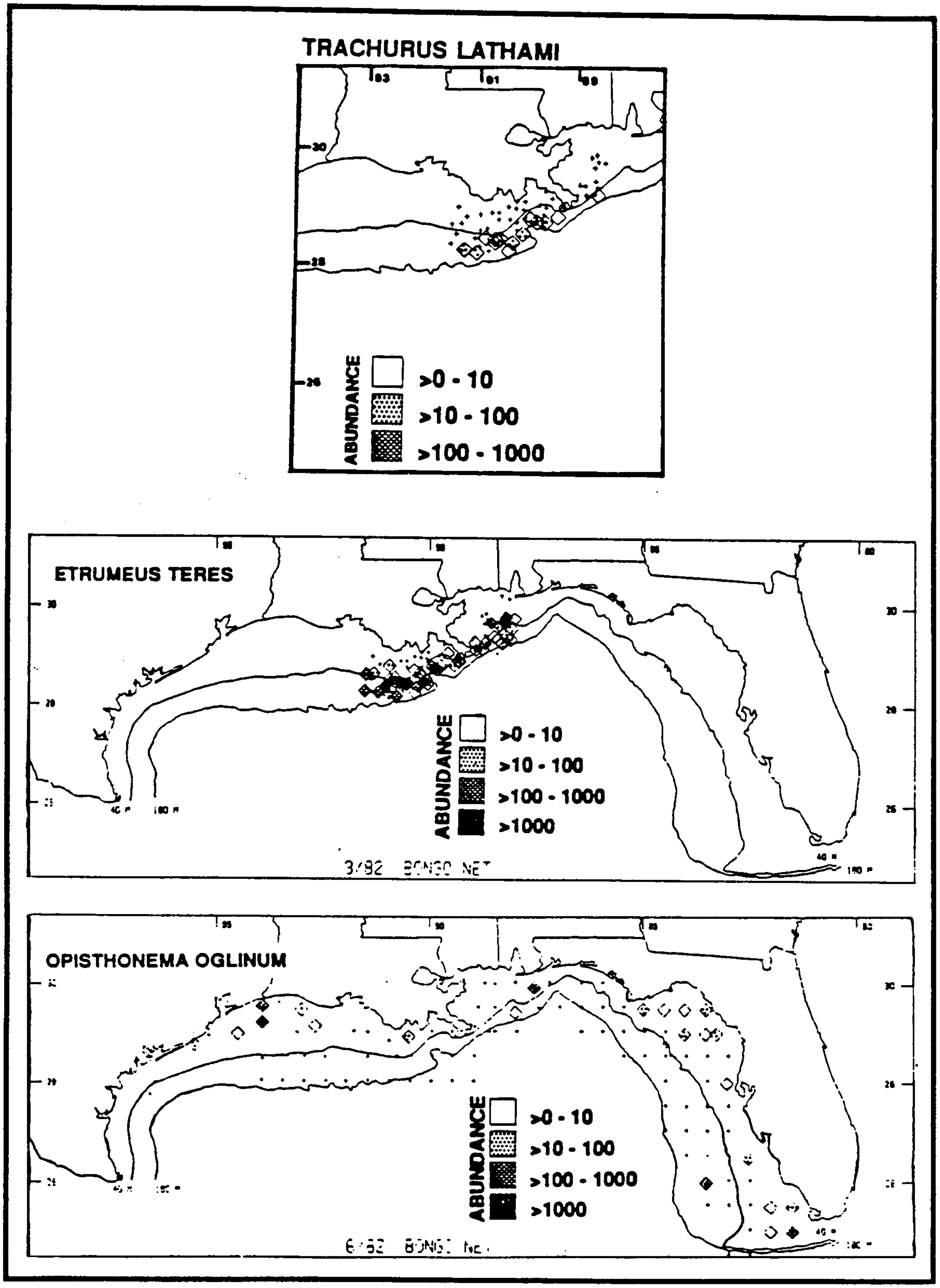

Figure 15.13. Distribution and abundance (no./10 m^2) of *Trachurus lathami, Etrumeus teres,* and *Opisthonema oglinum* larvae during March and June 1982 SEAMAP bongo net collections. ("+" represents stations sampled. Taken from Shaw and Drullinger 1990a, b).

depth contour) then downstream transit times can be calculated thereby generating supplemental lagrangian estimates.

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HYPOXIA COMPONENT: MISSISSIPPI RIVER PLUME HYDROGRAPHY LATEX PHYSICAL OCEANOGRAPHY PROGRAM

Dr. Nancy N. Rabalais
Louisiana Universities
Marine Consortium

INTRODUCTION

The distribution and dynamics of the oxygen-deficient bottom waters prevalent on the Louisiana shelf and sometimes upper Texas coast are intimately tied to the Mississippi and Atchafalaya River effluents and the coastal boundary layer. Density stratification is a function of surface water salinities which reflect the freshwater input of the Mississippi and Atchafalaya Rivers. The organic matter which fuels decomposition and the depletion of bottom oxygen most probably originates from surface phytoplankton biomass, but the contributions of the surface plumes of the Mississippi and Atchafalaya Rivers and the coastal boundary layer are not known.

Zones of critically depressed dissolved oxygen conditions in the northern Gulf of Mexico may cover up to 9,500 km^2 during mid-summer on the inner continental shelf (Figure 15.14) (Rabalais *et al.* 1991). The zones of hypoxia are continuous, widespread, and persistent, and may envelop up to 40 percent of the water column in 10 to 30 m water depth. Hypoxic bottom waters are present on the southeastern Louisiana shelf from mid-April through mid-October. The temporal variability of hypoxia on the southwestern Louisiana shelf is less well known, but hypoxic bottom waters have been recorded in July of most summers since 1981 (Gaston 1985; McKinney *et al.* 1985; Pokryfki and Randall 1987; Rabalais *et al.* 1991; Rabalais *et al.* in press).

Oxygen-deficient bottom waters on the northern Gulf of Mexico shelf are maintained by an intense and persistent salinity-controlled pycnocline resulting from large coastal freshwater inputs and weak wind mixing and strong solar heating during the summer months. The low salinity waters of the coastal boundary layer are separated from the mid-shelf waters by an intense salinity front. Wind events affect this frontal boundary and the distribution of the adjacent hypoxic water mass. The migration of a convergence region along the upper Texas coast and onto the Louisiana coast modifies the strong pycnocline which intersects the seabed and possibly the breakdown of the physical structure that maintains hypoxic waters.

Besides the physical features which control hypoxia, seasonal oxygen depletion in the northern Gulf of Mexico is linked to increased nutrient inputs, the transport of organic materials from surface to bottom waters, and the decomposition of organic materials and depletion of oxygen levels in near-bottom layers isolated from oxygenated surface layers below a strong pycnocline. The principal source of the organic matter respired in the bottom waters appears to be from phytoplankton production in surface waters.

OBJECTIVES OF STUDY

The objective of the hypoxia component of this program is to define the occurrence and extent of hypoxic bottom waters within and just seaward of the coastal boundary layer, with particular attention being devoted to this task during the hydrographic surveys conducted in the summer months. Additionally, because bottom water hypoxia has been recorded on the Louisiana shelf as early as mid-April and as late as mid-October, the distribution of hypoxia will also be available from hydrographic and near-field plume cruises which span this time frame.

Further objectives include

- Definition of the distribution of hypoxia in relationship to the physical structure of the water column and the coastal boundary layer.
- Relationship of low dissolved oxygen in bottom waters with the hydrographic data collected on the hydrographic cruises.
- Configuration of the hypoxic water mass in relationship to local wind patterns and current meter measurements.
- Relationship of hypoxic water masses to the Mississippi and Atchafalaya River plumes and the coastal boundary layer as characterized in the remote sensing work.
- Comparison of the distribution of hypoxic bottom waters to that of previous years where systematic surveys have been conducted (e.g., Rabalais *et al.* conducted in 1985-1991; Pokryfki and Randall 1987).
- Determination of short-term spatial differences in the distribution of hypoxic bottom waters in July as defined from the hydrographic cruises compared to that obtained from the Rabalais, Turner and Wiseman "Hypoxia Monitoring" studies of the National Oceanic and Atmospheric Administration, Nutrient Enhanced Coastal Ocean Productivity program within one week prior or after the Texas-Louisiana (LATEX) cruise.

SAMPLING AND METHODOLOGY

Hydrographic surveys will be conducted as part of Task B-3, General Hydrography. Bottom water hypoxia is most likely to be widespread and persistent on the LATEX shelf during June through August. One of the hydrographic cruises each year will be made during mid-July. At locations where

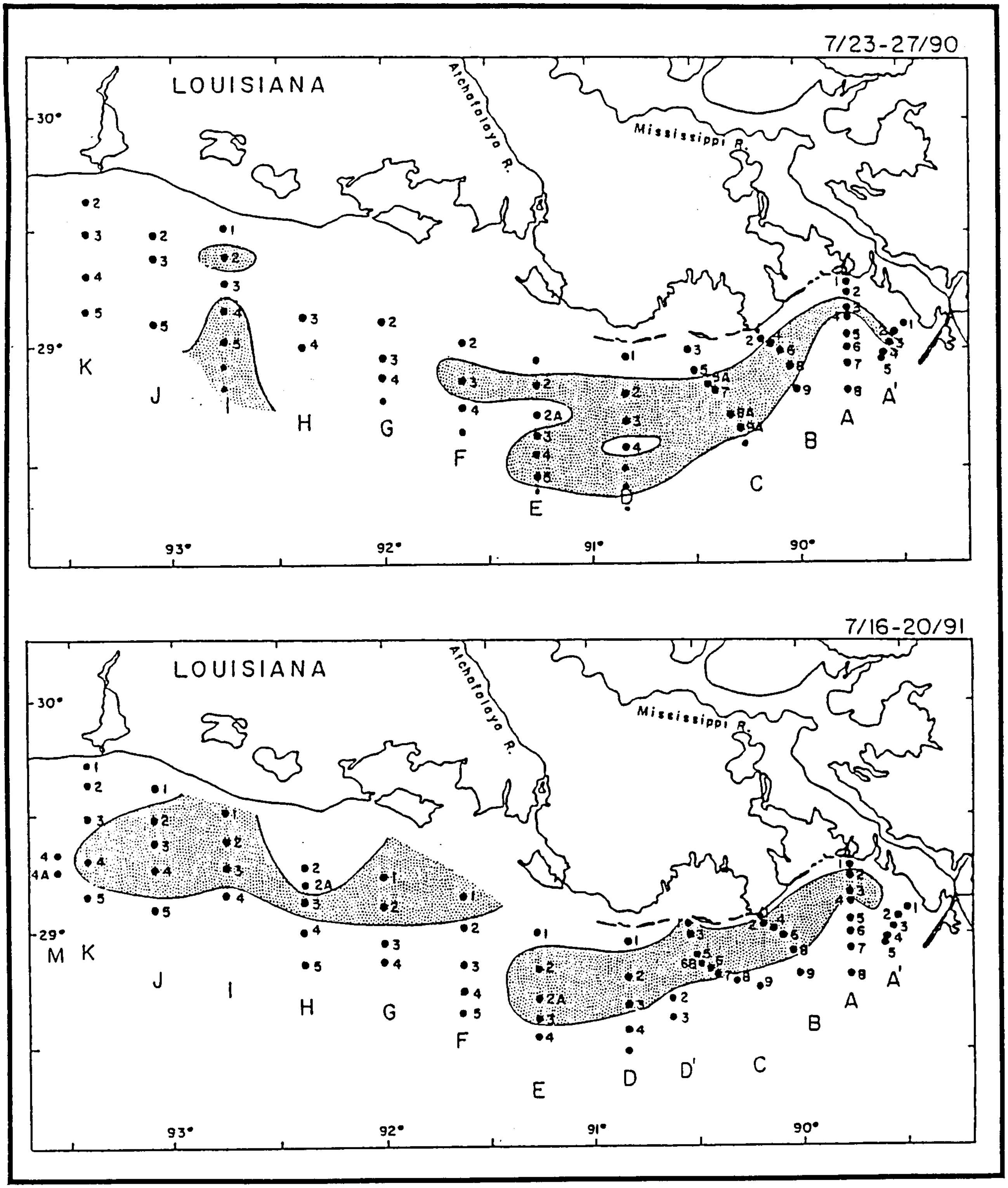

Figure 15.14. Distribution near-bottom water hypoxia (<2 mg/l dissolved oxygen) for dates and years shown (from Rabalais *et al.* in press).

bottom water hypoxia is likely to occur, longer survey transects will be run in an offshore direction to define the occurrence and extent of hypoxia within the coastal boundary layer and seaward. The hypoxia zones will vary from year-to-year in dimension.

Standard, continuous water column profiles, including dissolved oxygen, will be collected with a SeaBird conductivity/temperature/depth (CTD) unit. At stations where hypoxia is likely to occur, the speed of lowering of the CTD unit will be slowed to the minimum possible, to allow for equilibration of the dissolved oxygen (DO) sensor. For each cruise, a cross-calibration curve for the CTD/DO probe will be determined from water samples collected from the rosette and titrated by Winkler methods. Where near-bottom water values fall below 2 mg/l, a rosette-collected water sample will be titrated routinely by the Winkler method for DO concentrations. This is likely to occur most often on the mid-summer cruises and less frequently on the spring and fall cruises.

During the mid-summer hydrographic surveys when hypoxia is likely to occur, samples for phytoplankton systematics will be collected at selected stations for the transects which extend into hypoxic waters. Phytoplankton systematics (Q. Dortch, LUMCON) will be used to trace the source of the material fueling hypoxia, probably large diatoms. The source areas will be studied under the general hydrography task, but data from the hypoxic area is required to establish a link with the source areas and to determine mechanisms of transport.

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DATA MANAGEMENT AND INFORMATION TRANSFER ELEMENT OF THE LATEX PLUME STUDY

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The processing, archiving, and transmission of data and results from a scientific project are best accomplished when the procedures are well thought out, integrated with each other, and practiced in advance. In this section I will report on the goals and plans that have been made regarding (1) Data Processing and Data Management (2) Quality Assurance and (3) Information Transfer to achieve these ends.

DATA PROCESSING AND DATA MANAGEMENT

To meet the overall goals of the project, our data management objectives are to insure the following:

- centralized data management,
- no loss of data,
- extensive and consistent data quality assurance/quality control (QA/QC),
- data processing and analysis utilizing uniform and standard procedures, hardware and software,
- rapid access to program data by all program personnel and Minerals Management Service (MMS), and
- efficient transfer of data and standard products from data management group to key personnel, MMS, and NODC.

Data Acquisition

Aboard the hydrographic survey vessel, the chief scientist will maintain a master cruise log noting any and all data acquisition problems, cruise decisions, and overall cruise performance. The log will be created with the daily input from the leading personnel of all disciplines aboard. From this log, including individual investigator logs, notations appropriate to each data set will be collected and maintained at the central data facility. The log will be electronically backed up regularly and a paper copy of all updates created each day. A text version of this electronic log will be "published" on the Louisiana State University (LSU) network after each cruise.

Louisiana State University Database

The primary mode of storage and analysis of the data will utilize the LSU network. Computer access will be configured so that each investigator associated with the project will be issued a unique logon identification (ID) and password. Data sets will be configured to allow read only, or read/write privileges for various combinations of logon ID's thus protecting data from contamination while allowing each researcher maximum flexibility in access to the data and programs. A logon ID and appropriate access privileges will be provided to the sponsoring agency in order to allow 24 hour access to the status of the data.

All data and program files associated with this project will be stored on line and available 24 hours/day. Access to the data and programs will be restricted to logon ID's and passwords assigned to this project only. In addition, a log of all attempts (successful as well as unsuccessful) to access the data sets will be automatically kept and these records will be reviewed by the data manager on a monthly basis.

Table 15.5 contains a list of parameters for which data are to be acquired as well as the standard data products to be generated. This table also contains the standard QA/QC tests which will be performed on each parameter. We will require that all instrument calibration sheets and researcher notes concerning data acquisition as well as the cruise notes be on file at the central data management facility.

"Publishing" the data on the LSU network means writing the most accurate version of the data for a parameter in a standardized format to a write protected data set. The data are now available for the production of standard data products as well as for acquisition by investigators for subsequent analysis. When a data set has been "published" it will be given a revision number and announced data on LSU network "bulletin board", announced at monthly Principle Investigator (PI) meeting, and posted on GULF.MEX.

It is anticipated that all parameters will be "published" within three months of the completion of a cruise. If this deadline for publication will not be met for a particular parameter, a notice will be posted on the "bulletin board" indicating the problems encountered and the anticipated publication date. Copies of this notice will be forwarded to the contractor.

Table 15.5. Standard Data Products and Quality Assurance.

Parameter	Instrumentation	Standard Product Treatment *										QA/QC Treatment **								
		I	II	III	IV	V	VI	VII	VIII	IX	X	I	II	III	IV	V	VI	VII	VIII	IX
nutrients	autoanalyzer	X	X	X				X				X					X			X
natrual flourescence	PNF light profiler	X	X			X						X					X			
primary productivity	PNF light profiler	X	X			X		X				X					X			X
photosynthetically active radiatio	PNF light profiler	X	X			X						X					X			
extinction coefficient	PNF light profiler	X	X			X		X				X					X			
upwelling irradiance	PNF light profiler	X	X									X					X			
temperature	PNF light profiler	X	X					X				X					X			
secchi depth	secci disc	X							X			X								
zooplankton	paired tows	X							X			X								
pollutant chemistry	30 liter water sampler	X										X								
temperature at transducer	ADCP @ surface						X										X			
backscatter	ADCP @ dz = 1m				X	X						X					X			
u current component	ADCP @ dz = 1m	X			X	X						X					X			
v current component	ADCP @ dz = 1m	X			X	X						X					X			
weather log	ROSCOP format observations	X										X								
u and v time series	Bottom Boundary Layer Tripod						X					X					X			
pressure	Bottom Boundary Layer Tripod						X					X					X			
suspended sediment	Bottom Boundary Layer Tripod						X					X							X	
minitrap sampling	Bottom Boundary Layer Tripod											X								
vertical particulate flux	Sediment Traps	X	X									X				X			X	
satellite data	Earth Scan Laboratory				X					X	X	X								
chlorophyll A	fluourometer	X		X	X	X		X				X					X		X	
conductivity	CTD "Sea Bird"		X	X	X	X						X	X	X	X		X			
temperature	CTD "Sea Bird"		X	X	X	X						X	X	X	X		X			
salinity	CTD "Sea Bird"		X	X	X	X						X	X	X	X		X		X	
dissolved oxygen	CTD "Sea Bird"		X	X	X	X						X	X	X	X		X		X	
backscatter	CTD "Sea Bird"		X	X	X	X						X	X	X	X		X			
transmissivity	CTD "Sea Bird"		X	X	X	X						X	X	X	X		X		X	
downwelling irradiance	CTD "Sea Bird"																	X		
fluourescence	CTD "Sea Bird"	X	X	X								X					X			
phytoplankton systematics	CTD "Sea Bird"	X										X					X			
suspended particulates	water sampler	X										X								
Loran	MIDAS							X				X					X			
Salinity	MIDAS											X					X			
temperature	MIDAS							X				X					X			
chlorophyll	MIDAS			X				X				X					X	X	X	
turbidity	MIDAS							X				X					X			

*** Product Treatment**

I Printout in tabular format
II Parameter vs. depth plot
III Selected constant depth sections contoured
IV Selected longshore sections contoured
V Selected cross-shore sections contoured
VI Time series plot
VII Parameter vs. salinity plot
VIII Plot on project base map
IX Gulfplot formatted maps
X Profiles of remotely sensed surface temperature and albedo

**** QA/QC Treatment**

I Visual inspection of plot/table
II Flag all points outside one standard deviation
III Test for electronic drift
IV Vert. ave. value of profile against seasonally adj. expected value assigned pre-cruise
V Fit linear or log trend and flag points +/- one standard deviation from trend
VI Test for spikes, outliers
VII Compare results of duplicate instrumentation where stations overlap
VIII Comparison to and/or correction by analysis of water sample(s)
IX internal controls - blind duplicates

Data sets will be configured with all of the data which have been "published" on the LSU network available at all times. The data management group will provide copies of data to investigators on DOS or Macintosh disk or on 9 track magnetic tape as they are requested. These requests will be processed in a timely manner. It should be emphasized however, that all data can be down loaded via BITNET, INTERNET, or modem connection at any time.

An information sheet will be written which will give step-by-step instruction for logging on remotely to the LSU network. In addition, assistance will be provided by the data management group to researchers requesting assistance in establishing a logon procedure from their remote site.

Standard Data Products

Table 15.5 details the standard products which will be produced for each parameter. Many of the computer programs to generate these products already exist. The data management group will work with Evans-Hamilton, Inc. prior to the first cruise to standardize the products and create a basemap for the project. All products will be generated under the supervision of the data manager and each product will be visually reviewed by the data manager before it is released. The data products will be generated within three months of the completion of a cruise. If this deadline for standard products will not be met for a particular parameter, a notice will be posted on the "bulletin board" indicating the problems encountered and the anticipated date for standard product generation. Copies of this notice will be forwarded to the contractor.

Data Set Updating

If errors are reported for data after a given parameter has been "published" on network database:

- a written data exception report will be sent to/from senior scientist;
- data will be edited only on written approval of senior scientist and data manager;
- all data exceptions will be reported in writing to Dr. S.P. Murray, Program Manager;
- if data is edited a new data set with a new revision number will be "published' on network database;
- the old data set will be removed from network database
  - it will be archived with documentation of error
  - it can only be accessed with written approval of the Program Manager;
- a notice of data change will be posted on the LSU network "bulletin board"; and
- a written notice to all principal investigators will be distributed at the monthly staff meeting.

Backup Procedures

Backup of disk data sets and programs on the LSU network will occur twice a month utilizing the 6250 bpi tape drives and standard labeled tape password security of the LSU IBM system. This security system can be configured so that a user logon ID must be supplied whenever tapes are read and/or written to, eliminating the chance that a data tape will be erroneously mounted for another user's job. A verification program will be run after each backup and duplicate copies of all tapes will be stored off site at all times. Backup tapes will be rotated so that there will always be two consecutive months of backup tapes available at all times.

After they are generated for mailing to the Records Section of NODC, three additional sets of NODC archiving forms and data tapes will be made. One will be located in project office, one stored in the tape library at SNCC with the above mentioned standard labeled security, and one will be mailed to Dr. Guinasso at Texas A&M University.

The Earth Scan Lab will provide for data management, duplicate copies of all 35 mm. slides generated for the project. These slides will be kept in chronological order in a locked cabinet in the data management office. A log will be maintained of all scenes which are electronically or visually reviewed by the Earth Scan Lab. The data management group will archive a separate copy of this log which will be updated on a monthly basis. If a scene is selected for additional processing or analysis, the portion of the scene selected and the pertinent scaling factors and commands will be saved to disk. In addition, any scene for which a telemail transmission is generated will be saved to disk. These scenes will be backed up to 6250 bpi tape on a weekly basis. Duplicate copies of these backup tapes will be stored in the data management office.

All telemail transmissions regarding project data, including but not limited to those generated by the Earth Scan Laboratory, will originate from the data management office. Before the telemail transmissions are sent, they will be reviewed by the data manager for reasonability. The only exceptions to the above policy will be during the intensive interactive analysis and communication which will be generated by the Earth Scan Lab during "squirt alerts" and cruises. During these periods, all transmissions on telemail which are not transmitted from the data management group will be copied to the data manager for review. Copies of all transmissions will be reported in writing to the Program Manager in the monthly Project Management Staff meeting. In addition, all transmissions will be back-upped on diskette and archived in chronological order in the data management office.

QUALITY ASSURANCE/ QUALITY CONTROL

The Data Manager will be responsible for overview of the team's overall QA/QC program. At least quarterly during the data acquisition portion of the project, she will visit each Principal Investigator's laboratory facilities while sample or data processing is taking place to review:

- instrument calibration procedures and history,
- how sample processing and data reduction QA/QC procedures are being followed,
- to discuss any errors (consistent or otherwise) which are appearing in the data sets,
- to assist in determining if any equipment is in need of repair or replacement,
- to ensure that documentation of QA/QC activities is occurring properly,
- to ensure coordinated transfer of QA/QC results throughout our team and to MMS and other LATEX contractors as appropriate, and
- to provide good communication concerning data quality or problems throughout all team members.

The Cruise Chief Scientist, Dr. Curtis C. Ebbesmeyer or his replacement, will lead the onboard QA/QC efforts to ensure proper instrument operation, accurate data collection, and onboard sample processing. Instrumentation in use will be calibrated and checked by each PI utilizing the instruments and who are the most familiar with the instruments and their proper operation.

Quality assurance will be an overall team priority focused at ensuring that specific QA/QC procedures for specific equipment and measured parameters are appropriate and followed throughout the course of this program, that any new standard QA/QC techniques developed within the scientific community affecting this program are integrated into our QA/QC plan, and that our QA/QC efforts and results are well documented and brought to the attention of MMS and all interested scientists so that each knows of any data problems and corrections immediately. To this end, QA/QC will be a line item on the agenda of every monthly principal investigators meeting.

Table 15.5 contains a list of parameters for which data are to be acquired and the standard QA/QC tests which will be performed on each parameter. We will require that all instrument calibration sheets and researcher notes concerning data acquisition as well as the cruise notes be on file at the central data management facility. These notes will be reviewed as the statistical QA/QC is run on the data.

All instruments utilized will be calibrated routinely. Each time a calibration takes place a copy of the calibration report will be filed with the data manager. Calibrations reports will be reviewed in the checkoff process for data before data sets are "published" for use.

In the event data for a parameter are found questionable or fail a standard QA/QC test, a data exception memo will be sent to the senior investigator. No data will be "published" on the LSU network until every data exception memo is returned with a recommended course of action for the data in question. A final review of a data set will be made by the data manager for data reasonability as well as to ascertain that all of the above steps have been successfully accomplished.

INFORMATION TRANSFER

Information Transfer includes deliverables, presentations at MMS meetings, and electronic mail. Electronic mail is the most accessible of these three because data and notices will be updated on a regular basis and published on Omnet, a system that is available to all interested parties. The groups we envision using the electronic mail system include MMS, other LATEX contractors, other federal agencies, the fishing industry, Sea Grant, and the general public.

As stated above, when a data set has been "published", a notice will be posted on the electronic Telemail bulletin board that the data is now available for read only by project participants. These data sets and plots required by MMS will be posted via Telemail for all MMS researchers, while large data sets can be accessed by direct computer-to-computer backups. Each time a researcher logs onto the system, a "notices" macro written especially for this project will notify the researcher of any recent announcements specific to the project.

Remote Sensing

Remote sensing images will be reviewed daily to support cruise planning and operations at sea. Specific items include

- GULFPLOT files of frontal locations at least twice a week. These files will include profiles of surface temperature and albedo along selected cross-shelf transects.
- Alerts and documents of special events, especially "Squirt Alerts." Squirts are filaments of shelf water which flow seaward off the shelf. It is essential to detect and notify Team C of these squirts as quickly as possible because we do not know the time scales of these features.
- Overnight delivery of the latest series of useful images prior to departure.
- Satellite overpass dates, times, and nadir ground track location information for SST/OCEAN color "ground truth" measurements. This will provide operators with timing and pixel size information of satellite passages. The information will include data on the NOAA satellites, Landsat, SPOT, and other relevant satellites as feasible.

Electronic Mail

Results from the hydrographic cruises will be posted by electronic mail, including:

- Precruise notices and station/transect charts, 10 days before each cruise. Dr. Curt Ebbesmeyer, chief ship scientist, will be responsible for this information.
- Post-cruise summaries and station/transect charts. Actual cruise tracks will be posted as part of the cruise summaries within 10 days of cruise completion. Again, Dr. Ebbesmeyer is responsible for this.
- Mooring or instrument sites/charts.
- Public meeting details, if the need for public meetings arises.
- The NODC data archiving notices. A telemail notice of the submission of an NODC tape will be posted on GULF.MEX within 10 days of the submission of the tape.
- Notices of unusual or interesting data. An internal review by the program and data managers will be conducted before this data is published.

Loading Estimates of Pollutants

A key aspect of our research relies upon developing loading estimates of various pollutants derived from information gathered from other studies which are being performed concurrently. We will provide the researchers on these other projects with data summaries from each cruise. Concurrent studies include

- Mississippi River Study, U.S. Geological Survey, Dr. Robert Meade, Denver.
- Estuarine Monitoring and Assessment Program, Environmental Protection Agency, Dr. John Paul, Narragansett.
- National Status and Trends Program, NOAA, Dr. Thomas Connor, Rockville.
- Louisiana Department of Environmental Quality, Dr. Paul Templet, Baton Rouge.

Ms. Mary L. White has been a Research Associate at Louisiana State University for a total of 13 years. Ms. White's experience includes the data processing and archiving of scientific data for numerous projects federally, state, and privately contracted. Ms. White received her M.S. in marine science from Louisiana State University. Ms. White is currently pursuing a Ph.D. from the Department of Oceanography and Coastal Sciences at Louisiana State University.

RESEARCH PLANS BY PRINCIPAL INVESTIGATORS: "GULF OF MEXICO EDDY CIRCULATION STUDY"

Session:	RESEARCH PLANS BY PRINCIPAL INVESTIGATORS: "GULF OF MEXICO EDDY CIRCULATION STUDY"
Co-Chairs:	Dr. Walter Johnson Dr. Thomas J. Berger
Date:	November 7, 1991

Presentation	Author/Affiliation
Research Plans by Principal Investigators: "Gulf of Mexico Eddy Circulation Study": Session Introduction	Dr. Walter Johnson Minerals Management Service Gulf of Mexico OCS Region and Dr. Thomas J. Berger Science Applications International Corporation
Task B-1: Remote Sensing	Dr. Lawrence J. Rouse, Jr. and Dr. Oscar K. Huh Coastal Studies Institute Louisiana State University
Eddy Circulation Study Overview	Dr. Thomas J. Berger Science Applications International Corporation
Texas-Louisiana Eddy Circulation Study: Scientific Program	Dr. Peter Hamilton Science Applications International Corporation
Data Management and Information Transfer in the Texas-Louisiana Eddy Study	Dr. Robert J. Wayland Science Applications International Corporation
Program Logistics and Ships-Of-Opportunity in the Texas-Louisiana Eddy Study	Mr. James J. Singer Science Applications International Corporation
Year-Round Remote Sensing in the Gulf of Mexico	Dr. David Sheres Center for Marine Science University of Southern Mississippi

RESEARCH PLANS BY PRINCIPAL INVESTIGATORS: "GULF OF MEXICO EDDY CIRCULATION STUDY": SESSION INTRODUCTION

Dr. Walter Johnson
Minerals Management Service
Gulf of Mexico OCS Region
and
Dr. Thomas J. Berger
Science Applications
International Corporation

This is the last of the three LATEX Study sessions. Our principal investigators will present descriptions of their plans for the field work, the analyses, and the information management activities required by the contract for Part C, Gulf of Mexico Eddy Circulation Study. This information is being provided to inform the public of the scope of the work and to assist coordinating program managers in forming their plans for collateral use of the data which will be shared throughout the Gulf of Mexico marine science community.

Dr. Walter Johnson joined the Minerals Management Service Branch of Environmental Modeling in July 1989. Dr. Johnson received his B.S. in physics and an M.S. physical oceanography from the University of Miami and his Ph.D. in marine studies from the University of Delaware. He was a faculty member of the Institute of Marine Sciences at the University of Alaska Fairbanks. His expertise is in fields of coastal oceanography, including wind-driven and buoyancy-driven flows, and numerical modeling.

Dr. Thomas Berger has been with Science Applications International Corporation in Raleigh, North Carolina since 1987. His research interests are in remote sensing of mesoscale processes. Dr. Berger received his B.A. in zoology from Catholic University in 1959, his M.S. in physical oceanography from the Naval Postgraduate School in 1970, and his Ph.D. in physical oceanography from Old Dominion University in 1987.

TASK B-1: REMOTE SENSING

Dr. Lawrence J. Rouse, Jr.
and
Dr. Oscar K. Huh
Coastal Studies Institute
Louisiana State University

This remote sensing task is effectively the "eyes" of the Texas-Louisiana (LATEX) Project, Parts A, B, and C, providing real-time synoptic views of the study area. It will maintain a continuous surveillance of the Gulf of Mexico, accumulating areal and temporal synoptic measurements of gulf and shelf features and their behavior. The primary source of the data for this effort will be the imagery from the Advanced Very High Resolution Radiometer (AVHRR) of the National Oceanic and Atmospheric Administration (NOAA) polar orbiting environmental satellites. These data are being captured by the Earth Scan Laboratory (ESL) of Louisiana State University (LSU), a NOAA Satellite High Resolution Picture Transmission (HRPT) earth station that has been in full operation since June 28, 1988. This task has three major components: real-time ocean surveillance, analysis of historical data, and data synthesis and interpretation.

OBJECTIVES

The objectives of the real-time ocean surveillance component are

- To establish and maintain a daily, multiyear NOAA satellite surveillance of the primary and secondary features of the central and western Gulf of Mexico including: the Loop Current, detached eddies, smaller anticyclonic and cyclonic eddies, squirts and jets (seaward extended plumes of shelf water), Mississippi River discharge plume, Atchafalaya River discharge plume, coastal boundary layer, and shelf edge fronts. This surveillance shall include use of the standard ocean analysis products of NOAA in conjunction with directly accessed AVHRR data.

- To provide data including frontal maps and descriptions of features observed to Tasks A, B, and C in real-time to guide at-sea measurement programs.

- To maintain a "squirt-alert," for timely flagging of any "squirt" or jet developments, so aircraft teams of Task C can make the needed measurements.

- To provide abstracts of the information content of these data to Minerals Management Service (MMS) and other participants in the program in near real-time.

The objectives of the analysis of historical data component are

- To obtain, inspect, and analyze a representative sample of available historical, AVHRR, CZCS, Landsat, and manned spacecraft photography, plus any other appropriate satellite and aircraft data for information on the structure and behavior of the ocean features of the LATEX study area.

- To create graphic and statistical summaries of the patterns and behavior of observed oceanographic features, in particular the position and movement of the coastal boundary layer (CBL). In addition, this effort will document major oceanographic events.

The objectives of the data synthesis and interpretation component are

- To synthesize the years of historical and new satellite data from the surveillance, with the relevant measurements such as hydrographic, current meter, ARGOS buoy, meteorological, water level, river discharges, and satellite altimetry. One key objective of this synthesis is to determine the relation between the CBL features and dimensions as seen from satellite data and the observed dimensions acquired at sea.

- To enumerate and characterize the physical processes as can be determined from the observational and measurement network of the LATEX program.

DATA ACQUISITION AND ANALYSIS

Real-Time Ocean Surveillance

Efforts are presently underway to fully automate most of the capture and pre-processing of the HRPT data. All HRPT data which are broadcast by the NOAA satellites when they are imaging the Gulf of Mexico will be captured and archived by the ESL. For each swath of data captured by the ESL receiving station, the data for the northwestern portion of the Gulf of Mexico will be extracted, calibrated, and stored on disk for review. The specific minimum area of coverage by this project will be 88° to 98°W and 24° to 30.5°N. (Note that, because of the translation of the satellite orbits, the entire study area will not be included in all of the swaths captured.) These stored scenes will be screened daily to select images for further analysis. The primary screening parameters will be cloud cover, areal coverage of the image, and length of time since the previous analysis. Each day, those scenes selected will be registered, SST calculated, and displayed for visual enhancement. The analysis of each scene selected will include a search for estuarine and riverine discharge plumes, CBLs, mud streams, shelf edge fronts, Loop Current and associated eddies, other Gulf eddies, and evidence of continental shelf waves. If these features are present in the imagery, locations will be digitized to delineate them and a data file will be generated. Profiles of temperature and albedo will be extracted along selected transects and stored in data files. At least twice a week, files of frontal analyses and selected profiles will be placed on the selected electronic bulletin board (EBB). The frontal files will be in SEAPLOT format. The profiles will be in ASCII format and will include the position of both ends of the transect. These profiles may be downloaded from the EBB and plotted using any of a number of available plotting packages (including most spreadsheets). A SEAPLOT format file containing the positions of the ends of each transect will be transmitted along with each set of profiles. Slides (35 mm) will be taken of each of the analyzed images. Specific circulation features which are significant to this project will be displayed in zoomed format to render the full detail available from the AVHRR. These features will also be photographed for the archive.

These analysis activities will take place daily and on weekends when clear sky or specific circulation events require such effort. The analysis activity will also increase during periods of cruises associated with all the study units of this program so as to provide as much information as possible to the research vessels.

Analysis of Historical Data

The historical imagery will be analyzed to obtain information on geometry, and changes in geometry, of oceanographic features of the Gulf of Mexico. Plumes, CBL, and current rings will be projected over appropriate base charts from which locations of ocean features will be determined. To analyze the historical images, line drawings will be produced from each one. From these, key geometrical variables will be extracted including: (1) position of the CBL; (2) discharge plume locations and dimension; (3) length, width, and position of squirts; and (4) diameter, axes, and centroid of eddies. We will attempt to determine the mean and standard deviation of the location of the outer edge of the CBL along selected transects.

The resulting information will be "binned" by month. This will elucidate the seasonal variability derived from a multitude of years. Initial attention will be given to data from the spring season which will be most useful for the first scheduled cruises.

Data Synthesis and Interpretation

Hydrographic data will be obtained from both the data manager in this task, and those associated with Tasks A and C. Ancillary data will be obtained from other sources.

The investigators will access river discharge data from the Corps of Engineers and U.S. Geological Survey throughout the period of investigation. The investigators will summarize wind field data from onshore and offshore (platform) weather stations to help in interpretation process. The investigators will acquire actual measured water level data from the relevant U.S. Army Corps of Engineers and National Ocean Survey Tide stations.

DATA PRODUCTS

Real Time Ocean Surveillance

The output products from the acquisition and processing system will include

- a SEAPLOT format file from the daily analysis of frontal locations to be placed on the designated EBB at least twice each week;
- profiles extracted from the satellite data of temperature and albedo along selected transects to be placed (in ASCII format) on the selected EBB at least twice each week;
- a 35 mm slide archive of analyzed images and selected features of importance to this program (copies of these slides will be distributed to MMS and other participants as directed);
- a digital archive of data extracted from appropriate imagery which coincide with ship and aircraft transects occupied in connection with this project; and
- a digital archive of all images analyzed for this program.

In addition to the routine surveillance of the Gulf of Mexico, special services will be provided by the ESL to research vessels and aircraft associated with this program. The ESL will provide investigators on cruises and aircraft missions with:

- Alerts and documentation of any special developing events. Of particular importance are "Squirt-Alert" messages. Squirts are filaments of shelf water which flow seaward. As the time scales of these features are not well known, early detection, recognition, and timely notification of the Task C team is essential if they are to have adequate time to mobilize the aircraft and sample the feature. We will place a SEAPLOT format file containing the outline of the squirt on the EBB and place a phone call to the Task C leader to inform him of the presence of the squirt and to supply other information that he may deem necessary.
- Overnight delivery of the latest series of useful satellite images in photographic or color Xerox

format to the appropriate task leaders just prior to cruise departures. Throughout the duration of each cruise we will monitor the conditions in the cruise area and provide the appropriate task leaders with the latest satellite information, including fax copies of enhanced analyzed image products.

- A table of satellite overpass dates, times, and nadir ground track. This information, provided for each cruise, will permit cruise scientists to acquire surface samples that can be useful for relating satellite data to actual sea surface conditions. This table will include data for the NOAA satellites, Landsat, SPOT, and other relevant satellites.

Analysis of Historical Data

Historical images from the many sources will be analyzed to obtain information about the location and extent of such shelf features as estuarine and river plumes, mud streams, and fronts which delineate the CBL. The data products will be line drawings and tables which synthesize the monthly mean location of these features and a range or standard deviation of this position along selected transects. In addition, satellite images which represent the monthly or seasonal conditions and significant deviations from the mean conditions will be presented. The first months to be analyzed will be those chosen for the initial cruises for this program so that cruise scientists will have an estimate of the "sea surface climate" of the study area. These products will be included with the monthly progress reports as they are generated and will be compiled into a single report by the end of the project.

Data Synthesis and Interpretation

The objective of the synthesis is to characterize the physical transport processes inherent in the surface and subsurface waters through the combination of time series of remotely sensed temperature and turbidity (albedo) patterns and the *in situ* measurements. It will characterize the Mississippi/Atchafalaya CBL and shelf flow system and processes of change in terms of time and space scales, stages of development, and sequences of patterns and events. Field measurement data will be merged with the remotely sensed data. Images with "ground truth" overlays will be produced throughout the project and included, as appropriate, in the monthly reports. As part of the final report, we envision a collection of image sequences which depict the evolution of circulation features observed during the conduct of this program. As an example, we would include a sequence of five or six images acquired over a period of a few days which depict the evolution of a squirt. These images would be "zoomed" to display the feature at the full resolution of the AVHRR. The images would also be available in digital format for "time-lapse" display on image processing computer systems.

Dr. Lawrence Rouse has been at LSU for over 19 years. He is presently an Associate Professor in the Coastal Studies Institute and the Department of Oceanography and Coastal Sciences. He is also Associate Director of the Earth Scan Laboratory, the NOAA environmental satellite earth station at LSU. His research interests are shelf and estuarine transport processes and analysis of these processes using remotely sensed data. Dr. Rouse received his B.S. in physics from Loyola University and the Ph.D. in physics from LSU.

Dr. Oscar Karl Huh has been a researcher at the Coastal Studies Institute, LSU since 1976. He is also a Professor in the Department of Oceanography and Coastal Sciences at LSU and Director of the Earth Scan Laboratory. His areas of research are in aerospace remote sensing of coastal and continental shelf physical processes and coastal sedimentation. Dr. Huh received a B.S. in geology from Rutgers, the State University of New Jersey, and the M.S. and Ph.D. degrees in geology from Pennsylvania State University.

EDDY CIRCULATION STUDY OVERVIEW

Dr. Thomas J. Berger
Science Applications
International Corporation

The third element (TASK C) of the Texas-Louisiana (LATEX) Physical Oceanography

Program, the Eddy Circulation Study, will be conducted by Science Applications International Corporation (SAIC) with the following objectives:

- Monitoring and characterizing Loop Current eddies and the eddy shedding process, interaction of smaller cyclones and anticyclones with the upper slope, and small scale shear zones - "squirts and jets" - usually located near the upper slope, using air deployed drifters, aerial surveys, and satellite altimetry,

- Providing efficient, centralized logistics, including Service ARGOS liaison for small meteorological buoys, air and ship deployed satellite tracked drifters, and expendable probes,

- Disseminating data and information on a regular basis to project scientists, including those executing other components of the LATEX Physical Oceanography Program, the Minerals Management Service (MMS), and interested parties in industry and academia.

Major program participants and principal investigators (PIs) include Drs. Peter Hamilton and James Lewis of SAIC, Drs. George Born and Robert Leben of the University of Colorado, and AeroMarine Surveys, Inc. Dr. Hamilton will be responsible for the study of small eddy interactions on the upper slope and study of the small scale shear zones called squirts and jets. Dr. Lewis will be responsible for description of Loop Current eddy circulation processes derived from drifter tracks and for placing these descriptions in the context of a long-term eddy database. Drs. Born and Leben, as co-PIs, will be responsible for preparation of a climatology of publicly available GEOSAT data. AeroMarine Surveys will perform all required aerial surveys and drifting buoy deployments for this study.

The study comprises 12 tasks which can be grouped into the scientific effort; support tasks and analysis; reporting and data sharing. Each of these groups will be described more fully in later presentations. Figure 16.1 illustrates the study scheduling.

The scientific effort consists of locating and tracking Loop Current eddies, slope eddies, and squirts and jets using AXBTs and AXCPs for locating the eddies and air launched lagrangian drifters (Clearwater Consultants - LSD2) for tracking the eddies. During the "locating" phases, the aircraft operator will take approximately 1,000 70 mm photographs of areas near fronts for use by Dr. David Sheres of the University of Southern Mississippi. Finally, Drs. Born and Leben will evaluate methods of compiling a GEOSAT altimetric climatology including charts of the Loop Current eddy cycle for the April 1985 - September 1989 period. There is no operational altimetry phase in the present program.

The support tasks include provision of drifters to Tasks A and B and collection of the data from these drifters via Service ARGOS; quality control of all drifters to ensure proper operation; handling of any returned drifters; operation of a Ship-of-Opportunity program as directed by MMS; and return of Government furnished equipment to MMS at the end of the program.

The analysis, reporting, and data sharing tasks include data quality control; preparation of annual reports, including a final synthesis report; data management and data sharing through electronic means and periodic submission of provisional data to National Oceanographic Data Center.

The program is now in a pre-deployment phase of approximately six months duration during which orders are being placed for materials and services, subcontracts are finalized, and plans for the initial surveys are being formulated. The actual field schedule is largely reactive to the schedules of the other programs and to the occurrence of the phenomena being studied. The first slope survey will be coordinated with the shelf hydrographic surveys and will occur in April 1992. The field portion of the study will be completed in March 1995.

Dr. Thomas Berger has been with Science Applications International Corporation in Raleigh, North Carolina since 1987. His research interests are in remote sensing of mesoscale processes. Dr. Berger received his B.A. in zoology from Catholic University in 1959, his M.S. in physical oceanography from the Naval Postgraduate School in 1970, and his Ph.D. in physical oceanography from Old Dominion University in 1987.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991										AWARD	Order: buoys AXBTs AXCPs XBTs	
1992	Material Deliveries Begin			LCE SES			SES/SEB					SES/SEB SJS/SJB LCE
1993	Inventory, reorder as needed			LCE SES/SEB SJS/SJB			PI SES	D		SES LCE	M	P
1994	M Inventory, reorder as needed	F		LCE SES/SEB SJS/SJB			PI SES	D		SES LCE	M	P
1995	M	F		End Field Work			PI	D			M	P
1996	M	F										

End of Eddy Circulation Study

Notes:

Annual Report Activities

PI - Principal Investigator Inputs to Annual Report
D - Draft Annual Report/Draft Technical Summary
P - Proof Copy Final Report
M - MMS Comments
F - Final Annual Report/Final Technical Summary

Field Activities

SES - Slope eddy survey
SEB - Slope eddy locator/buoy
SJS - Squirts and jets survey
SJB - Squirts and jets locator/buoy
LCE - Loop Current eddy locator/buoy

Monthly reports, meetings, and NODC data submisions are not shown.
Double lines enclose Field Program.

Rev. 11/5/91

Figure 16.1. LATEX eddy circulation study program schedule.

TEXAS-LOUISIANA EDDY CIRCULATION STUDY: SCIENTIFIC PROGRAM

Dr. Peter Hamilton
Science Applications
International Corporation

The principal objectives of the Texas-Louisiana (LATEX) eddy circulation study are to monitor the deeper waters of the central Gulf of Mexico with particular emphasis on processes that interact with the LATEX Shelf. There are four components to the scientific part of the program. They are: (1) Loop Current Eddies, (2) Mesoscale Slope Eddies, (3) Shelf-Slope Exchange, and (4) a Ship-of-Opportunity Program (SOOP). All field work except the SOOP will be performed from aircraft.

Loop Current (LC) eddies will be monitored after detachment by AXBT surveys. The purpose is to determine when major LC anticyclones detach and track them as they propagate westward or southwestward across the Gulf of Mexico. The decision to survey (with AXBTs) a recently detached eddy will be based on imagery from Task B and SOOP reports when imagery is not available in the summer and fall. The AXBT survey will be used to determine where to deploy a drifter that will track the eddy over periods of 6 months to one year. The deployment of two inverted echo sounders by Task A (Figure 16.2) will assist in monitoring the passage of major anticyclones into the western Gulf of Mexico.

There will be nine seasonal slope AXBT surveys covering the region from the 200 m to the 2000 m isobath (i.e., Figure 16.2). They are designed to extend the Task A hydrographic measurements over the slope and will be coordinated with the shelf seasonal surveys. The region of the survey will shift from east to west over the three year field program. When vigorous lower slope mesoscale cyclones and anticyclones are observed either in imagery or in the seasonal surveys, a one day AXBT/AXCP survey of the feature will be initiated (see Figure 16.2) and a drifter deployed near the center on the following day.

At about the same time as the seasonal slope surveys, there will be a pair of two day AXBT/AXCP surveys, separated by about five to seven days, designed to look at smaller scale exchange events or "squirts and jets" in the upper slope and outer shelf. Each "squirt and jet" survey will be followed by a drifter deployment in the feature. The area of these events is quite small (2-20 km scales) and the location will be dependent on the results of the large scale hydrographic surveys of both the slope and shelf as well as imagery in the winter and spring. Pairs of surveys and drifter deployments are planned so that the evolution of the exchange event can be examined and related to current meter observations.

A provisional schedule for the seasonal slope surveys, the slope eddy location, and the pairs of squirts and jets surveys is given in Figure 16.3. In addition, there will be five more "on demand" squirt and jet surveys and six LC eddy location surveys over the three year field program. It is planned to deploy a total of 750 AXBTs and 100 AXCPs during these surveys as well as 20 ARGOS drifters; 6 in LC eddies, 4 in slope eddies, and 10 in "squirts and jets." A total of 65 flight days will be required for this work.

The SOOP part of the study is to supply 1,000 T-7 expendable bathythermographs (XBTs) to appropriate ships doing surveys of the deep Gulf during the period of the field program. The direction of the SOOP XBTs will be determined by mutual consultation with interested parties under the direction of Minerals Management Service. Large scale XBT surveys have proved very useful in previous programs in showing the relationships between eddies in the main basin.

Dr. Peter Hamilton has been with Science Applications International Corporation in Raleigh, North Carolina since 1977 where he has been Principal Investigator on several Minerals Management Service studies including MASAR, the five year Gulf of Mexico Physical Oceanography Program, South Atlantic Physical Oceanography Program, Frontal Eddy Dynamics Experiment, and the current Straits of Florida Physical Oceanography Program. He has considerable expertise in data analysis and in numerical modelling. He received

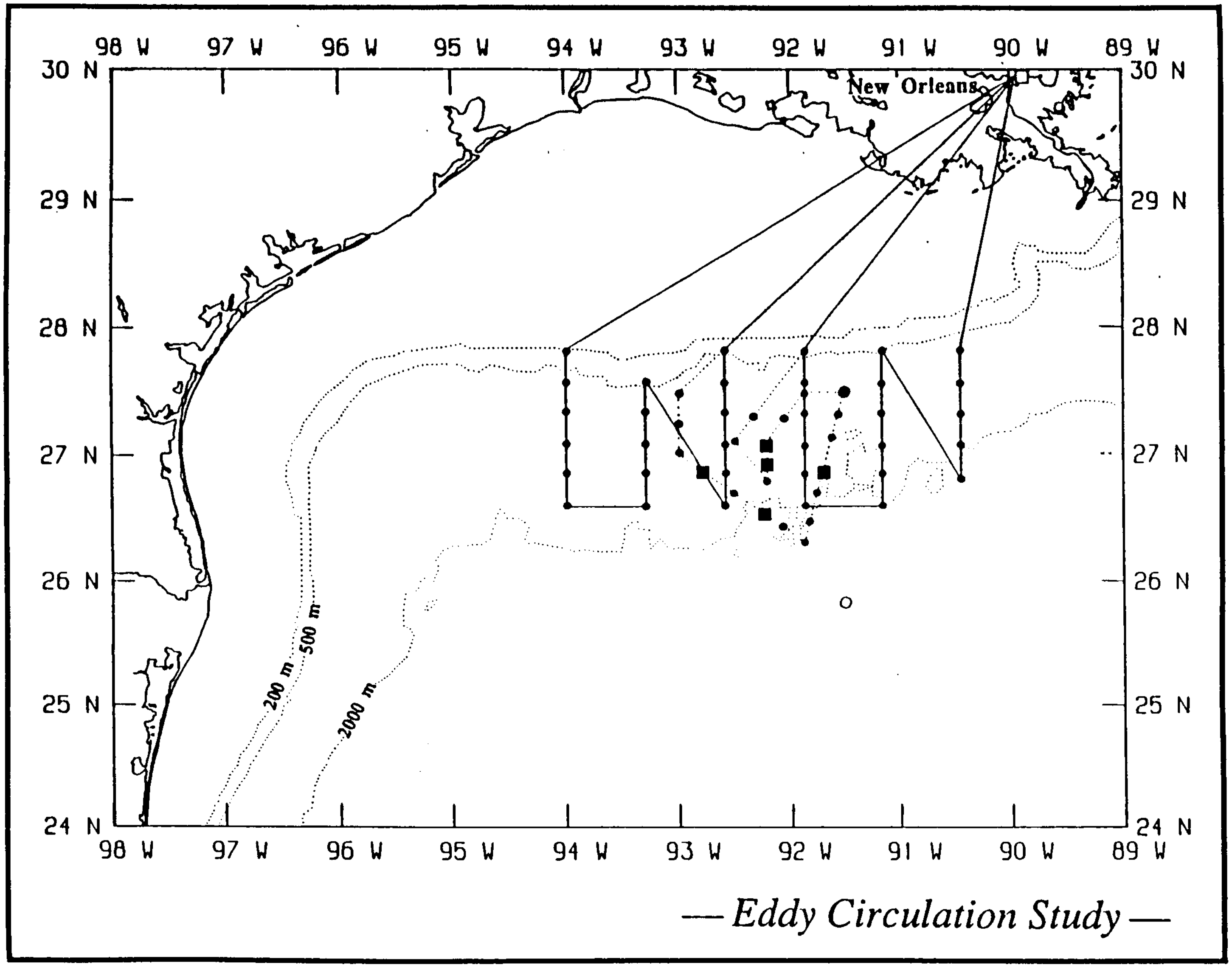

Figure 16.2. Proposed two day seasonal slope survey for year 1 (solid track line). (A Slope Eddy Location Survey is shown nested within the Slope Survey [dashed track line]. (The AXBT stations are solid dots, AXCP stations are squares and Inverted Echo Sounder positions are given by open circles. Flights originate in New Orleans, Louisiana.)

SURVEY	SPRING	SUMMER	FALL	WINTER
TASK A				
Shelf Hydrography	H	H	H	H
YEAR I				
Slope Survey	X	T		T
Eddy Location		X,B		X,B
1st Squirts & Jets				X,B
2nd Squirts & Jets				X,B
YEAR II				
Slope Survey	T	X	X	
Eddy Location	X,B		–	
1st Squirts & Jets	X,B			
2nd Squirts & Jets	X,B			
YEAR III				
Slope Survey	T	X	X	
Eddy Location	X,B			
1st Squirts & Jets	X,B			
2nd Squirts & Jets	X			

H - Ship Hydrographic Survey
X - AXBTs and AXCPs
T - AXBTs
B - Survey is followed by drifter deployment

Figure 16.3. Provisional aerial survey schedule for the slope and squirts and jets surveys (Task C).

his B.S. (1970, First Class Honor) from University of Sussex (Great Britain) and Ph.D. (1973) from University of Liverpool (Great Britain). He was a Research Associate at University of Washington (1973-1977) and visiting scientist at Brookhaven National Laboratory (1975-1976).

Dr. Hamilton received a 1989 editor's citation for excellence in refereeing from the Journal of Geophysical Research and a Science Applications International Corporation award in 1990 for best technical publication for a paper in the Journal of Geophysical Research on deep currents in the Gulf of Mexico. He is currently a member of the Environmental Protection Agency Modelling Evaluation Group for Long Island Sound Studies.

DATA MANAGEMENT AND INFORMATION TRANSFER IN THE TEXAS-LOUISIANA EDDY STUDY

Dr. Robert J. Wayland
Science Applications
International Corporation

The Eddy Circulation Study, which is designed to study the effects of ring features on the Texas-Louisiana (LATEX) shelf and slope, is a companion study to the other LATEX Physical Oceanographic Programs: Shelf Circulation Study and Mississippi River Plume Study. Thus, data management and information transfer between these programs is of vital importance in obtaining a successful integrated process synthesis of the relevant physical oceanographic processes within the LATEX Study Area. It is essential that a timely schedule is maintained in the collection, quality assurance/quality control, processing, and dissemination of these data among the many Principal Investigators (PIs) participating in these programs. This presentation deals with methodology of data management and information transfer for the LATEX Eddy Circulation Study.

The overall program will consist of 37 ARGOS-tracked Clearwater drifting buoys. Twenty of these drifters are assigned to the Eddy Circulation Study, where six will be deployed in Loop Current eddys, four in slope eddys, and 10 in "squirt and jet" features. Of the remaining 17 buoys, 16 are deployed under the Shelf Circulation Study (Task A) and one in the Mississippi River Plume Study (Task B). However, all of these buoys will be tracked and archived through Science Applications International Corporation (SAIC)/Raleigh. Additionally, AXBT, AXCP, and XBT data will also be collected during this program as part of the buoy deployment surveys. Each of these data types (e.g., lagrangian and profile) will be processed and analyzed using the SAIC/Raleigh Physical Oceanographic Data Base Management System. Figure 16.4 shows a schematic of the SAIC/Raleigh Physical Oceanographic Data Base Management System which shows the overall information flow through this system.

As outlined in the Request For Proposal, all data collected under this program will be submitted to the National Oceanographic Data Center (NODC) in Master File Format within 90 days of completion of the data collection activities. The NODC has assigned Task C a project code number of 0209. This number should be used in all correspondence with NODC regarding data requests/inquiries for the Eddy Circulation Study. The NODC formats relevant to this study (Task C) are as follows:

- Drifting Buoy Data (F156)
- AXBT Data (F022)
- AXCP Data (F004)
- XBT Data (F022)

Prior to submission of the data to NODC, data products packages consisting of raw and smoothed buoy trajectories, horizontal and vertical temperature cross-sections, and cruise/flight plans will be distributed to all PIs involved in the Eddy Circulation Study. Finally, a Ship-of-Opportunity (SOOP) Data Report will be generated, which will summarize each of the SOOP cruises conducted during the program by providing a cruise track and vertical temperature cross section for each cruise.

Near-real-time dissemination of the above information is critical during the on-going field programs. The primary mode for this communication will be OMNET's E-MAIL system. The major components of information transfer will be as follows:

- Transfer of raw, ARGOS format drifter data to Texas A&M University (TAMU) and Louisiana State University for their drifting buoys (weekly);

- GULFPLOT file for all currently transmitting buoys (bi-weekly);

- The AXBT, AXCP, and XBT data in IGOSS format (within 7 days of survey completion); and

- Regular Program Notices

    - Pre-Flight Sampling Plans
    - Post-Flight Survey Plans
    - Buoy Deployment Locations
    - The NODC Archiving Completion Date
    - Details of Any Public Meetings

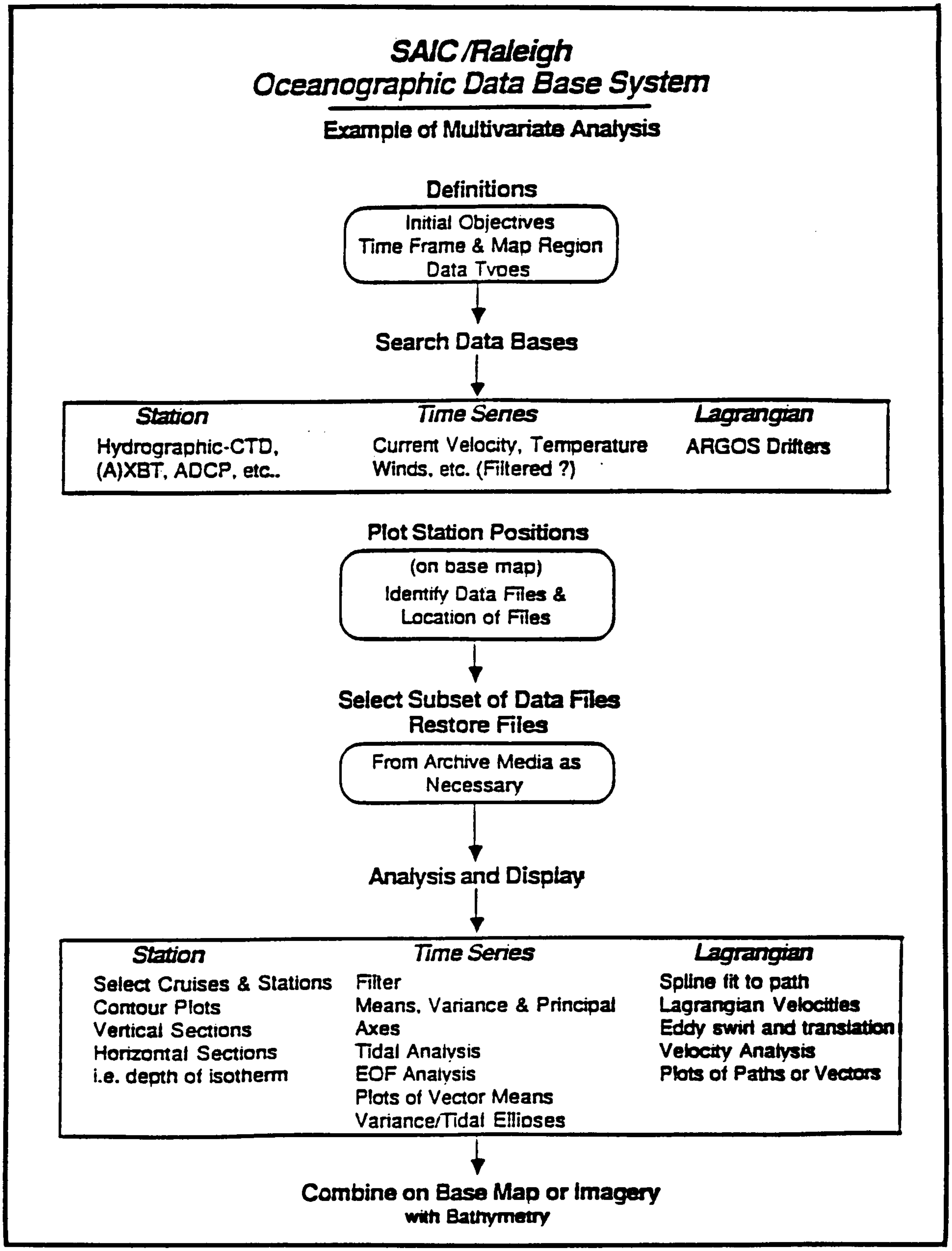

Figure 16.4. Schematic of the SAIC/Raleigh physical oceanographic data base management system.

To facilitate this process, SAIC has opened a new mailbox, LATEX.EDDY, from which all of these messages/data will originate. Additionally, any questions or comments should be addressed to the Data Manager at the above mailbox. Also, SAIC/Raleigh will be making regular contributions to the LATEX Calendar/Schedule, which is being handled by the TAMU Data Management Center.

Dr. Robert J. Wayland has been employed at SAIC for the past 8-1/2 years serving in a variety of functions including scientific programmer, data base manager and Principal Investigator. His areas of research expertise include marine atmospheric boundary layer physics, ocean-atmosphere exchange processes, and meteorological/oceanographic data analysis and management. Dr. Wayland was the Principal Investigator on the Meteorological Summary of the Gulf of Mexico and served as Data Manager on Program Years 1-5 of the Gulf of Mexico Physical Oceanography Program. He received his B.A. and M.S. in environmental sciences from the University of Virginia, and his Ph.D. in atmospheric science from North Carolina State University.

PROGRAM LOGISTICS AND SHIPS-OF-OPPORTUNITY IN THE TEXAS-LOUISIANA EDDY STUDY

Mr. James J. Singer
Science Applications
International Corporation

INTRODUCTION

Three major areas of logistics are identified. These include receiving and storage, coordination and out-shipping, and testing of ARGOS drifters and government furnished equipment (GFE). In addition, a quick-response capability is built into the program for short-notice requests of expendable bathythermographs (XBTs) and data acquisition hardware for the Ship-of-Opportunity (SOOP) program.

DISCUSSION

A receiving and storage facility is to be identified in time to take receipt of the first shipments of ARGOS drifters and expendable probes prior to April 1992. Totals include receipt of 17 near-surface drogued ship-deployed ARGOS drifters, 20 air-deployed ARGOS drifters, 750 AXBTs, 100 AXCPS, 996 T-7 XBTs, and some GFE in support of ARGOS drifter testing and the SOOP program. Table 16.1 summarizes these items, including a projected delivery schedule by year for all expendables. Clearwater Consultants' LSD-2 and LSD-3 ARGOS drifters will be obtained. Expendable probes will be obtained from Sippican Ocean Systems, Inc. and/or Spartan of Canada, Ltd.

Table 16.2 summarizes the coordination and anticipated out-shipping from the storage facility. Coordination with the Task A and B logistics managers will be maintained for timely shipment and receipt of the 17 ship-deployed near-surface drogued ARGOS drifters to Galveston and Cocodrie or any other destination they might specify. The Task C logistics manager will also be coordinating the flights for the Task C program. He will therefore be able to solely coordinate the shipment and delivery of all expendable probes and air deployed ARGOS drifters to coincide with the proposed aerial surveys or drifter deployments. Shipping for these aspects of the program is tentatively scheduled for New Orleans, Lafayette, and Corpus Christi, but will be adjusted as necessary. In addition, funds have been set aside to respond to the recovery of up to 10 ARGOS drifters. These funds will be used to take receipt of the drifters from the finder, to ship the drifters back to the manufacturer, and for refurbishment.

Short-notice quick-response shipments of 5 to 10 cases of T-7 XBTs for the SOOP program will likely be handled by bus. Other arrangements will be made, if deemed necessary. Foreign (i.e., Mexico) shipments of XBTs and XBT data acquisition equipment will require acquisition of a temporary export license and will take more time. However, the procedures and contacts to implement such arrangements are already established.

The ARGOS drifter quality control will be maintained as part of a four step program. This includes testing on receipt to storage, testing on out-

Table 16.1. Receiving and Storage.

A. ARGOS DRIFTER (Clearwater LSD-2 and LSD-3) — (YR1/YR2/YR3)

• 17 near-surface drogued ship-deployed	(8/5/4)
• 6 100-m drogued air-deployed	(3/3/0)
• 4 200-m drogued air-deployed	(3/1/0)
• 10 <50-m drogued air-deployed	(6/4/0)

B. EXPENDABLE PROBES — (YR1/YR2/YR3)

• 750 AXBTs (Sippican/Spartan)	(250/250/250)
• 100 AXCPs (Sippican)	(50/25/25)
• 996 T-7 XBTs (Sippican/Spartan)	(336/336/324)

C. GOVERNMENT FURNISHED EQUIPMENT

- 1 Telonics T-SUR-B ARGOS Uplink Data Receiver
- 2 Sippican M-9 XBT Controllers
- 2 Sippican LM-3A Handheld Launch Guns with Test Canisters
- 2 HP-85B micro-computers with software

Table 16.2. Coordination and Out-Shipping.

(Tasks C-1, C-2, C-3, C-4, C-6 and C-8)

- 16 Ship-deployed drifters to Texas A&M University (Galveston)
- 1 Ship-deployed drifter to Louisiana State University (Cocodrie)
- 6 Air-deployed drifters and 126 AXBTs (21/survey) to LC Eddy Surveys (New Orleans and/or ?)
- 4 Air-deployed drifters, 352 AXBTs, and 45 AXCPs to nine (3/year) slope surveys and four (~1/yr) slope eddy location surveys (New Orleans, Lafayette, Corpus Christi)
- 10 Air-deployed drifters, 192 AXBTs, and 54 AXCPs to six (2/year) squirts and jets surveys (New Orleans, Lafayette, Corpus Christi)
- 5 Small scale feature surveys with 80 AXBTs (16/survey) (New Orleans, Lafayette, Corpus Christi)
- Up to 10 recovered drifters back to the manufacturer for refurbishment
- 996 T-7 XBTs plus Sippican Mk-7 data acquisition system (5-10 cases/shipment).

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shipment, testing prior to deployment, and the provision of a spare drifter when available. These aspects involve use of both the Telonics T-SUR-B Uplink Data Receiver and an end-to-end checkout through System ARGOS. Some coordination between the Task A and B programs will be required prior to the respective drifter deployment.

Mr. James Singer is a physical oceanographer and field logistics manager with Science Applications International Corporation in Raleigh, North Carolina. He was responsible for field logistics and the SOOP program during the Gulf of Mexico Physical Oceanography Study for Minerals Management Service (MMS) and has served as logistics manager and chief scientist on numerous other MMS and private sector studies over the last 10 years while at SAIC. Prior to that he was a Research Coordinator at Skidaway Institute of Oceanography in Savannah, Georgia. He has a B.S. in chemistry and an M.S. in physical oceanography from North Carolina State University in Raleigh, North Carolina.

YEAR-ROUND REMOTE SENSING IN THE GULF OF MEXICO

Dr. David Sheres
Center for Marine Science
University of Southern Mississippi

INTRODUCTION

Remote sensing is becoming a very important method of collecting oceanographic information. Currently, there are a number of satellites continuously collecting ocean surface data over our earth. Synthetic aperture radar (SAR) is a high resolution cloud penetrating method of obtaining ocean data. The ERS-1 is a SAR carrying satellite launched this July. Other SAR carrying satellites will soon follow.

In the Gulf of Mexico (GOM) there are energetic Loop Current fronts and associated eddies that are followed with interest by different groups. It is very difficult, if not impossible, to observe these energetic fronts with conventional satellite imagery during most of the summer months. The SAR data offers a potential capability to locate as well as measure the strength of these fronts year-round.

The SEASAT SAR imagery obtained during the summer of 1978, near the edge of the Loop Current in the GOM, shows a rich assembly of ocean features. Fronts are clearly seen in these images together with other more unusual features.

The determination of frontal strength from images of waves refracted by the front is useful (Sheres *et al.* 1985), particularly during periods of uniform temperatures on both sides of the fronts (such as the Loop Current during part of the summer). Interpretation of SAR imagery, especially with respect to wave refraction pattern observations, is an area of active research.

Also, there have been reports of sudden destructive waves near strong ocean current fronts. It has been suggested (Irvine and Tilley 1988) that these waves are generated by the refraction and focusing of the ambient waves by curved velocity fronts. The Texas-Louisiana (LATEX) data will give us the opportunity to investigate the possibility of wave energy focusing near curved fronts in the GOM.

PLAN

The data set that will be acquired by LATEX, including the high quality aerial photography, will provide a unique opportunity to determine the utilization of SAR imagery of fronts and eddies in the GOM. The SAR imagery (potential sources are ERS-1, SIR-C, and the JPL aircraft SAR program) of such features will be correlated with data collected simultaneously at these features. The data will include *in situ* measurements and high quality aerial photos. The wave refraction patterns observed in the SAR and aerial photos will be compared with each other and with the results obtained from a wave refraction model. The wave imagery will be enhanced and filtered using methods similar to what is described in Sheres *et al.* 1985.

The investigation of wave focusing by curved fronts will be guided by the predictions of the wave refraction model (Sheres *et al.* 1987). Input to the model will include velocity data from LATEX drifters, frontal locations from AVHRR, wave predictions from NOARL West and wave observations from aerial photos. The airplane will take photos near the predicted focus and shadow regions by the curved fronts. The wave refraction patterns in the photos will be analyzed to determine possible wave energy focusing effects.

During March 1990 and May 1991, we had dedicated flights of SAR and interferometric SAR carrying JPL/NASA aircraft over the GOM. The data obtained during those flights are being processed at JPL. During the 1990 flight some *in situ* observations were conducted by a ship of opportunity (courtesy of Lykes Shipping Co.). During the 1991 flight, *in situ* measurements were obtained by the R/V *Tommy Munro* from the Gulf Coast Research Laboratory. These data together with historical SEASAT SAR imagery of the GOM will provide a useful background for the analysis of the LATEX data.

SUMMARY

The aerial photos and other data from the LATEX experiment will be used to do the following:

- Help develop the capability to use SAR for year-round (including summer) observations of fronts and other energetic ocean features in the GOM.
- Investigate the focusing of wave energy by curved fronts (e.g., eddies).
- Help in the interpretation of SAR imagery of waves by comparing them to simultaneous high quality aerial photos and *in situ* data.

REFERENCES

Irvine, D.E. and D.G. Tilley. 1988. Ocean wave directional spectra and wave current interaction in the Agulhas from the Shuttle Imaging Radar-B Synthetic Aperture Radar. J. Geoph. Res. 93(C12):15, 389-15, 401.

Sheres, D., D.T. Chen, and G.R. Valenzuela. 1987. Remote sensing of wave patterns with oceanographic implications. Int. J. Remote Sensing 8(11):1629-1640.

Sheres, D., K.E. Kenyon, R.L. Bernstein, and R.C. Beardsley. 1985. Large horizontal surface velocity shears in the ocean obtained from images of refracting swell and *in situ* moored current data. J. Geoph. Res. 90(C3):4943-4950.

Dr. David Sheres received a B.S. degree in electrical engineering from Massachusetts Institute of Technology, an M.S. degree in electrical engineering from the University of Wisconsin, and a Ph.D. degree in oceanography from the Scripps Institution of Oceanography. Currently, he is an Associate Professor of Physical Oceanography at the Center for Marine Science, University of Southern Mississippi. His interests include remote sensing of the ocean, dynamics of the upper ocean and the air-sea interface.

AGENDA

Minerals Management Service, Gulf of Mexico OCS Region
Information Transfer Meeting

Session I

Tuesday, November 5, 1991

International Ballroom (16th Floor)

Opening Plenary Session: Decisionmaking

Chairs: Dr. Richard Defenbaugh and Mr. Ruben Garza

9:30 a.m. **Welcome, Opening Remarks**

Dr. Richard Defenbaugh,
MMS, Gulf of Mexico OCS Region
and
Mr. Ruben Garza
Geo-Marine, Inc.

Agency Welcome

Mr. J. Rogers Pearcy, Regional Director,
MMS, Gulf of Mexico OCS Region

9:45 a.m. **Decisionmaking within the MMS Natural Gas and Oil Program**

Mr. J. Kenneth Adams
Regional Supervisor, Leasing and Environment
MMS, Gulf of Mexico OCS Region

10:00 a.m. **"Adequacy of Information" for Decisionmaking**

Ms. Dinah Bear
Council on Environmental Quality

10:45 a.m. **Risk Analysis as a Tool to Focus Decisionmaking Issues**

Dr. Dale Nesbitt
Decision Focus, Inc.

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Session II.A

Tuesday, November 5, 1991

Crescent "A" Room (16th Floor)

MMS Environmental Studies Program Progress Reports I

Chairs: Dr. Robert Avent and Dr. Robert Rogers

1:30 p.m. **Welcome, Opening Remarks**

Dr. Robert Avent
MMS, Gulf of Mexico OCS Region

1:40 p.m. **Marine Mammals and Sea Turtle Populations of the North-Central Gulf of Mexico**

Dr. Keith Mullin
National Marine Fisheries Service

2:10 p.m. **Distribution, Abundance and Movements of the Marine Mammals of the Western and Central Gulf of Mexico**

Dr. Randall Davis
Texas A&M University

Mr. Larry Hansen
National Marine Fisheries Service
and
Dr. Bruce Mate
Oregon State University

2:55 p.m. **Refreshment Break**

3:20 p.m. **Behavior and Movements of Sea Turtles in the Western and Central Gulf of Mexico**

Dr. Warren Stuntz
National Marine Fisheries Service

3:50 p.m. **Ecology of Chemosynthetic Communities on the Continental Slope in the Northern Gulf of Mexico**

Drs. James Brooks and Ian MacDonald
Texas A&M University
and
Dr. William Schroeder
Dauphin Island Sea Laboratory

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Session II.B

Tuesday, November 5, 1991

Crescent "B" Room (16th Floor)

Scoping Socioeconomic Concerns and Issues in the Gulf of Mexico Region

Chairs: Mr. John Greene and Mrs. Linda Castaño-Vélez

1:30 p.m. **Welcome, Opening Remarks**

Mr. John Greene
MMS, Gulf of Mexico OCS Region

1:40 p.m. **Oil and Gas Related Social and Economic Issues and Concerns of the State of Alabama**

Ms. Angie Chandler
Mobile Area Chamber of Commerce

1:55 p.m. **Oil and Gas Related Social and Economic Issues and Concerns of the State of Florida**

Ms. Debby Tucker
Office of the Governor

2:10 p.m. **Oil and Gas Related Social and Economic Issues and Concerns of the State of Louisiana**

Dr. Robert Gramling
University of Southwestern Louisiana

2:25 p.m. **Oil and Gas Related Social and Economic Issues and Concerns of the State of Mississippi**

Mr. Van Evans
Mississippi Department of Economic Development

2:40 p.m. **Oil and Gas Related Social and Economic Issues and Concerns of the State of Texas**

Mr. Robert L. Armstrong
Director, Governor's Energy Office

2:55 p.m. **Oil and Gas Related Social and Economic Issues and Concerns of the Mid Continental Oil and Gas Association**

Mr. Jim Porter
Mid Continental Oil and Gas Association

3:10 p.m. **Refreshment Break**

3:40 p.m. **Roundtable Discussion**

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Session II.C

Tuesday, November 5, 1991

Rosedown Room, (2nd Floor)

Development Potential of Hard Mineral Resources in the Exclusive Economic Zone of the Northern Gulf of Mexico

Chairs: Mr. Gary Rutherford, Mr. Gerald Crawford, and Dr. Mark Byrnes

1:30 p.m. **Welcome, Opening Remarks**
Mr. Gary Rutherford
MMS, Gulf of Mexico OCS Region

1:40 p.m. **Characterization of the Development Potential of Ship Shoal Sand for Beach Replenishment of the Isles Dernieres: Introduction and Objectives**
Dr. Mark Byrnes
Louisiana Geological Survey

1:55 p.m. **Dredging Technology for Mining Hard Minerals Resources in the EEZ**
Mr. Tom Richardson
Coastal Engineering Research Center
U.S. Corps of Engineers

2:25 p.m. **Exclusive Economic Zone (EEZ) Overview for the Gulf of Mexico**
Mr. John Rowland and
Mr. Barry Drucker
MMS, INTERMAR

2:45 p.m. **Refreshment Break**

3:00 p.m. **Geologic Framework of Ship Shoal**
Dr. Shea Penland
Louisiana Geological Survey

3:15 p.m. **Physical Environmental Impacts of Sand Mining at Ship Shoal**
Dr. Mark Byrnes
Louisiana Geological Survey

3:30 p.m. **Comparable Onshore Resources**
Ms. Karen Ramsey
Louisiana Geological Survey

3:45 p.m. **Economics of Sand Mining at Ship Shoal**
Mr. Gerald Crawford and
Mr. Robert Kelly
MMS, Gulf of Mexico OCS Region

4:05 p.m. **Summary and Future Direction**

Dr. Mark Byrnes

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Session II.D

Tuesday, November 5, 1991

Madewood "A" (2nd Floor)

Produced Water: Disposal Technologies/Regulations

Chairs: Ms. Gail Rainey and Dr. Pat Roscigno

1:30 p.m. **Welcome, Opening Remarks**

Ms. Gail Rainey
MMS, Gulf of Mexico OCS Region

1:50 p.m. **Status of Proposed Effluent Limitations Guidelines**

Mr. Marvin Rubin
U.S. Environmental Protection Agency

2:20 p.m. **Status of the State of Louisiana Produced Water Regulations**

Mr. Doug Hale
Louisiana Department of Environmental Quality

2:40 p.m. **The Department of Energy's Produced Water Research Program**

Dr. Brent Smith
U.S. Department of Energy

3:00 p.m. **Refreshment Break**

3:10 p.m. **A Review of Technology for Cleaning Produced Water**

Dr. Charles Petty
Michigan State University

3:35 p.m. **Current Status of Membrane Treatment for Produced Water Discharges**

Mr. Ken Arnold
Paragon Engineering

4:00 p.m. **Marathon's Operating Experience with the Use of Ceramic Membranes for Filtering of Produced Water**

Mr. Peter Oswald
Marathon Oil Company

4:15 p.m. **The Offshore Operator's Committee Study of Flotation Systems**

Dr. Michael Stephenson
Texaco, Inc.

4:35 p.m. **Changes in Exxon's Grand Isle Produced Water Disposal System**

Mr. Larry Ziems
Exxon Offshore Production

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Session III.A

Wednesday, November 6, 1991

International Ballroom (16th Floor)

Oil Spills Response I

Chairs: Capt. W. J. Loefstedt and Ms. Darice Breeding

8:30 a.m. **Welcome, Opening Remarks**

Ms. Darice Breeding
MMS, Gulf of Mexico OCS Region
and
Capt. W. J. Loefstedt
Eighth U. S. Coast Guard District

8:45 a.m. **Bioremediation for Marine Oil Spills**

Dr. William E. Westermeyer
Office of Technology Assessment

9:10 a.m. **Oil Weathering with Variable Winds in the Gulf of Mexico**

Dr. Bruce E. Kirstein
Chemical and Process Engineering Associates

9:25 a.m. **Oil Spill Contingency Planning for Trust Resources of the U.S. Fish and Wildlife Service**

Dr. Brian Cain
U.S. Fish and Wildlife Service

9:50 a.m. **Refreshment Break**

10:05 a.m. **Contingency Planning for the Treatment of Oiled Birds**

Mrs. Lynne Frink
Tri-State Bird Rescue and Research, Inc.

10:30 a.m. **Clean Gulf Associates Oil Spill Response Capabilities: An Update**

Ms. Belinda Breaux
Clean Gulf Associates

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Information Transfer Meeting

Session III.B

Wednesday, November 6, 1991

Crescent "A" Room (16th Floor)

MMS Environmental Studies Program Progress Reports II

Chairs: Dr. Robert Rogers and Dr. James J. Kendall

8:30 a.m.	**Welcome, Opening Remarks**	Dr. Robert Rogers MMS, Gulf of Mexico OCS Region
8:40 a.m.	**Mapping and Biological Reconaissance of the Mississippi-Alabama Pinnacle Trend**	Mr. Richard Shaul Continental Shelf Associates, Inc.
9:00 a.m.	**Overview of Oil and Oil Dispersants Toxicity Program: Dispersed Oil Toxicity Tests with Biological Species Indigenous to the Gulf of Mexico**	Mr. Ken Fucik T. H. E. Laboratories
9:20 a.m.	**Refreshment Break**	
9:40 a.m.	**Environmental Monitoring at the East and West Flower Garden Banks**	Dr. Steve Gittings Texas A&M University
10:00 a.m.	**Growth Rates of Corals and the Incorporation of Trace Metals in Coral Skeletons at the Flower Garden Banks**	Mr. Ken Deslarzes Texas A&M University
10:20 a.m.	**The Effects of Oil Spills on the Corals of the Gulf of Eilat, Red Sea**	Dr. Yossi Loya Tel Aviv University
10:40 a.m.	**Mississippi-Alabama Continental Shelf Ecosystem Study Data Integration and Synthesis**	Dr. Rezneat Darnell Texas A&M University

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Session III.C

Wednesday, November 6, 1991

Crescent "B" (16th Floor)

Social and Economic Studies and Issues

Chairs: Ms. Linda Castaño-Vélez and Mr. John Greene

8:30 a.m.	**Welcome, Opening Remarks**	Ms. Linda Castaño-Vélez MMS, Gulf of Mexico OCS Region
8:40 a.m.	**Socioeconomic Impacts of Declining Oil and Gas Activity in the Gulf of Mexico**	Mr. Lawrence S. McKenzie Applied Technology Research Corporation
9:00 a.m.	**Eliminating the Environmental Costs of OCS Oil and Gas Development and Marine Oil Spills**	Mr. Garry L. Brown A. T. Kearney Mr. Rich Winnor MMS, Economic Studies Branch
9:20 a.m.	**Impacts of Oil and Gas Development on the Recreation and Tourism Off the Florida Straits**	Mr. Garry L. Brown A. T. Kearney
9:40 a.m.	**Refreshment Break**	
10:00 a.m.	**Theory and Practice of Social Impact Assessment: Economic Focus**	Dr. Larry Leistritz North Dakota State University
10:20 a.m.	**Theory and Practice of Social Impact Assessment: Social Focus**	Dr. Hopson Bryan University of Alabama
10:40 a.m.	**MMS Socioeconomic Workshop Plans**	Dr. Shirley Laska University of New Orleans Dr. Robert Gramling University of Southwestern Louisiana

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Session III.D

Wednesday, November 6, 1991

Rosedown (2nd Floor)

The Sea Grant College Program:
A National Perspective and Gulf of Mexico Regional Initiatives

Chairs: Dr. Robert Avent and Mr. Dennis Chew

8:30 a.m. **Welcome, Opening Remarks**

Dr. Robert Avent
Mr. Dennis Chew
MMS, Gulf of Mexico OCS Region

8:40 a.m. **A Description of the National Program: Mandates, Objectives, Organization, History, and Programmatic Directions**

Mr. Robert Shephard
Acting Deputy Director
Oceanic Research Program - NOAA

9:20 a.m. **Texas Sea Grant Program**

Mr. Dewayne Hollin
Texas Sea Grant College Program
Texas A&M University

9:50 a.m. **Refreshment Break**

10:05 a.m. **Florida Sea Grant Program**

Dr. James Cato
Florida Sea Grant College Program
University of Florida

10:35 a.m. **Mississippi and Alabama Sea Grant Program**

Dr. Jess Tupaz
Mississippi-Alabama Sea Grant Consortium

11:05 a.m. **Louisiana Sea Grant Program**

Mr. Ronald Becker
Louisiana Sea Grant College Program
Louisiana State University

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Session IV.A

Wednesday, November 6, 1991

International Ballroom (16th Floor)

Oil Spills Response II

Chairs: Capt. W. J. Loefstedt and Ms. Darice Breeding

1:30 p.m. **Welcome, Opening Remarks**

Ms. Darice Breeding
MMS, Gulf of Mexico OCS Region
and
Capt. W. J. Loefstedt
Eighth U. S. Coast Guard District

1:40 p.m. **MSRC: An Update**

Mr. Robert Allred
Marine Spill Response Corporation

2:05 p.m. **Shoreline Cleanup Assessment Teams Applications in the Gulf of Mexico**

Ms. Karolien Debusschere
Louisiana Geological Survey

2:30 p.m. **LOOP's Recent Spill Response Initiatives**

Ms. Casandra Cooper-Gates
LOOP, Inc.

2:55 p.m. **Refreshment Break**

3:10 p.m. **Federal Oil Spill Research and Development and Oil Pollution Act of 1990 - An Update**

Comdr. Pete Tebeau
Research and Development Center
U.S. Coast Guard

3:35 p.m. **MMS Oil Spill Research: An Update**

Mr. Joseph V. Mullin
MMS, Technology Assessment Research Branch

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Session IV.B

Wednesday, November 6, 1991

Crescent "A" Room (16th Floor)

MMS Environmental Studies Program Progress Reports III.
MMS/LUMCON "University Research Initiative"

Chairs: Dr. Richard Defenbaugh and Dr. Paul Sammarco

1:30 p.m. **Welcome, Opening Remarks**

Dr. Richard Defenbaugh
MMS, Gulf of Mexico OCS Region

1:35 p.m. **Overview of MMS/LUMCON "Universities Research Initiative" Program**

Dr. Paul Sammarco
Executive Director
Louisiana Universities Marine Consortium (LUMCON)

2:05 p.m. **A Review and Reexamination of OCS Spatial-Temporal Variability as Determined by Previous MMS Studies in the Gulf of Mexico**

Dr. Robert Carney
Coastal Ecology Institute
Louisiana State University

2:35 p.m. **Nekton Use of the Marsh Surface: A Comparison Between Channelized and Natural Marshes**

Dr. Lawrence Rozas
Marine Research and Education Center
LUMCON

3:05 p.m. **Refreshment Break**

3:20 p.m. **Influence of Hypoxia on the Interpretation of Effects of Petroleum Production Activities**

Dr. Nancy Rabalais
Marine Research and Education Center
LUMCON

3:45 p.m. **Fate and Transport of Particle-Reactive Aromatic and Heterocyclic Hydrocarbons in a Sediment-Water-Colloid System**

Dr. Jay Means
Institute for Environmental Studies
Louisiana State University

4:15 p.m. **Effect of Shoreline and Shallow Habitat Contamination and Loss on Dominant Infaunal Invertebrates**

Dr. Darryl Felder
Department of Biology
University of Southwestern Louisiana

4:40 p.m. **Effects of Oil Spills and Recovery on Coastal Wetlands**

Dr. Irv Mendelssohn
Center for Wetland Resources
Louisiana State University

Twelfth Annual
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Session IV.C

Wednesday, November 6, 1991

Crescent "B" (16th Floor)

Monitoring, Assessment and Prevention of Marine Debris on Gulf Beaches-Post MARPOL V

Chairs: Mr. Villere Reggio and Dr. Robert Rogers

1:30 p.m. **Welcome, Opening Remarks**

Mr. Villere Reggio
MMS, Gulf of Mexico OCS Region

1:45 p.m. **Take Pride Gulf-Wide Beach Cleanups - The Use of Volunteer Data in Marine Debris Monitoring**

Ms. Linda Maraniss
Center for Marine Conservation

2:15 p.m. **Marine Debris Monitoring on the Gulf's National Seashores**

Mr. John Miller
Padre Island National Seashore

Ms. Gail Bishop
Gulf Islands National Seashore

2:45 p.m. **Refreshment Break**

3:00 p.m. **Marine Debris Monitoring on Mustang Island, Texas**

Mr. Anthony Amos
The University of Texas Marine Science Institute

3:30 p.m. **Industry's Waste Management and Monitoring Program**

Mr. Bernie Herbert
Offshore Operators Committee

Mr. Rodney Foreman
ARCO Oil and Gas Company

4:00 p.m. **Use of Annex V Reception Facilities and Landfills Throughout the Gulf**

Mr. Dewayne Hollin
Texas Sea Grant College Program

Mr. Mike Liffmann
Louisiana Sea Grant College Program

4:30 p.m. **One Company's Response to Offshore Waste Management**

Mr. Dexter Babin
Texas USA

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Session IV.D

Wednesday, November 6, 1991

Rosedown (2nd Floor)

Research Plans by Principal Investigators:
"Texas-Louisiana Shelf Circulation and Transport Processess Study"

Chairs: Dr. Murray L. Brown and Dr. Worth Nowlin

1:00 p.m. **Welcome, Opening Remarks**

Dr. Murray L. Brown
MMS, Gulf of Mexico OCS Region

1:10 p.m. **Preview of MMS Ocean Modeling in the Gulf of Mexico with Emphasis on the LATEX Area**

Ms. Terri Paluszkiewicz and Dr. Walter Johnson
MMS, Headquarters Office

1:40 p.m. **An Overview of the Texas-Louisiana Shelf Physical Oceanography Study**

Dr. Worth Nowlin
Texas A&M University

2:10 p.m. **A Review of Critical Shelf Phenomena and Processes**

Prof. Robert O. Reid
Texas A&M University

2:40 p.m. **Refreshment Break**

3:00 p.m. **A Study of Extratropical Cyclogenesis Events Along the Mid- to Outer-Continental Shelf**

Dr. S. A. Hsu
Coastal Studies Institute/Louisiana State University

3:30 p.m. **A Shelfwide Program of Direct Current Measurements: Moorings, Drifters, and Shipboard Acoustic Doppler Current Profiles**

Mr. Robert Hamilton
Evans-Hamilton, Inc.

4:00 p.m. **A Program of Standard Grid Hydrography for the LATEX Shelf**

Dr. Denis Wiesenberg
Texas A&M University

4:30 p.m. **Critical Aspects of Data and Information Management**

Dr. Norman Guinasso
Texas A&M University

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Session V.A

Thursday, November 7, 1991

Crescent "A" Room (16th Floor)

The Panama Oil Spill Recovery Study, I

Chairs: Dr. James J. Kendall and Dr. Robert Carney

8:30 a.m. **Welcome, Opening Remarks**

Dr. James J. Kendall
MMS, Gulf of Mexico OCS Region

8:35 a.m. **A Review of the Spill, the First Few Weeks**

Dr. Brian D. Keller
Smithsonian Tropical Research Institute

9:00 a.m. **Reef Flat Sessile Biota, Infauna, and Sea Urchins**

Dr. John D. Cubit
Smithsonian Tropical Research Institute

9:25 a.m. **Refreshment Break**

9:45 a.m. **Reef Flat Stomatopods**

Dr. Roy L. Caldwell
University of California

10:10 a.m. **Subtidal Reef Corals**

Mr. Héctor M. Guzmán
Smithsonian Tropical Research Institute

10:35 a.m. **Subtidal Seagrass Communities**

Dr. Michael J. Marshall
Mote Marine Laboratory

11:00 a.m. **Open Discussion for Additional Questions**

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Session V.B

Thursday, November 7, 1991

Crescent "B" Room (16th Floor)

Environmental Hazard Assessment Considerations and the Deep Sea, I

Chairs: Dr. James P. Ray and Dr. Robert M. Avent

8:30 a.m. **Welcome, Opening Remarks, and Introduction**

Dr. James P. Ray
Shell Oil Company
and
Dr. Robert M. Avent
MMS, Gulf of Mexico OCS Region

8:40 a.m. **Deep-Water Oil and Gas Operations**

Mr. Carl Wickizer
Shell Offshore, Inc.

9:15 a.m. **Physical Oceanography Considerations**

Dr. Peter Hamilton
Science Applications International Corporation

9:50 a.m. **Refreshment Break**

10:20 a.m. **Geological Considerations**

Dr. Harry H. Roberts
Coastal Studies Institute
Louisiana State University

10:55 a.m. **Biological Considerations**

Dr. Benny J. Gallaway
LGL Ecological Research Associates, Inc.

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Session V.C

Thursday, November 7, 1991

Rosedown Room (2nd Floor)

Research Plans by Principal Investigators:
"Mississippi River Plume Hydrography Study"

Chairs: Dr. Alexis Lugo-Fernandez and Dr. Stephen Murray

8:00 a.m. **Welcome, Opening Remarks**

Dr. Alexis Lugo-Fernandez - MMS, Gulf of Mexico OCS Region

8:15 a.m. **An Introduction to the Mississippi River Plume Hydrography Study**

Dr. Stephen Murray - Coastal Studies Institute/LSU

8:45 a.m. **The Accoustic Doppler Survey Element of the Plume Study**

Dr. Curt Ebbesmeyer - Evans-Hamilton, Inc.

9:00 a.m. **The Pollutant Chemistry Element of the Plume Study**

Dr. Jay Means - Aquatic Toxicology Laboratory/LSU

9:15 a.m. **The Near-Field Mississippi Plume Survey Element of the Plume Study**

Dr. Larry Rouse - Coastal Studies Institute/LSU

9:30 a.m. **The Benthic Boundary Layer Element of the Plume Study**

Dr. Don Wright -Virginia Institute of Marine Science

9:45 a.m. **The Sediment Flux Element of the Plume Study**

Dr. Wilf Gardner and Dr. Mary Jo Richardson - Texas A&M University

10:00 a.m. **Refreshment Break**

10:15 a.m. **The Biological Oceanography and Phytoplankton Element of the Plume Study**

Dr. Gene Turner - Coastal Ecology Institute/LSU

10:35 a.m. **The Zooplankton Element of the Plume Study**

Dr. Rick Shaw - Coastal Fisheries Institute/LSU

10:50 a.m. **The Hypoxia Element of the Plume Study**

Dr. Nancy Rabalais - Louisiana Universities Marine Consortium

11:05 a.m. **The Data Management and Information Transfer Elements of the Plume Study**

Ms. Mary White -Coastal Studies Institute/LSU

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Session VI.A

Thursday, November 7, 1991

Crescent "A" Room (16th Floor)

Panama Oil Spill Recovery Study, II

Chairs: Dr. James J. Kendall and Dr. Robert Carney

1:30 p.m. **Welcome, Opening Remarks**

Dr. James J. Kendall
MMS, Gulf of Mexico OCS Region

1:35 p.m. **Brief Review of the Morning Session**

Dr. Brian D. Keller
Smithsonian Tropical Research Institute

1:55 p.m. **Mangrove Forests**

Dr. Norman C. Duke
Smithsonian Tropical Research Institute

2:20 p.m. **The Mangrove Fringe and the Epibiota of Mangrove Roots**

Dr. Sally C. Levings
Smithsonian Tropical Research Institute

2:45 p.m. **Hydrocarbon Analyses**

Dr. Kathryn A. Burns
Bermuda Biological Station for Research

3:10 p.m. **Refreshment Break**

3:25 p.m. **Tying It All Together: Open Panel Discussion -- All Participants and Scientific Review Board Members!**

Dr. Robert Carney, SRB Chair, Louisiana State University
Dr. Edward Van Vleet, SRB Member, University of South Florida
Dr. Richard Dodge, SRB Member, Nova University
Dr. Roger Green, SRB Member, University of W. Ontario
Dr. Yossi Loya, SRB Member, Tel Aviv University
Dr. Donald Aurand, SRB Member, Marine Spill Response Corp.

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Session VI.B

Thursday, November 7, 1991

Crescent "B" Room (16th Floor)

Environmental Hazard Assessment Considerations and the Deep Sea, II

Chairs: Dr. James P. Ray and Dr. Robert M. Avent

1:30 p.m. **Welcome, Opening Remarks**

Dr. James P. Ray
Shell Oil Company
and
Dr. Robert M. Avent
MMS, Gulf of Mexico OCS Region

1:40 p.m. **Deep Water Drill Discharge and Produced Water Modeling**

Dr. Robert C. Ayers, Jr.
Exxon Production Co.

2:15 p.m. **Technical Considerations for the Hazard Assessment Process**

Dr. Jerry M. Neff
Arthur D. Little, Inc.

2:50 p.m. **Refreshment Break**

3:20 p.m. **Panel Discussions**

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Information Transfer Meeting

Session VI.C

Thursday, November 7, 1991

Rosedown Room (2nd Floor)

Research Plans by Principal Investigators:
Gulf of Mexico Eddy Circulation Study

Chairs: Dr. Walter Johnson and Dr. Tom Berger

1:45 p.m. **Welcome, Opening Remarks**

Dr. Walter Johnson,
MMS, Branch of Environmental Operations and Analysis

2:00 p.m. **The Remote Sensing Element of the LATEX Plume Study and Program-Wide Information Support**

Dr. Larry Rouse
Coastal Studies Institute/Louisiana State University

2:30 p.m. **An Overview of the LATEX Eddy Circulation Study**

Dr. Tom Berger
Science Applications International Corporation

3:00 p.m. **Buoy Placement and Tracking in the LATEX Eddy Study**

Dr. Peter Hamilton
Science Applications International Corporation

3:30 p.m. **Refreshment Break**

3:45 p.m. **Data Management and Information Transfer in the LATEX Eddy Study**

Dr. Bob Wayland
Science Applications International Corporation

4:15 p.m. **Program Logistics and Ships-of-Opportunity in the LATEX Eddy Study**

Mr. Jim Singer
Science Applications International Corporation

4:45 p.m. **Cooperative Study of Wave/Mesoscale Circulation Interaction in the LATEX Eddy Study**

Dr. David Sheres
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