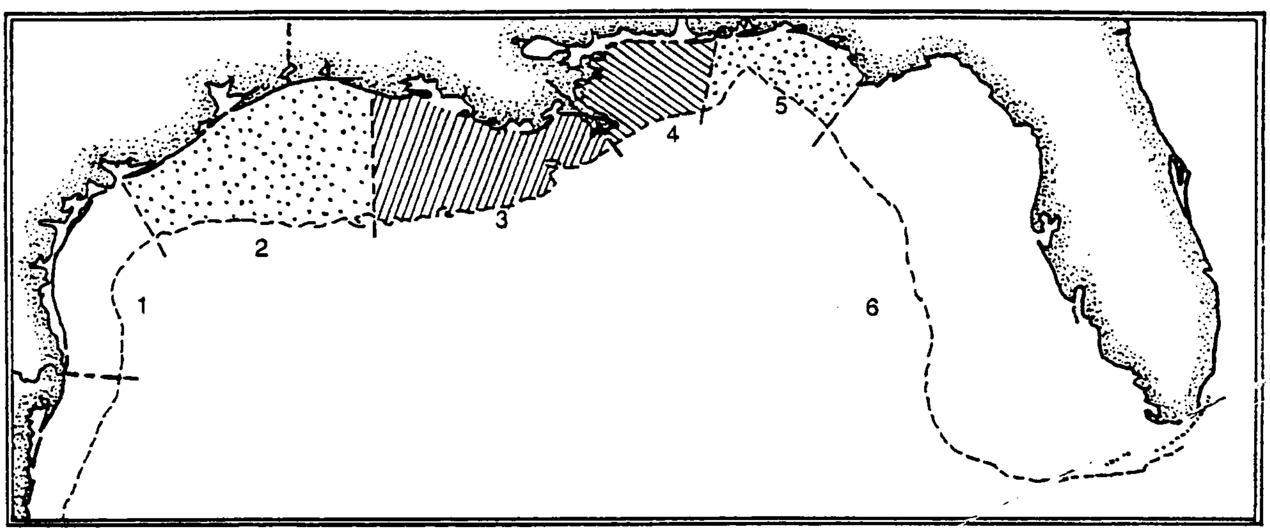
OCS Study
MMS 90-0018

Northern Gulf of Mexico Environmental Studies Planning Workshop

Proceedings of a Workshop Held in New Orleans

August 15-17, 1989



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

OCS Study
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Editor

Robert S. Carney
Coastal Ecological Institute
Louisiana State University

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ABOUT THE COVER

Cover artwork is from the abstract presented by Dr. Rezneat M. Darnell, Department of Oceanography, Texas A&M University, at the Northern Gulf of Mexico Environmental Studies Planning Workshop. The original figure appears on page 125 in the following proceedings.

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EXECUTIVE SUMMARY

A meeting was held on August 15-17, 1989, in New Orleans, Louisiana to provide technical input into three planned Minerals Management Service (MMS) studies in the Gulf of Mexico. These studies were to be (1) a process oriented ecosystem study in the Texas and Louisiana Outer Continental Shelf (OCS) region (The TEXLA Ecosystem Study), (2) a long-term monitoring program designed to understand natural variation throughout the Gulf of Mexico OCS (The Long-Term Monitoring Study), and (3) a study to examine the potential of low-level, chronic impacts possibly associated with low-level, long-term chronic stresses at established oil and gas activities (Effects of Long-Term Production Sites). MMS staff presented these projects from the management perspective. Invited scientists with a breadth of expertise on coastal ocean processes then gave brief technical contributions for approximately one day. Following the presentations, three separate working groups were formed to address specific issues of design.

Common to all three studies was the challenge and obligation to be the first implementation of new MMS directions stressing process oriented studies, post leasing activity, and studies in regions of high oil and gas activity. The difficult task of participating scientists was to propose process studies of obvious and immediate mission value at a time when the full potential of these approaches has yet to be fully explored in basic research. In spite of the pioneer status of both the management and the scientific components, it was concluded that all three studies were feasible. New, process oriented studies were feasible and could lead to a great improvement in predictive capability in the OCS if fostered and developed carefully.

The TEXLA Ecosystem Study should consist of intensive field sampling linked to simulation modeling with special emphasis upon the benthic component, MMS' traditional focus, as part of a larger system. The dynamics of the whole system are greatly influenced by physical factors which both regulate transport and impose a source of physical disturbance. The flow of carbon (food) and nutrients (primarily nitrogen) is of central importance. The design of field sampling must take into account the major physical features of the region including the Mississippi/Atchafalaya plume, coastal boundary currents, and gyres and rings of the Loop current. The TEXLA Ecosystem Study must include a major modeling effort and be closely linked with MMS physical oceanography studies. Success of this implementation of a process oriented study will require a management structure which encourages innovation, coordination, and careful, critical review of ongoing projects.

The Long-Term Monitoring Study differs from site characterization studies in that it seeks to understand long-term variation and the relationship among variables. It should focus upon changes in benthic populations, but include monitoring of the water column and of chemical evidence of changing contaminant levels. Ideally, it would include transect sampling in six regional subdivisions quarterly for a period of at least ten years. Transect sampling would include six stations across a bathymetric gradient. These transects could be augmented with a site of greater spatial coverage in conjunction with the TEXLA study. A predictive modeling effort would be required which would be charged with predicting future field results on the basis of past results, then improving the model after annual comparisons are made. Success of this implementation of a long-term study requires a management structure which encourages innovation, central planning, and multi-institution participation.

The Effects of Long-Term Production Sites Study is tasked with resolving the persistent concern about long-term, subtle impacts resulting from low-level chronic stresses against a background of great natural variation. This project must limit itself to testing specific hypothesized impacts linked to a specific toxin. Components must document the behavior of the candidate toxins in the natural environment and then assess the nature and extent of their toxicity. These two tasks will require both innovative field and laboratory work. Special attention must be given to application of new methods of detecting the stress and the resulting impact at the organism level. Field efforts should make use of a paired platform design in which a simple gradient of possible impact is sampled for at numerous sites. This departs from the traditional intensive "bulls eye" sampling around a limited number of platforms. Success of this implementation of a long-term study requires a management structure which encourages innovation and careful quality assurance and control.

If fully implemented, each study would differ so greatly from the others that sharing of resources, ships, and data would not be greatly beneficial. However, if funding limits result in a reduced scope, portions of the TEXLA Ecosystem Study and the Long-Term Monitoring Study could be combined with respect to stations, cruises, and data. The detection of stress requires work in contaminated areas and can not be easily combined with either

of the other projects. Planned MMS physical oceanography studies should be coordinated with the biological projects. Of the three, the TEXLA Ecosystem Study has the greatest need for physical data. Cooperation with physical studies should include simultaneous data collection, modeling, analysis, synthesis, and ongoing planning.

1.0 INTRODUCTION

1.0 INTRODUCTION

1.1 Background

In response to the high level of oil and gas activity in the Gulf of Mexico and an important shift in Minerals Management Service (MMS) emphasis to high activity areas and post leasing activity, it is anticipated that the Northern Gulf of Mexico will be the site of unprecedented studies beginning in fiscal year 1990. In order to meet evolving environmental management concerns in the region, three new studies are now in the planning phase.

Texas-Louisiana Marine Ecosystem Study (TEXLA) - This study marks the transition to a greater emphasis upon process studies. It is to be designed to gain a useful level of understanding of the relationships between the inherently changing environment and the ecosystem of the region. Such a regional understanding of natural function will allow for better informed decisions as to the potential undesirable impacts resulting from oil and gas activities.

Long-Term Monitoring at Selected Sites in the Northern Gulf of Mexico - Due to the Gulf of Mexico's continuing potential for future oil and gas development, it is the ideal region to undertake studies of natural spatial and temporal variation. The study is to be designed so that a quantitative assessment of variation and relationship among varying parameters will be determined. This information will allow for improved sampling design in future studies and greatly aid interpretation of any studies in which the high level of natural variation is potentially confounding.

Detection of Impacts associated with Long-Term Oil and Gas Activity Sites -Due to the length of oil and gas development in the Gulf of Mexico, this region is ideally suited to examine the lingering national question of chronic low-level stresses. The study is to be designed to make it possible to test for previously undetectable levels or types of impacts in the proximity of structures beyond the small zone of well demonstrated acute near-field effects.

1.2 Purposes

While it was the purpose of the workshop to provide technical input to each of the three separate projects, there were three common information needs to be addressed. These can be summarized as follows.

What is effective long-term monitoring? What are the appropriate impact related questions to be asked in long-term studies, and in what way is long-term substantially different from short-term characterization?

How are low-level stresses to be recognized? Is a chronic low-level stress of the same nature but just of less intensity as acute stresses, or are they a distinct category of impact requiring new ways of looking for effects?

How is the transition made from descriptive to more meaningful process studies? Exactly what is the management potential of process studies, and how can MMS maximize the application to management needs.

1.3 Symposium and Workshop Structure

The workshop was designed for each of the three separate studies to take advantage of a single pool of expertise drawn primarily from the scientific community. The task of employing this talent was assigned to working group chairs and cochairs selected from MMS and the scientific community. These groups were:

Texas-Louisiana Marine Ecosystem Study

Dr. R. Eugene Turner, Chairman, Dept. Marine Sciences,
Louisiana State University
Dr. Gilbert Rowe, Chairman, Dept. Oceanography, Texas A&M University
Dr. Robert Avent, MMS Gulf of Mexico OCS Region

Long-Term Monitoring at Selected Sites in Northern Gulf of Mexico

Dr. Rezneat Darnell, Dept. Oceanography, Texas A&M University
Dr. Robert Rogers, MMS Gulf of Mexico OCS Region

Detection of Impacts Associated with Long-Term Oil and Gas Activity Sites

Dr. James Ray, Shell Oil Corporation
Dr. James Kendall, MMS Gulf of Mexico OCS Region

Formal presentations during the first day and a half were invited from knowledgeable people to review both the current level of knowledge and to learn about the changing emphasis of MMS Outer Continental Studies (OCS) studies. A total of 25 speakers were invited. In selecting participants, an effort was made to find scientists capable of addressing the generic problems as well as specific details of design and execution.

2.0 INVITED PRESENTATIONS

2.0 INVITED PRESENTATIONS

2.1 An Introduction to Changing Management Needs

It was the purpose of this section to introduce to the participants both the specific topics for technical input and a general sense of the management needs which MMS must fulfill through its studies. The tasks facing MMS are presented from three perspectives, the national-level planner, the regional studies chief, and the contracting officer's technical representative. Across these three perspectives there is an evolution in the view taken from the broadly generic to the highly specific task details. From the generic national view, MMS management is faced with designing a program structure to meet changing national needs and concerns on any coast effectively and efficiently. From the regional view, the primary task is the design, scoping, and contracting of highly specific project components with direct management value in the Gulf of Mexico.

The studies that are carried out as a result of this workshop will be among the first to reflect the changing generic emphasis within the MMS Environmental Studies Program (ESP). As such, there is an added complexity to the task of study design. This complexity arises from the difficulty in taking some of the generic changes outlined in sections 2.1.1 and 2.1.2 and translating them into the three specific field tasks outlined in section 2.1.3 through 2.1.5. This difficulty is most readily apparent with respect to monitoring for long-term, low-level cumulative impacts and the development of process studies to provide a better understanding of the mechanisms causing the observed impacts.

No matter how conceptually obvious it is that long-term and ecosystem level studies will ultimately improve MMS' ability to predict or avoid impacts, it is less obvious in practice how to design real studies which will meet management needs. In the coastal ocean, studying and fully understanding the processes of change are complex tasks not yet successfully completed on the scales required by MMS' information needs. Indeed, the oceanographers who study such processes are still at that unrefined phase of science in which new ideas are still being explored.

The three proposed studies were:

- Texas-Louisiana Shelf Marine Ecosystems Program - an ecological characterization study, including both descriptive and processes components to complement currently available information; to be conducted on the TEXLA Shelf.

- Long-Term Monitoring at Marine Ecosystem Sites - a program to study natural variability over the long-term at representative non-impacted sites; to be conducted at selected sites Gulf-wide.

- Effects of OCS Development and Production Activities - a program to study the chronic and cumulative impacts of OCS oil and gas activities at selected industry sites, with particular emphasis on sites of petroleum development and throughout the Gulf where a history of OCS petroleum development exists (primarily on the TEXLA Shelf, but also on the Mississippi-Alabama Shelf).

2.1.1

CHANGING EMPHASES IN OCS STUDIES

Dr. Thomas E. Ahlfeld
Staff Oceanographer
Minerals Management Service
Branch of Environmental Studies

INTRODUCTION

The Minerals Management Service (MMS) of the U.S. Department of the Interior is responsible for the leasing and supervision of offshore oil and gas operations on the outer continental shelf (OCS) of the United States. A commitment to obtaining and using environmental information during all phases of the Offshore Oil and Gas Program is demonstrated by the establishment of the Environmental Studies Program (ESP) in 1973. Since its inception, the ESP has expended approximately $470 million towards the collection, analysis, and dissemination of environmental and socio-economic information used to support decision-making in the Offshore Oil and Gas Program.

The OCS Lands Act Amendments of 1978 provided the ESP with the objective of "... establishing information needed for prediction, assessment, and management of impacts on the OCS and the nearshore area which may be affected." Studies were designed to support four basic ESP goals.

- Enhance the OCS oil and gas leasing process by providing information on the status of the environment which may be used in predicting impacts.
- Provide information on the ways and extent that OCS development can potentially impact human, marine, and coastal environments.
- Ensure that information already available, and that to be collected in the future, is in a form that can be used in OCS decision-making.
- Provide a basis for future monitoring of OCS operations.

These original ESP goals have been expanded, and the current (and planned future) emphasis is on the collection of environmental information used to support post-lease decisions and evaluate operational impacts. Studies designed to monitor the effects of OCS oil and gas development and production activities now represent a high priority to the ESP.

MAJOR EVENTS AND PAST ACCOMPLISHMENTS OF THE ESP

From 1973 to 1978, the focus of the ESP was on baseline characterizations, also called benchmark studies. These were large, multidisciplinary investigations designed to characterize the nature, abundance, and diversity of biological communities, the physical characteristics of the seafloor and overlying waters, and concentrations of certain trace metals and hydrocarbons in the water, sediments, and biota prior to any OCS oil and gas activity in an area. In concept, a series of monitoring studies was to follow each baseline characterization to provide information on changes in environmental characteristics relative to the baseline data as oil and gas activities proceeded. This program design was criticized by internal Department of the Interior reviews for not providing timely and appropriate information for OCS decision-making. Reviews conducted by the General Accounting Office (GAO) and National Research Council (NRC) were also critical of this program design. The NRC review advised that the marine environment is too variable for a statistically valid baseline to be determined in the time frame, and on the spatial scale necessary for projected post-lease monitoring. For these reasons, the ESP was restructured to answer more immediate pre-lease decision-making needs, and the baseline approach was abandoned. The restructured ESP required a clear relationship between a study and OCS decisions and issues.

From 1978 to 1985, there was considerable emphasis placed on physical oceanographic and marine biological field studies to characterize the ecological resources at risk in various planning areas and to provide data necessary for circulation modeling. Although the majority of studies during this period were designed to support pre-lease environmental analysis, monitoring studies were also undertaken to evaluate the impacts associated with OCS oil and gas exploration activities. The three-year Georges Bank Monitoring Program is considered a key study in demonstrating that effects of drilling fluids and cuttings from OCS exploration are limited to within a few hundred meters of the discharge and are not long-term in nature.

By 1985, the MMS had concluded that it would be appropriate to reevaluate the focus of the ESP. One step in this reevaluation was the initiation of work on a Long-Range Study Plan. Another step was to request the NRC to review the ESP for a second time to offer advice on the future direction of the program. Additionally, a more recent GAO audit was completed in June 1988. This generally favorable audit recommended changes in the MMS - National Oceanic and Atmospheric Administration relationship in the management of Alaska OCS Environmental Assessment Program studies.

Two recent publications have played key roles in the current ESP restructuring. They are "Oil in the Sea: Inputs, Fates, and Effects," published in 1985 by the National Academy of Sciences and "Long-Term Environmental Effects of Offshore Oil and Gas Development," edited by Boesch and Rabalais in 1987.

FUTURE DIRECTION AND CHANGING EMPHASES IN THE ESP

When development of the Long-Range Study Plan began in 1985, it was envisioned as a link between the ESP and the anticipated events in a specific five-year period. It became obvious, however, that the long lead time for planning environmental studies, along with the time necessary to complete many field studies, did not lend itself to a five-year planning window. Consequently, the MMS chose to focus on likely pre- and post-lease events for the next ten years to determine study needs. Because these needs must be considered in the context of existing information, the document presents an analysis of the current status of knowledge for each topical area of proposed studies. The Long-Range Study Plan then concentrates on issues of high priority amenable to resolution through scientific investigations.

A second draft of the Long-Range Study Plan is nearly ready for release for public comment. The plan will not provide detailed descriptions of all anticipated studies. Rather, it will focus on goals and objectives to be accomplished. This information will direct the annual planning efforts, during which individual studies are identified and funding priorities are set.

Based on the Draft Long-Range Study Plan, it is possible to summarize some of the expected future trends for the ESP. The major shift in emphasis to post-lease issues will continue. In frontier areas where environmental information is scarce and where the potential for oil and gas development and production exists, the ESP will continue the collection of descriptive information for use in pre-lease decision-making. There are lease areas, however, where an adequate data base exists on which pre-lease decisions have been made in the past and can be made in the future. Additional descriptive studies designed only to refine the baseline data for pre-lease decisions will not be supported.

The ESP will focus on areas of known oil and gas resources as sales are held and exploration follows. In areas with little or no potential for oil and gas development, limited or no study will be sponsored by the ESP. In areas with oil and gas development and production, the ESP will undertake studies to monitor the effects of these activities on the environment. These studies will concentrate on the evaluation of long-term, low-level cumulative impacts of oil and gas development on the marine environment. Rather than merely documenting changes in environmental conditions through classical monitoring techniques, the MMS plans to emphasize the development of process studies to provide a better understanding of the mechanisms causing observed impacts. This change in emphasis is demonstrated by this workshop ("MMS Northern Gulf of Mexico Studies Planning Workshop") and others sponsored by the ESP. Session 2 of this workshop, "General Concerns in Long-Term Designs and the Application of Process Studies", will provide a basis for deliberations concerning the development of process-oriented monitoring for oil and gas production impacts in the northern Gulf of Mexico.

Another trend evident in the Long-Range Study Plan is the phasing of studies to provide information at appropriate times in the OCS decision process. Each phase of the Offshore Oil and Gas Program, from the scheduling of lease sales through the production of hydrocarbon resources, has different information requirements with unique study opportunities. For example, given the localized nature of potential impacts, it is impractical to develop site specific information prior to a lease sale. It is relatively common for questions related to operational impacts to arise during the pre-lease evaluation process, but all such issues cannot be resolved at that time. In addition, much of the data available for other regions may be useful in interpreting potential impacts. Pre-lease studies, where needed, will emphasize broader area, more generalized characterization.

A fifth trend established by the Long-Range Study Plan is that the ESP will support studies to evaluate oil spill impacts whenever circumstances suggest that a study would be appropriate and resources are available. Because the occurrence of major oil spill events is unpredictable and relatively rare, ESP funding will not always be available. However, the ESP has sponsored studies of three recent spills. In 1986, a major spill at Bahia Las Minas, Panama significantly impacted coral reef, seagrass, and mangrove communities similar to those of south Florida. The ESP took advantage of this natural laboratory opportunity and the 15-year pre-spill data base established by the Smithsonian Tropical Research Institute to fund a 5-year assessment of the oil spill impacts. The MMS also sponsored intertidal and subtidal investigations along the Olympic National Park coast of Washington State following the NESTUCCA oil barge spill in 1988. Most recently, the ESP sponsored environmental and socio-economic impact studies of the EXXON VALDEZ tanker spill in Alaska.

Finally, the Long-Range Study Plan places emphasis on efforts to improve the accessibility and usefulness of data collected through the ESP. Synthesis reports, technical position papers, dissemination of technical summary information, and study planning workshops will have a high priority.

2.1.2

MINERALS MANAGEMENT SERVICE PLANNING FOR NORTHERN GULF OF MEXICO ENVIRONMENTAL STUDIES: THE GULF OF MEXICO OCS REGIONAL OFFICE PERSPECTIVE

Dr. Richard E. Defenbaugh
Chief, Environmental Studies Section
Minerals Management Service
Gulf of Mexico OCS Region

The "Northern Gulf of Mexico Environmental Studies Planning Workshop" is being held to provide a forum for discussion to support planning for three studies (see below) which have been approved by the Minerals Management Service (MMS) for substantial multi-year funding. The purpose of this presentation is to provide administrative direction to the workshop discussions.

The studies discussed, their study areas, and the general focus (as originally conceived) of each study are:

- Texas-Louisiana Shelf Marine Ecosystems Program - an ecological characterization study, including both descriptive and processes components to complement currently available information; to be conducted on the TEXLA Shelf.

- Long-Term Monitoring at Marine Ecosystem Sites - a program to study natural variability over the long-term at representative non-impacted sites; to be conducted at selected sites Gulf-wide.

- Effects of OCS Development and Production Activities - a program to study the chronic and cumulative impacts of OCS oil and gas activities at selected industry sites, with particular emphasis on sites of petroleum development and throughout the Gulf where a history of OCS petroleum development exists (primarily on the TEXLA Shelf, but also on the Mississippi-Alabama Shelf).

Workshop participants have been invited to represent many perspectives, but the academic perspective was purposely emphasized. No bounds will be placed on workshop technical discussions, although certain procurement management decisions and MMS policies are outside the scope of the workshop. MMS recognizes that the nature of these studies, and even the number of projects to be awarded, must be reconsidered following completion of the workshop.

The planning bases to be considered by MMS for these studies will include several components: a list of potential study elements, focusing on topics of interest or concern to MMS; study methods to accomplish the various study elements; study priorities or study sequences, to provide a scheduling base; and an understanding of how study results will have management utility. The objective of the workshop is to develop, through open discussion, these planning bases.

MMS' mission involves leasing, permitting, and regulating exploration, development, and production of petroleum and non-energy minerals on the Outer Continental Shelf (OCS), and funds research which supports this mission. The MMS Environmental Studies Program was initiated in 1973 by the Bureau of Land Management (BLM) to support OCS leasing and lease-management decisions. In 1981-2, OCS-mission components of the U.S. Geological Survey and of the BLM were merged to form the MMS. Since 1973, the BLM/MMS has awarded more than $72.4 million for studies to support the OCS program in the Gulf of Mexico (Table 1). To date, these studies have emphasized descriptive characterizations of marine ecosystems, physical oceanographic studies, and studies of the ecological effects of oil and gas activities.

Table 1. MMS Environmental Studies Program for the Gulf of Mexico: Funding by Study Series, 1973 to July 1989.

	Awards	Funding
Environmental Mapping	14	$ 6,359,164
Physical Oceanography	27	10,607,337
Marine Ecosystems	45	38,417,231
Coastal Studies	4	3,995,493
Endangered Species	10	2,434,576
Ecological Effects of Oil and Gas	17	8,418,715
Socio/Economic Studies	5	944,772
Cultural Resources Studies	2	537,803
Information Management	5	685,321
Totals	129	$72,400,412

The MMS Environmental Studies Program (ESP) supplies information for use within MMS, as well as by other users. Within MMS, this information is used for development of the programmatic environmental impact statement (EIS) which is the primary document for 5-year OCS lease sale planning; for development of the EIS' for each OCS sale; for development of special measures to mitigate anticipated impacts to valued offshore resources or to protect human and environmental safety; to support agency environmental and engineering reviews of industry's plans for offshore exploration, development, production, transportation, and platform removals. Users outside the MMS include marine and coastal resource managers in state or other federal agencies; scientists in academic and consulting organizations; scientists, engineers, and managers for the offshore and coastal oil and gas industry; environmental interest groups; and a variety of other individuals and organizations.

As detailed in section 2.1.1 by Ahlfeld, recent guidance issued by the MMS Headquarters Office (Aurand 1988) directs the ESP to (1) emphasize collection of information for post-lease decisions, rather than pre-lease decision; (2) focus on OCS areas with known oil and gas resources; (3) concentrate on evaluating long-term, low-level cumulative impacts of oil and gas development on the environment, with emphasis on process-oriented studies to explain mechanisms causing observed impacts; (4) phase studies to provide information appropriate to the decisions at hand; (5) study impacts of accidental oil spill when appropriate; (6) support wide accessibility and utility of data and information, including synthesis reports and position papers; and (7) support information management and dissemination activities to provide reliable information to concerned citizens and non-MMS decision-makers.

The MMS plans environmental studies on an annual basis, with planning activities preceding funding approvals by about two fiscal years. Each annual planning exercise within the Gulf of Mexico OCS Region considers future-year planning for five to seven years from the time of the planning workshops. Based on these regional studies plans, program emphasis for the Gulf of Mexico for the five-year period beginning in fiscal year 1990 will be on the three studies discussed at the workshop plus:

- a major physical oceanography program planned for the TEXLA Shelf, and a companion circulation modeling study;
- studies of the populations of sea turtles and marine mammals within the Gulf of Mexico, and of possible impacts due to OCS activities;
- a program administered within Louisiana universities for study of the effects of long-term production of OCS oil and gas;
- studies to support oil spill control or clean-up, including use of oil dispersants;

- continued development of a geographic information system (GIS) for environmental analysis; and

- information transfer meetings and workshops.

The MMS ESP is implemented through contracts and contract-like agreements with researchers in private firms, academic institutions, and federal and state agencies. The usual contracting is by competitive procurement, according to standard Federal Acquisition Regulations, to the private sector. Other modes include inter-agency agreements with federal agencies having unique research or support capabilities, and cooperative agreements with state agencies or universities when a mutual benefit between MMS and the recipient institution is possible.

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2.1.3

PLANNING FOR LONG-TERM MONITORING AT SELECTED MARINE ECOSYSTEM SITES

Dr. Robert M. Rogers
Environmental Studies Staff
Minerals Management Service
Gulf of Mexico OCS Region

INTRODUCTION AND HISTORY

Responsiveness to changing environmental concerns voiced by federal agencies, states, and individuals with respect to Outer Continental Shelf (OCS) oil and gas leasing and operations is a constantly evolving process faced by the Environmental Studies Program (ESP) of the Minerals Management Service (MMS). One recent program change of emphasis is renewed interest in evaluation and explanation of long-term, low-level cumulative impacts of oil and gas development. An important facet of pursuing this new emphasis is the development of appropriate process-oriented studies to allow explanations of the causal mechanisms underlying any apparent impacts.

While most researchers agree that acute impacts from operational discharges from OCS oil and gas facilities are either localized or resolvable through mitigation, there is less certainty concerning chronic, sublethal effects (Aurand 1988). Such impacts, if present, are difficult to detect and quantify. Studies directed at these types of impacts were not a high priority in the early days of the ESP before even gross acute impacts were not well defined. With the resolution of acute impact questions, chronic impacts have become more critical as research topics (NRC 1985; Boesch and Rabalais 1987).

We are here today to plan for a long-term monitoring program at selected marine ecosystem sites in the Gulf of Mexico. This study effort was originally nominated for funding consideration in fiscal year (FY) 1988. At that time it had the study title of "Long-term Monitoring at Topographic Features and Selected Marine Ecosystem Sites." Through the staff planning process, it was soon apparent that two distinctly different monitoring projects were embodied in this study title. Monitoring of topographic features, namely the East and West Flower Garden Banks, was a relatively straightforward task involving visually monitoring coral growth, competition, and general health of the coral community. However, monitoring of long-term effects of selected marine ecosystem sites was a more complicated process with planning difficulties arising from even the most basic tasks such as selecting the sites to be monitored. With this in mind, the two study efforts were separated for procurement and monitoring at the Flower Garden Banks was begun in late FY 1988.

This left us with the study title of "Long-term Monitoring at Selected Marine Ecosystem Sites." From this workshop, we hope to generate a working hypothesis on exactly what we can expect to accomplish from a long-term monitoring program. This must be framed in the context of why the MMS carries out studies. This can be paraphrased from the mandates as established by the OCS Lands Act Amendment of 1978: (1) to establish information needed for assessment and management of environmental impacts on the human, marine, and coastal environments which may be affected; (2) to predict impacts on the marine biota which may result from chronic low level pollution or large spills associated with OCS production; and (3) to monitor the human, marine, and coastal environments of such areas in a manner designed to provide time-series and data trend information for the purpose of identifying any significant changes in the quality and productivity of such environments.

The MMS, and formerly the Bureau of Land Management (BLM), funded many large-scale environmental studies in the Gulf of Mexico, to characterize the environment and to assess impacts of OCS activities. Each study would have benefitted from a better understanding of long-term natural variability at the study sites at the time those studies were conducted; this planned study will build on the data bases generated during those studies to develop a better understanding of long-term environmental variability Gulf-wide. This program will complement the planned study, "Effects of OCS Development and Production Activities, Northwestern Gulf of Mexico"; but will differ in the focus on understanding natural variability, as compared to "effects" studies at sites where impacts have occurred due to petroleum development and production activities.

It is presently thought that if OCS oil and gas activities pose a problem, the impacts would be expressed as changes in ecological processes or population, and that these processes and populations already possess a tremendous variability. This should be the focus of this workshop's looking at long-term monitoring, i.e., what is the natural variation in the Northern Gulf monitoring, both on a spatial and a temporal scale?

SITE SELECTION

Site selection will be critical to successfully observing impacts, if they are there. Ideally sample site selection would be in an area strongly impacted by oil pollution (high hydrocarbon concentrations, low numbers and diversity of organisms). A short distance away in a comparable benthic environment, there would be a completely pristine site. Needless to say, such an ideal study site probably will not be found.

Difficulties in data interpretation in past studies have resulted from the lack of consideration in sample site selection from conflicting signals due to the impacts of riverine input, especially from the Mississippi River, proximity to shipping channels, and the effects of hurricane passages and winter storm events. The location of control sites is also very important in generating data that can be meaningfully interpreted.

Another factor in site selection should be the comparability of ecological regimes. It has certainly been learned that sampling of a series of sites in different regions, whether due to depth, sediments, or numerous other considerations, can only confuse comparability of the resulting data.

A further consideration in site selection will be the possibility of utilizing previously occupied sites. How valuable are the time-series data already gathered from previous baseline studies, whether MMS or other? Despite out-of-date methodologies and changes in taxonomy, can some of the data be effectively utilized?

SAMPLING METHODOLOGIES AND INTENSITY

Although it is obvious that an understanding of processes is important in investigating environmental impacts, the emphasis in sampling for this monitoring effort will be in the benthic environment, concentrating on this more stable region of relatively sedentary organisms and populations of greatest longevity. Departing from the "baseline" philosophy of sampling everything, however, the question becomes "what do we sample?

Equally important is the intensity of sampling. A number of questions will have to be addressed.

- Is diel sampling necessary?
- Is seasonal or monthly sampling necessary?
- Just how "long" is long-term monitoring? What information exists to indicate how long sampling should continue?
- How many sample replicates should be taken? It would appear that more attention should be given to variance at each station in selecting the number of replicates.
- Should there be an emphasis on spatial patterns in sampling?
- Would transect sampling be useful or is enough information available related to spatial variability?

OTHER RESEARCH PLANNING QUESTIONS

Of course, it will be necessary to discuss the types of information to be gathered at each station. This will include what physical, geological, and chemical information is needed in support of biological parameters; and which biological elements (macroinfauna, meiofauna, epifauna, and fishes) should be sampled.

Other topics to be considered during the course of this workshop will be the relation of this study to the other studies being planned during this workshop. Some of the topics to be discussed here are relatively straightforward; some are more difficult. The important thing is to frame the hypothesis--to insure that we are asking the right questions. Numerous researchers have emphasized the importance of a well thought-out study design in environmental impact assessment and the ambiguities of not having one (Green 1979; Carney 1987). Perhaps, more planning will be necessary following this workshop and a preliminary information gathering and limited field sampling initiated before the actual long-term field program is implemented.

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2.1.4

DETECTION OF EFFECTS AT LONG-TERM PRODUCTION SITES

Dr. James J. Kendall
Environmental Studies Staff
Minerals Management Service
Gulf of Mexico OCS Region

Since the inception of the Outer Continental Shelf (OCS) Environmental Studies Program (ESP), a stated aim has been the characterization of the effects of offshore oil and gas activities either through a comparison of current ecosystem data with earlier "benchmark" data or through special studies oriented toward monitoring specific agents/activities or groups of agents/activities. The results of these studies have been important in understanding the impacts of these activities, including both the nature and the extent of the impact. Information of this sort has been used to develop mitigating measures, where needed, and to reduce or otherwise limit adverse impacts due to OCS oil and gas activities.

The study(s) to be conducted under Regional Study Number G-031/G90-F003, "Effects of OCS Development and Production Activities, Northwestern Gulf of Mexico," are intended to elucidate the chronic low-level, long-term stresses of developmental drilling and production activities in an area with a long history of oil and gas development, production, and transportation. In particular, sites in the Western and Central Gulf of Mexico far enough west to be outside the perpetual influence of the Mississippi River plume. The fiscal year (FY) 1990 effort is conceived as the first of several study years, to be funded in recurring 3-year cycles. The continuation of this study, or suite of related studies, over a multi-year period will allow the Minerals Management Service (MMS) to define these chronic low-level, long-term stresses of OCS drilling and production activities.

This program will built on the findings of past rig and platform monitoring studies conducted in the Gulf of Mexico, Pacific, and Atlantic OCS Regions, as well as other ecosystems studies in the northwestern Gulf previous to, or concurrent with, this effort. This program will complement our planned study, "Long-Term Monitoring at Marine Ecosystem Sites," but will differ by focusing on production sites where impacts may have occurred due to offshore oil and gas industry activities, as compared to studies of natural variability at sites believed to have not been impacted by such activities.

The importance of this study to the decision-making process of the MMS is that the ESP has recently shifted its focus to studies of chronic, low-level, long-term environmental impacts due to offshore oil and gas activities in developed regions. Ecosystem processes and functions are also to be examined to allow for an explanation of the mechanisms at work to cause the observed impacts (Aurand 1988). To learn more concerning the biological/ecological effects of long-term exposures to petroleum, the MMS Pacific OCS Region has recently completed a study examining the adaptations of marine organisms to chronic hydrocarbon exposure. Early in 1989, the MMS Gulf of Mexico OCS Region awarded a cooperative agreement to a consortium of Louisiana universities, Louisiana Universities Marine Consortium (LUMCON). This award is for a five (5) year term to perform projects which focus on environmental, social, or economic effects of long-term production of offshore oil and gas. The study(s) to be conducted under Regional Study Number G-031/G90-F003 will differ from the efforts of LUMCON in that it will provide information on the "effects" of chronic, low-level stresses at actual long-term "production sites."

Information derived from this long-term study will be important to scientists and environmental analysts concerned with natural variability of the marine environment and with the effects of OCS oil and gas activities on marine communities of interest or concern. Knowledge of these chronic low-level, long-term stresses will be used in the design of future environmental monitoring and effects studies as well as formulation of lease stipulations. This information will also be useful to various pre-lease, post-lease, and study-planning decisions.

The activities in the development of an offshore oil and gas field may have a variety of effects on the marine environment (Table 2). Effects studies have concentrated on either usual or unusual agents/activities associated with offshore oil and gas development. Unusual events/activities would include disastrous events or major unanticipated shifts in program activity.

Table 2. Effects on the marine environment which may occur as a result of the development of an offshore oil and gas field (adapted from Neff et al. 1987).

ACTIVITY	POTENTIAL EFFECTS
Platform installation	Seabed disturbance resulting from placement and subsequent presence of platform
Drilling	Discharges of drilling fluids and cuttings; risk of blowout
Completion	Increased risks of spills
Platform servicing	Discharges from vessels
Separation of oil and gas from water	Chronic discharges of petroleum and other pollutants
Offshore emplacement of storage and pipelines	Seabed disturbance; effects of structures
Transfer to tankers and barges	Increased risk of oil spills; acute and chronic inputs of petroleum
Pipeline operations	Oil spills; chronic leaks

A considerable body of data has already been collected from areas where OCS oil and gas activities have occurred in the past or may occur in the future. This includes rig and platform monitoring studies in the Atlantic, Pacific, and Gulf of Mexico OCS Regions supported and administered by the MMS' Environmental Studies Program (e.g., Table 3), as well as studies sponsored by other federal agencies (e.g., Environmental Protection Agency/National Marine Fisheries Service, Buccaneer Gas and Oil Field Studies; Environmental Protection Agency drilling fluid studies) and private industry.

While most research agrees that the short-term or "acute" effects resulting from the operation of an oil and gas platform or rig on the OCS are localized and ephemeral, there is less certainty regarding chronic, long-term stresses (National Research Council 1985; Boesch and Rabalais 1987; Aurand 1988). As early as 1981, the National Marine Pollution Program Plan (Inter-agency Committee on Ocean Pollution Research, Development, and Monitoring) concluded that the most significant unanswered questions for offshore oil and gas development are those regarding the effects on ecosystems of chronic, low-level exposures resulting from discharges, spills, leaks, and disruptions caused by development activities (Boesch et al. 1987).

The effects on the marine environment which may "potentially" result from the development of an OCS oil and gas field are listed in Table 4. By no means is this list complete, rather, it is intended to stimulate and focus the discussions to follow. For example, the possible long-term effects of chemically dispersed oil may also wish to be considered. A review of the use of oil spill dispersants has recently been completed by the National Research Council (NRC) (U.S.) Committee on the Effectiveness of Oil Spill Dispersants (NRC 1989). Logistically, what are the criteria for selecting an individual platform, complex of platforms, or an entire lease block for study and how long should the "impacts" be examined/monitored before they are judged as "significant" against natural variability?

In order to provide a means to assess the long-term, ecological effects of pollutant influx, the identification of the processes of bioaccumulation and biomagnification of contaminants introduced to the shelf also needs to be

Table 3. Fates and Effects Studies in the Gulf of Mexico supported and administered by the Minerals Management Service, Gulf of Mexico Region, Environmental Studies Program (USDI, MMS 1989).

CONTRACT NO.	STUDY TITLE	CONTRACTORS	FINAL REPORT
CT5-30	Exploration Rig Monitoring Study: Component of MAFLA OCS Benchmark Study	State University System of Florida Institute of Oceanography	SUSIO 1977
CT6-17	Exploratory Rig Monitoring Program: Component of South Texas OCS Baseline of Study	University of Texas, Texas A&M Univ., Rice Univ., Univ Texas at San Antonio	UTMSI 1977
CT8-17	Ecological Investigations of Petroleum Production Platforms in the Central Gulf of Mexico	Southwest Research Institute	SRI 1978
MUO-37	An Ecosystem Analysis of Oil and Gas Development on the Texas-Louisiana Continental Shelf	U.S. Fish and Wildlife Service, LGL Ecological Research Associates	Gallaway 1981
CT9-36	A Study of the Effects of Oil and Gas Activities on Reef Fish Populations in the Gulf of Mexico OCS Area	Continental Shelf Associates	CSA 1982
CTO-65	IXTOC I Oil Spill Economic Impact	Restrepo & Associates	Restrepo et al. 1982
CTO-71	IXTOC I Oil Spill Environmental	Energy Resources Co., Inc.	ERCO 1982
FWS/OBS-82/27	The Ecology of Petroleum Platforms in the Northwestern Gulf of Mexico: A Community Profile	LGL Ecological Research	Gallaway & Lewbel,
MUO-21	Effects of Petroleum on the Development and Survival of Marine Turtle Embryos	U.S. Fish and Wildlife Service	USFW 1982
CTO-71	Investigation on the Source of Beached Tar Samples	Energy Resources Co.	ERCO 1982

Table 3. (cont'd) Fates and Effects Studies in the Gulf of Mexico supported and administered by the Minerals Management Service, Gulf of Mexico Region, Environmental Studies Program (USDI, MMS 1989).

CONTRACT NO.	STUDY TITLE	CONTRACTORS	FINAL REPORT
29122	An Evaluation of Effluent Dispersion and Fate Models for OCS Platforms	MBC Applied Environmental Sciences and Analytic and Computational Research, Inc.	MBC 1983
30012	A Numerical Mud Discharge Plume Model for Offshore Drilling Operations	U.S. Army Engineers Waterways Experiment Station	USCOE 1985
30252	Causes of Wetland Loss in the Coastal Central Gulf of Mexico	Coastal Ecology Institute Louisiana State Univ.	CEI 1988

Table 4. Potential long-term environmental effects of offshore oil and gas development activities (adapted from Boesch et al. 1987).

- Chronic biological effects resulting from the persistence of medium and high molecular weight aromatic hydrocarbons and heterocyclics and their degradation products in sediments.
- Effects on benthos of drilling discharges accumulated through field development, including: changes in benthic diversity, changes in sediment texture/mineralogy, sediment contamination by cuttings from oil-bearing shales, and contamination of sediments by trace metals.
- Effects of produced formation waters discharged offshore.
- Effects of contaminants being recycled and/or accumulated within resident food webs should platforms act as nutrient and/or energy traps (e.g., pathological conditions in fishes).
- Chronic biological effects resulting from the use of antifouling compounds on OCS structures.
- Effects of platform discharges of nutrient-laden effluents, including hydrocarbons, sulfur, and particulate organic material on ecosystem production.
- Reduced fishery stocks due to the mortality of eggs and larvae resulting from low level chronic releases of hydrocarbons associated with routine offshore operations
- Distinguish between habitat-limited species, where the presence of platforms may increase population stocks since habitat is increased, and those species whose populations may be dislocated and aggregated at platforms, but not increased. In the latter case, can the presence of platforms lead to the over exploitation of that species at the site?

addressed. Predicting the impacts of offshore oil and gas activities requires an understanding of the responses of marine biota to chronic, low-level concentrations of contaminants (Capuzzo 1987). This may be accomplished by comparing offshore areas impacted by chronic, low-level concentrations with observations made in experimental laboratory or field studies. Although experimental studies are constrained by a certain degree of artificiality (Capuzzo 1987), carefully conducted studies may contribute to our understanding of the responses of marine organisms to these chronic, low-level stresses. Enclosed ecosystems or mesocosms (Grice and Reeve 1982) may be ideal systems for studying the effects of these contaminants because a natural community can be studied in situ while a relatively precise dose can be established. Thus, cause-and-effect relationships can be examined under near natural conditions without the interferences/artifacts of the laboratory (e.g. microcosms) (Jones 1989).

In keeping with the theme of long-term environmental effects, discussions should focus on those effects which are likely to be long-lasting, possibly longer than two years as suggested by Boesch et al. (1987), and significantly deleterious to either resources (e.g., fisheries) or ecosystem integrity. Finally, it must be kept in mind that drilling and production facilities are evolving, and that future structures might be expected to have different environmental interactions (personal communication, Dr. Robert Carney).

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2.1.5

TEXAS AND LOUISIANA SHELF ECOSYSTEMS STUDY

Dr. Robert M. Avent
Environmental Studies Staff
Minerals Management Service
Gulf of Mexico OCS Region

INTRODUCTION

The purposes of this presentation are threefold. First, it is necessary to describe the past ecosystems studies funded by the Bureau of Land Management (BLM) and the Minerals Management Service (MMS). Second, due to the new emphasis upon process studies, it is informative to examine past research approaches, successes, and shortcomings. Third, against this background, the stage is set for participants' discussions on what new ecosystems studies are appropriate, especially on the Texas and Louisiana outer continental shelf.

With the requirements of the OCSLA in mind, (detailed in sections 2.1.1. and 2.1.2.) a number of questions are in order. Among these are:

- How does one predict the consequences of the petroleum and sulfur mining industries? Can a predictive capability be achieved, and if so, to what levels of accuracy?
- With respect to predicting consequences, what are the relative advantages in the "process" approach as opposed to the "descriptive" approach? Which processes truly reflect a "healthy" environment and which ones can be used to advantage in predicting anthropogenic impacts?
- Once a balance of process and descriptive studies has been identified, exactly what are the relevant scientific questions to be asked and which are possible to answer given technical, timing, and funding constraints?
- How is an adequate study defined? How much data of what types are enough?

BRIEF HISTORY OF THE GULF OF MEXICO MARINE ECOSYSTEMS STUDIES PROGRAM

Historically, marine ecosystems studies in the Gulf of Mexico have been descriptive, regional efforts stressing inventories of habitats, living resources, and abiotic conditions. These have been designed variously to: define faunal zonation patterns and the biotic similarities or dissimilarities among communities; describe and quantify communities and habitats of special interest; identify and quantify the abiotic conditions which influence or control those patterns; establish a baseline for future comparison; and detect anthropogenic change.

Successful study design hinges on spatial and temporal variability and should allow an accurate view of all variability found on the scale of sampling. Depending upon the expected biotic and abiotic conditions, homogeneity, "zonation", patchiness, etc., one may adopt one or more spatial sampling designs. These include high density mapping, spaced transect sampling, stratified random sampling, and habitat, depth, and site specific sampling. Likewise, temporal design must consider the expected rapidity and frequency of change. Temporal approaches include time-series sampling (e.g., day/night, monthly, seasonal, etc.), long-term monitoring, opportunistic sampling (e.g., following hurricanes or mud slumps), and continuous in situ monitoring. All have been used in the MMS programs at one time or another.

The amount and type of sampling must be tailored to the characteristics and variability in a study area (e.g., the distribution and abundance of diapirs and live bottom). While some BLM/MMS studies have relied mostly on conventional at-sea sampling methodologies (trawls, grabs, hydrographic instrumentation, etc.), others have required the deployment of manned submersibles, remotely operated vehicles (ROV's), side-scan sonar, photographic sleds, divers, in situ instrumentation, or remote (satellite) technology.

But regardless of design and approach, the data should be both accurate and statistically adequate to produce clear biological description, allow statistical correlation, and hopefully establish cause and effect. But some studies have suffered the consequences of great natural variability. The high cost of replication and/or high-frequency sampling (e.g., high biological diversity environments such as the deep-sea and areas of rapid fluctuations such as estuarine mouths) has limited our predictive capability. Furthermore some studies commenced without benefit of clearly-stated, testable, working hypotheses.

To date our efforts have largely been to study the anatomy, rather than the physiology, of the Gulf of Mexico--that is, its structure, rather than its function. Investigators have constructed large species lists and inventories of resources but have not often attempted to quantify energetic processes. Past studies can be lumped into two general types which resulted from historic program review, perceived study needs, and periodic program re-evaluation.

A. Regional Descriptive or "Benchmark" Studies--multidisciplinary studies describing many diverse elements of regional scope (i.e., tens to hundreds of thousands of square kilometers).

   - Eastern Gulf of Mexico Study
   - South Texas OCS Study
   - Southwest Florida Shelf Ecosystems Study
   - Northern Gulf of Mexico Continental Slope Study

B. Regional Community Studies--these differ somewhat from the above in that their focus is smaller (e.g., live-bottom, reefs, epifauna, and specific habitats).

   - Eastern Gulf seagrass studies
   - Southwest Florida live-bottom characterizations (in situ instrumented site studies)
   - Western Gulf topographic prominence studies
   - Central Gulf platforms study
   - Mississippi-Alabama pinnacle surveys
   - Northern Gulf of Mexico Continental Slope Study (investigations on chemosynthetic communities)
   - Proposed monitoring studies

TAKING A PROCESS APPROACH IN TEXAS-LOUISIANA (TEXLA)

Generally process studies stressing major energetic interactions have been overlooked in Gulf programs. The exceptions have included several efforts to estimate productivity. Conventional wisdom has it that the best estimates of environmental change will come from the benthic biological and geological record, at least for time scales on the order of decades.

The Texas and Louisiana shelf is the only remaining area in the Gulf which has not been the subject of a descriptive regional study. Whatever approach is adopted, the Texas-Louisiana (TEXLA) Shelf Study must be designed with a number of regional characteristics in mind.

- spin-off eddy circulation patterns;
- influence of the Mississippi River plume;
- patterns of hypoxia;
- massive presence of the petroleum and sulfur industries;
- long-term, low level pollution from many sources;
- interaction of estuarine lagoons and marine waters;
- effects of recreational and commercial fishing; and
- relative zoogeographic isolation of the western Gulf.

During planning for TEXLA, several critical questions should be addressed. Our purpose at this workshop is not specifically to design a new study for MMS. Our charge to the working group is to identify the most fruitful approaches and the major research elements for any new studies in light of what is presently known.

- Are any new "ecosystems" studies needed at all in the Gulf of Mexico after all the work done in the past?
- If so, should additional new studies in the Gulf and elsewhere stress processes or inventories or an admixture of the two? Which approaches serve to detect change? Which leads to a degree of confident prediction and a measure of environmental effect? Indeed, is it practical to detect the industry's environmental signals from background noises?
- Today, the term, "process", brings to mind biological (energetic), biogeochemical, and physical phenomena. Which processes and ecological interactions (if any) require additional investigation to meet MMS goals?
- How may this study or parts thereof be coordinated with, incorporated into, and share data with ongoing or planned monitoring and physical oceanography investigations?
- Should the study area be restricted to the areas of the western Gulf with high industry production (considering funding limitations) or should MMS include the entire Texas and Louisiana OCS? Should the study area include the upper slope?
- Considering the extent of oil and gas development and other sources of effects, are there any acceptable "control" sites?

2.1.6

LOUISIANA/TEXAS SHELF PHYSICAL OCEANOGRAPHY PROGRAM: A STATUS REPORT

Dr. Murray Brown
Environmental Studies Staff
Minerals Management Service
Gulf of Mexico OCS Region

INTRODUCTION

The Minerals Management Service (MMS), Gulf of Mexico OCS Region, sponsored a Symposium on the Physical Oceanography of the Texas/Louisiana (TEXLA*) Shelf in Galveston, Texas, on May 24-26, 1988. The symposium brought together a number of physical oceanographers, meteorologists, and ecologists to discuss the state of knowledge and to begin the planning process for a long-term study of shelf circulation covering the region from the mouth of the Mississippi River to approximately 24 degrees latitude along the Mexican coast and from the shore out to a depth of approximately 500 meters. The proposed study is expected to take place during the period 1990-1993. It is anticipated that the work will be done principally through contracts after a competitive procurement process. Specific charges to the participants were as follows:

- To assess the current state of knowledge concerning the circulation on the TEXLA shelf;
- To identify significant gaps in that knowledge,
- To recommend a field measurement program to address these gaps,
- To recommend a circulation modeling program for the TEXLA shelf that will improve MMS' oil spill risk assessments, and
- To identify and initiate coordination mechanisms and data-sharing arrangements with other proposed research efforts.

SUMMARY OF TOPICS

The forcing mechanisms important to shelf circulation in the TEXLA domain include wind stress, buoyancy flux, and mass flux (evaporation-precipitation) across the air-sea interface; influx of momentum/energy across the open seaward boundary; and influx of freshwater at the eastern lateral boundary. Loop current eddies (LCE's) are recognized as an important mechanism by which energy is transferred from the eastern Gulf toward the west and from deep water onto the shelf, with significant impacts on circulation and watermass characteristics. Transient storm systems can create shelf wave energy, which is effectively trapped by the TEXLA shelf.

The combined plume of the Mississippi and Atchafalaya Rivers has a significant density contrast with the surrounding shelf water and is traceable to the Texas/Mexico border. The plume front could serve as a barrier to onshore movement of pollutants and as a "fast lane" for pollutant transport down the Texas coast. Some of the boundary current appears to recirculate eastward along the outer shelf during summer, resulting in significant amounts of relatively freshwater over the middle and outer shelves. Satellite images have revealed highly complex frontal structures over and beyond the shelf. River fronts, turbidity fronts, the coastal boundary current front, remnant LCE's, and "squirts" and "jets" along the shelf break have all been observed, contributing to the complexity of measuring and modeling the circulation of this area.

*Throughout this document, the Texas-Louisiana Continental Shelf is referred to as TEXLA. In the Physical Oceanography Programs and other documents, the Continental Shelf is referred to as LATEX.

Meteorological effects on shelf circulation can be large. The general southeasterly wind flow most of the year can be interrupted by severe tropical storms during summer and early fall, and by cold frontal outbreaks ("northers") during winter. Front generation has been observed to shift from the coast in fall to the shelf break during winter. Since 1983, MMS has supported further development of the Gulf of Mexico circulation model developed by Hurlburt and Thompson. While providing accurate representations of deep-water circulation, including LCE's, the model is not optimal for representing shelf circulation. Several presentations on the wide variety of models that have been applied to Gulf regions indicated that, although seldom noted in the literature, there have been notable successes in simulating specific regions or events, such as hurricanes.

The prospects for major physical measurement or modeling activities by any other agency in the northwestern Gulf of Mexico during the target period are slim. No significant new initiatives were described, but a number of operational efforts will take place, including modeling work in Galveston Bay by the National Ocean Service, an increase in offshore meteorological stations supplying data to the National Weather Service, and continued hydrographic survey work by Texas A&M University, the Mexican Navy, and the Mexican Institute of Electrical Investigations. The MMS intends to share data and to coordinate program activities with other agencies working in the area, mainly by means of rapid data archiving at the National Oceanographic Data Center.

RECOMMENDED PROGRAM OBJECTIVES

Program needs as outlined above can be met through six studies outlined below.

Title: Northwestern Gulf of Mexico Circulation Modeling Study

The overall objective of the circulation modeling effort in any MMS Region is to provide reliable ocean current information that can be used in environmental assessment activities, principally the Oil Spill Risk Assessment (OSRA) Model. The specific aim is the development of a numerical modeling approach that embraces the various physical processes over continental shelves and the adjacent slope (as affected by major circulation systems further offshore). These processes have diverse spatial and temporal scales, ranging from major current systems, e.g. the Loop Current, and eddies (several hundred kilometers/several months), or continental shelf waves (several hundred kilometers/days) to major river plumes (kilometers/hours). Characteristic "excursion" values of wave-like motions, such as tides and inertial currents, lie intermediate between these extremes. To simulate these features will require a broad suite of models and modeling exercises, emphasizing aspects of the physics involved and performed at appropriate temporal and spatial scales.

The work of modeling the Gulf would take place within an overall program of concurrent measurements along the TEXLA shelf (the area of primary offshore oil and gas activity), and would include the use of previously collected data from the 1982-1986 field measurements program. Tides, realistic topography and coastline, true (non-deterministic) thermodynamics, fluvial input, wind forcing at all relevant frequencies, and meso-scale circulation features such as eddies and "squirts and jets" will be included in the model system, as appropriate. In line with current practices, the model system will also produce discrete surface particle trajectories for designated suites of "launch points" at various times throughout the multiyear simulations.

Title: Texas-Louisiana Shelf Circulation and Transport Processes Study

- To identify key dynamical processes governing circulation, transport and cross-shelf mixing on the TEXLA shelf,
- To upgrade existing empirical evidence on the same processes, fill in gaps in the evidence, synthesize the evidence into a scheme of circulation, and quantify transports and mixing rates,
- To develop conceptual models of small to large-scale processes and circulation features, from coastal plumes and fronts to shelf-edge eddy exchange, and large-scale shelf circulation, all on event to seasonal scales. (The conceptual models would support and assist in the development of a hierarchy of numerical models, described elsewhere.)

Title: Mississippi River Plume Hydrographic Study

The Mississippi River Plume is the nation's most significant example of a buoyancy driven flow regime. The volumetric outflow greatly exceeds any other U.S. river, and the region affected (TX, LA, AL, MS shelf regions) is one of the nation's most important fisheries. Although basic information is available on certain features of the plume, such as salinity balance and remotely sensed gross dimensions, variability of the system at time scales less than seasonal and at length scales less than hundreds of kilometers has not been attempted. The entire area of the nation's most intense offshore oil and gas activity is heavily influenced, biologically and hydrographically, by the plume, even to the extent that previous shelf monitoring studies have been overwhelmed by the fluvial signal. The proposed study, to be closely coordinated with a companion study of currents and hydrography of the TEXLA shelf, in general, would concentrate on measuring the plume's dimensions, flow characteristics, mass transport (including entrained sediments and pollutants), and mixing characteristics. Close attention would be paid to associated fronts, hypoxic areas, sedimentation rates, benthic boundary layer phenomena, productivity, and standard nutrient and hydrographic analyses.

Title: Gulf of Mexico Eddy Circulation Study

This study is aimed at monitoring and characterizing three classes of "meso-scale" circulation patterns that are important in abyssal and slope waters of the northwestern Gulf of Mexico.

- The eddy-shedding process and the physics of Loop Current eddies as they move westward in the Gulf of Mexico and interact with the TEXLA shelf and slope, as well as the resultant hydrographic alterations of upper slope/outer shelf waters, and changes in circulation;

- Smaller anticyclonic and cyclonic eddies that appear to form around and to move with the Loop Current eddies;

- "Squirts and jets" - poorly understood shear zones, usually located near the upper slope, that appear to reflect strong shelf/slope water exchange.

This study will provide rapid, entirely airborne surveys of these features, using a suite of expendable probes that can measure temperature, salinity, and current shear, as well as the aerial deployment of drifting buoys to monitor flow. Satellite thermal imagery of the entire Gulf, at sufficient resolution to support the survey and monitoring requirements of this study as well as the TEXLA Shelf Circulation and Transport Processes Study (G-971) and the Mississippi River Plume Hydrographic Study (G-973), will be provided within this study. The newest methodology available for eddy studies, satellite altimetry, will be used in an attempt to locate eddies passing through any of the approximately six accurate geoid lines presently available for the Gulf. These methods will make it possible to follow specific eddies in time and space, and to participate with industry, academic, or other interests in near real-time information exchange about these important Gulf features.

Title: East Breaks Ship-of-Opportunity Study

The proposed study consists of partial funding of a separately managed program of hydrographic surveys of the "East Breaks" region along the TEXLA slope. The work, conducted by Texas A&M University, involves nutrient and hydrographic stations on a fixed grid, three times per year. The work would be closely coordinated with the Eddy Study and the Shelf Study.

Title: Gulf of Mexico Data Buoy Study

The proposed work consists of the provision of two 3-meter, standard meteorological buoys at locations to be selected along the shelf edge offshore TEXLA. The locations would be closely coordinated with the existing Meteorological and Oceanographic Monitoring System (MOMS) operated by industry, the National Weather Service, and the National Data Buoy Center.

2.2 Technical Contributions: A Well Developed Starting Place

While all the previous sections have stressed the management and scientific challenge of Minerals Management Service's new emphasis upon long-term effects and process oriented studies, the following technical contributions demonstrate very clearly that much of the needed expertise does exist. Not only is there existing expertise from which to draw, but other organizations have made considerable progress towards appropriate study design.

Starting points for appropriate design can be found. The National Research Council is in the process of developing a generic model for linking management and monitoring in the coastal ocean (Boesch, section 2.2.1). Building upon previous MMS descriptive work, the State of Florida has developed a process oriented study on the Florida Keys reef tract (Vargo, section 2.2.6). Many design elements needed for an effective long-term program have been incorporated in a southern California MMS study (Brewer, section 2.2.7). The critical issue of appropriate statistical design are being considered in many planning efforts (Green, section 2.2.2)

Meaningful process oriented approaches are being developed. Understanding of coastal marine foodchains has been considerably advanced in the past few years (Pomeroy, section 2.2.3). The link from the foodchains of ecologists to the populations of MMS concern is being made possible through new techniques, such as isotopic analysis, which allows species and populations to be placed into correct trophic perspective (Fry, section 2.2.5). Increasingly, the benthos is becoming more than a time consuming inventory project; the dynamics of nutrient flux, sediment mixing, and community development are intricately linked (Rhoads, section 2.2.4 and Montagna, section 2.2.8). Not only is the ability to carry out studies of natural processes advancing, but oil and gas related sources of stress can now be viewed from a geochemical process perspective (Means, section 2.2.9 and Jones, section 2.2.10).

Within this developing management design and technology framework, the Northern Gulf of Mexico is the ideal location for long-term effect and process oriented studies. The ecosystems of the northern Gulf have been adequately described to begin process studies (Rabalais, section 2.2.15 and Schroeder, section 2.2.16). The distribution of hydrocarbons is now well understood so as to separate sources (Kennicutt, section 2.2.14). And, enough is known about ecological functions in these areas to design process studies effectively (Turner and Rabalais, section 2.2.11,; Rowe and Darnell, section 2.2.12; and Dortch, section 2.2.17). Finally, oceanographic linkage between physical and biological processes is now possible due to improved understanding of transport in the TEXLA region (Wiseman, section 2.2.13).

2.2.1

NATIONAL RESEARCH COUNCIL ASSESSMENT OF MARINE ENVIRONMENTAL MONITORING: IMPLICATIONS FOR MONITORING OIL AND GAS DEVELOPMENT IN THE GULF OF MEXICO

Dr. Donald F. Boesch
Louisiana Universities Marine Consortium
Chauvin, LA 70344

The Marine Board of the National Research Council has recently completed an assessment of environmental monitoring of U.S. coastal waters. I chaired a committee of experts which conducted this assessment which resulted in a report "Managing Troubled Waters: The Role of Marine Environmental Monitoring" to be published by the National Academy of Sciences Press in March 1990 (National Research Council 1990). The following is a brief overview of the findings together with a discussion of the implications of these findings for the design of environmental monitoring of oil and gas development in the Gulf of Mexico.

The Committee on a Systems Assessment of Marine Environmental Monitoring developed a framework for assessing the adequacy of monitoring which included not only technical design and implementation, but evaluation of the objectives of monitoring and the use of monitoring results (i.e., the monitoring system). It then directed three case studies in which experiences could be related to this framework. Two of these case studies concerned specific geographic regions and the third concerned monitoring the effects of particulate waste disposal in the ocean. Particulate wastes considered included dredged materials, sewage sludge, and oil and gas drilling and production discharges. Because of their relevance to offshore oil and gas development activities, the findings of the particulate waste case study are briefly reviewed.

With respect to institutional concerns, the particulate waste case study found that: (1) there is insufficient communication and coordination between agencies responsible for monitoring discharges; (2) there are frequently inaccurate public expectations of monitoring which, when not met, diminish confidence in the ability to manage the marine environment; (3) there are ocean disposal statutes and regulations with vaguely defined environmental goals as well as human health objectives; (4) problems frequently occur in making results available to decision makers in a timely fashion; and (5) public pressure has often brought about policy changes that are not supported by the results of monitoring. With regard to technical implementation, the case study reported that (1) monitoring design has not always been based upon an understanding of natural environmental variability; (2) it has been difficult to apply classical measures of biological or chemical change in the determination of unacceptable effects because the linkage between these changes and living resources is poorly understood; (3) data management and analysis are often the weak links in monitoring programs; (4) although quality assurance and quality control procedures have improved greatly, improvements are still needed; and (5) once a monitoring program is implemented, there tends to be resistance to any change which limits improving its efficiency.

The particulate waste case study noted that most monitoring has tended to be of a compliance and short-term, near-field nature. The responsibility for monitoring long-term system-wide impacts has been inadequately filled because of unclear responsibilities, abdication of responsibility, or lack of resources. While adequate compliance monitoring tools exist, trend monitoring tools, including instrumentation and conceptual and numerical models, are primitive and inadequate.

The Committee considered these findings, those of the other case studies and other evidence to develop overall conclusions and recommendations under three general headings.

MONITORING CAN STRENGTHEN ENVIRONMENTAL MANAGEMENT

The Committee concluded that marine environmental monitoring is an effective technology for defining the extent and severity of pollution, evaluating environmental policies and actions, helping to estimate the risks and consequences of future actions, and detecting emerging problems before they become severe. It is part of a broader complement of technical contributions to environmental management, which also includes fate and effects research and predictive modeling, which are seldom effectively coupled with monitoring to support integrated decision making. Monitoring needs to be an integral part of an effective environmental management system in which the results of monitoring are routinely used to guide and focus future actions, including regulating activities, influencing decisions, and refocusing efforts.

The Committee recommended that the effects of significant marine environmental management policies and actions should be monitored to evaluate the actions and to improve the ability to predict the consequences of management decisions. Monitoring programs should be sufficiently flexible for results to be used to redesign and eliminate components that have not produced or are not likely to produce useful information. Agencies charged with environmental management responsibilities should provide for periodic systematic reviews of the results of their monitoring programs.

COMPREHENSIVE MONITORING OF REGIONAL AND NATIONAL TRENDS IS NEEDED

The Committee concluded that the present array of compliance monitoring programs, regional monitoring programs, and the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program is inadequate to establish patterns and trends in the quality of the nation's coastal environments or to determine the effectiveness of environmental policies and regulations. Most resources spent on marine environmental monitoring are for monitoring compliance with specific permit conditions. Compliance monitoring meets limited, narrow objectives that do not necessarily address broader public concerns about whether the marine environment is being degraded or about what such degradation means. Regional status and trends monitoring is needed to better address public concerns, assess the threat of the cumulative impacts, and provide a context for interpretation and evaluation of site-specific compliance monitoring. It may be possible to reallocate some of the resources of compliance monitoring programs so that they contribute to regional status and trends information without additional effort or cost.

The Committee recommended that the Environmental Protection Agency (EPA) and NOAA should cooperate to develop a more effective national program to monitor environmental status and trends in the coastal ocean and estuaries, which combines regional programs with a sparser national network. The nucleus for this network should be developed through NOAA's NS&T Program and EPA's National Estuary Program and proposed Environmental Monitoring and Assessment Program (EMAP). New legal authority or regulatory policies should be instituted to allow some resources devoted to compliance monitoring to be reallocated to a regional status and trends monitoring program. Other federal, state, and interstate regional monitoring programs (such as those being planned for the Gulf of Mexico by the Minerals Management Service) should be strongly encouraged to participate in regional efforts by adopting compatible protocols. Those responsible for managing estuaries included under the National Estuary Program should be required to develop and implement a status and trends monitoring program. The coordination of marine pollution research and monitoring programs among the federal agencies should be critically evaluated and necessary administrative and statutory changes implemented to improve definition of responsibilities, interagency coordination, and overall effectiveness. Finally, NOAA should, in cooperation with EPA, prepare a report to Congress every three years which synthesizes the results of the national monitoring program, documents the status and trends of the coastal ocean, and evaluates management actions.

IMPROVED PROGRAM DESIGN AND INFORMATION PRODUCTS WILL MAKE MONITORING RESULTS MORE USEFUL

The Committee concluded that many monitoring programs are ineffective because they devote too little attention to the formulation of clear goals and objectives, technical program design, and the translation of data through analysis and synthesis into information that is relevant and accessible. Effective marine environmental monitoring programs must have the following features: clearly defined goals and objectives; a technical design based on an understanding of system linkages and processes, directed at testable questions and hypotheses, and subjected to peer review; methods that employ statistically valid observations and predictive models; and the means to translate data into information products tailored to the needs of their users.

The Committee recommended that monitoring programs should incorporate a rigorous design methodology. Compliance monitoring programs for major activities should be carefully evaluated by agencies requiring the monitoring to ensure that they meet design criteria. EPA, in cooperation with NOAA, should prepare guidance documents on the design of compliance and regional monitoring programs for use by its regional offices, state regulatory agencies, and permittees. NOAA and EPA should promote the development of new techniques and technical protocols for use in regional and national monitoring programs to ensure compatibility and comparability of data.

Although these findings and recommendations are of a general nature and do not include specific guidance for the design of environmental monitoring of offshore oil and gas development activities in the Gulf of Mexico, the National Research Council (NRC) report gives many examples of the pitfalls confronting effective monitoring and contains step-by-step conceptual guidance for program design which should be useful in the design of any monitoring program.

Turning to monitoring the effects of drilling and production activities, it is helpful to consult the recommendations of a report on the long-term environmental effects of offshore oil and gas development which was assembled for the Federal Interagency Committee on Ocean Pollution Research, Development and Monitoring (COPRDM) (Boesch and Rabalais 1987). That report recommended parallel studies in historically developed and newly developing areas to resolve potential long-term effects of operational discharges from offshore oil and gas development drilling and production on the benthos. The developed area recommended for investigation is an outer shelf (> 60 m) environment off southwestern Louisiana and southeastern Texas (Eugene Island to High Island South Additions) which is depositional and heavily developed but removed from the potentially confounding influence of the Mississippi River. The COPRDM report recommended the following study approaches:

- measure chemical tracers of drilling discharges in sediments (barium, chromium, lignosulfonate, medium weight aromatic hydrocarbons);
- assess sedimentologic and geochemical dynamics (sediment texture, erosion and deposition, exchanges with water column);
- determine bioavailability over time from sediments of potentially toxic components of drilling fluids to various trophic groups of benthos;
- measure biological effects at three levels:
    - individual: induction of enzyme systems, biochemical and physiological stress indices;
    - population: age and size structure, reproduction and recruitment, microbes;
    - community: biological interactions resulting from population alterations.

The implementation of monitoring programs for the Gulf of Mexico within the same time frame of physical oceanography and ecosystem studies offers a rare opportunity of synergistic integration of these studies. Physical oceanographic studies could provide information very useful in interpretation of monitoring results, such as the dispersal of contaminants in the water column, sediment (and contaminant) resuspension and transport, vertical water mass structure and dynamics, and definition of the regional transport field and its response to extreme events. Properly designed, ecosystem studies could also contribute significantly by addressing such questions as:

- What is the long-term fate of contaminants released by operations or accidents? How do these compare with other sources of these materials? What are the direct biological effects of these contaminants?
- How do dominant natural processes, such as hypoxia, land run off, slope water intrusions and storms, affect the ecosystem in ways which exacerbate, moderate or confound the detection of effects of oil and gas activities?
- What are the broader implications to the ecosystem, its health, and productivity, of extensive localized alterations in the environment resulting from OCS oil and gas development, e.g., seabed contamination or disturbance and the physical presence of oil and gas structures?

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2.2.2

DESIGN AND STATISTICAL CONCERNS FOR MONITORING

Dr. Roger H. Green
Department of Zoology
University of Western Ontario
London, Ontario
CANADA, N6A 5B7

INTRODUCTION

The emphasis of this presentation is on concerns for long-term monitoring and impact detection. There are three themes: hypotheses and response variables, basic questions of study design, and problems in study design related to natural variation.

HYPOTHESES AND RESPONSE VARIABLE

In designing any environmental study there should be a logical sequence of: purpose => question => hypotheses => model => study design statistical analysis and tests of hypotheses (Green 1984). Hypotheses are usually hierarchical, especially when there is natural variation. For example, the null hypothesis might be "natural variation only" and the alternate hypothesis "natural variation plus impact of development." Criteria for a good response variable include (1) relevance to impact effects and sensitivity of response, (2) intrinsic economic or aesthetic value, (3) low natural temporal and spatial variation, and (4) estimation quickly, precisely, and at low cost (Green 1987). Carney (1987) discusses appropriate response variables for studies of impacts related to more offshore petroleum exploitation. Bayne et al. (1988) provide examples of diverse response variables ranging from biochemical and cellular to community levels, within one marine pollution study. Further discussion of options and constraints in choice of response variables for environmental impact and monitoring studies is found in Green (1989). We should always be open to the potential of new response variables, such as isotope ratios in biological tissues or community level indices, in addition to well-established and accepted response variables (Green 1987, 1989).

BASIC QUESTIONS OF STUDY DESIGN

Emphasis is on three related questions. First, how many samples should one take? Some replication (n) at each location (l) and time (t) is always desirable, so the total number of samples would be equal to nlt, with n usually 3 or more. Replication should be sufficient to provide at least 10 error degrees of freedom in any statistical test. Second, what number of samples is needed to perform tests of hypotheses with a given power to detect real impact effects of a given magnitude? A pilot study can provide information about natural variation so that the error variance can be estimated, and then the necessary number of samples can easily be calculated given the error variance, the effect to be detected, and the desired Type I and II error levels (the Type I level usually = 0.05 and the Type II level = 1 - power) (Green (1979, 1989, in press, and references cited therein). Third, what is the appropriate level of variation in the study design for calculating the error variance to be used in tests of hypotheses about impact? We commonly use the variation among replicate field samples (at a given time and place) for this purpose, but in many instances this is inappropriate (Green 1984). Hurlbert (1984) has referred to this as "pseudoreplication". Often it is most appropriate to use re-sampled sites as replicates rather than re-randomized samples within sites, and the error term for tests is often calculated from the interaction between among-sites variation and among-times variation at given sites, i.e. variation in time trends among sites (Green 1989).

STUDY DESIGN RELATED TO NATURAL VARIATION

Obviously it is necessary to have knowledge of the extent and nature of natural variation in any particular situation, which requires a pilot study, or previous research on that system by other workers, or a long-term baseline study. Some natural variation can be "stratified out" by an appropriate study design (Green 1984), for example among-site variation or within-year temporal variation (e.g., seasonal, diel, tidal). However some within-year temporal variation can not be stratified out (e.g., seasonal patterns vary from year to year), and year-to-year variation can not be handled in this way at all. Often long-term among-years variation strongly influences marine coastal shelf communities, for example by infrequent events such as severe storms setting successional processes back to an earlier stage (Glemarec 1978).

What frequency of sampling is appropriate in a long-term monitoring study? If cost were no object, then obviously the answer would be as frequently as possible. With cost factored in, the answer will be some compromise between the frequency of sampling and the chance of detecting (or missing) a pollution impact event if it occurred. This is the philosophy of a power analysis again: how does the probability of detecting a pollution impact event of a given duration vary as a function of sampling frequency? I have developed a computer program which will analyze time series monitoring data, or if such data are not available it will simulate (and then analyze) a set of data having specified parameter values (i.e., mean frequency, temporal autocorrelation which determines cyclic pattern, and length of the time series). I have repeatedly run this program to simulate data covering a range of parameter values, and sampled each set of data using sampling frequencies covering a range of frequencies. Thus, points on a response surface representing "power to detect a pollution impact event" were estimated, as a function of sampling frequency, and of mean frequency and temporal autocorrelation of the pollution impact events. A simple empirical response surface model was fit to the results. I intend to continue with this approach, developing the model further, extending the parameter ranges, and re-fitting the response surface model, using a variety of sets of real time-series pollution impact monitoring data to estimate power curves, and adding to the program the capability of simulating background noise representing natural environmental variation having its own mean frequency and temporal pattern.

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2.2.3

MARINE FOOD CHAINS

Dr. Lawrence R. Pomeroy
Department of Zoology
University of Georgia
Athens, GA 30602

Marine foodchain research has undergone a minor revolution over the past decade, evolving from the view that marine foodchains are short and simple to the view that food webs are complex, composed of many frequently changing short chains. In oligotrophic subtropical water, a major part of primary production is by the cyanobacterial genus, *Synechococcus* and by picoeukaryotes that are from 0.5 to 5 um in maximum dimension. What is most revolutionary is the realization that more than 50% of consumption of primary production is by microorganisms, bacteria and protozoans. Bacteria utilize both dissolved and particulate materials in the sea. They utilize dissolved organic carbon (DOC) released by phytoplankton and DOC excreted by zooplankton, including protozoans. They utilize fecal materials, some of which are compact pellets but much of which are rather diffuse particles. They also utilize senescent phytoplankton and allochthonous inputs from river plumes and continental fallout. Because phytoplankton tend to grow very rapidly when nutrients are available, zooplankton having longer life cycles cannot catch up, and so the phytoplankton deplete the nutrients and become stressed, sick or dead. In this state they are invaded by bacteria and sometimes fungi and thraustochytrids. Protozoans varying from a few um to several cm in size, utilize the picoautotrophs, the bacteria, and some even catch and eat large diatoms and crustacean zooplankton (Reid et al. 1989). So marine foodchains are dominated by microbial metabolism, with bacteria competing with zooplankton and their consumers for particulate material (Pomeroy and Weibe 1988) (Figures 1 and 2).

Many measurements of photosynthesis have been made, but serious questions remain about our ability to estimate primary production on a regional scale. Few measurements of respiratory rate have been made in the sea and coastal waters, because the technology of measuring very small changes in dissolved oxygen has been challenging. We are now beginning to accomplish rate measurements. On the Southeast Atlantic shelf, Griffith (1990) found respiratory rates exceeded photosynthetic rates: the continental shelf waters are heterotrophic, and nearly all of this respiration is bacterial. This was predicted on theoretical geochemical grounds by Smith and McKenzie (1987) (Figure 3). Thus, we see marine food webs as microbially dominated systems in which zooplankton and fishes generally compete poorly. They compete comparatively well in highly productive systems like the TEXLA shelf waters.

Will measurements of ecosystem processes, such as photosynthesis and respiration, be useful to managers who are concerned with the effects of potentially toxic materials released as a result of offshore and coastal oil and gas operations? The answer is not a satisfying one. Many studies in both fresh and marine water suggest that the community as a whole tends to be resilient to perturbations unless and until they are extreme. This resilience is the result of the natural species diversity of aquatic and especially marine systems. At any time one or a few species of phytoplankton, zooplankton, and microorganisms will be numerically and metabolically dominant. But many rare species that have different requirements and sensitivities lie in wait. If there is a change in nutrient concentrations, toxin concentrations, temperature, or water transparency, new dominants will emerge rapidly. Rates of photosynthesis and respiration may change little, except for transitory variations, unless the perturbation exceeds the tolerance of all species in that community. Numbers of bacteria were seen to change little at an ocean dump site, but species composition of culturable bacteria changed markedly (Singleton et al. 1984). Other studies suggest that rate processes can indeed be highly sensitive to seemingly minor perturbations. Chavez and Barber (1987) measured photosynthesis by modern, toxin-free techniques in the equatorial Pacific comparing Niskin samplers, a bucket, and Go-Flo samplers. The rates measured in water drawn from the Niskin samplers were <10% of those measured in water from the bucket or the Go-Flo samplers. We now know that this is because the rubber used inside the Niskin sampler to close the end caps is toxic to phytoplankton, even after months of use in the sea, and even when the exposure is for just a few minutes.

Boesch (1984) cites a case in which the high variability of biological samples is reason for discontinuing a monitoring program. Perhaps the problem was as much with the questions asked and the expectations for answers as with the monitoring program itself. Marine ecosystems, especially tropical and subtropical ones, are

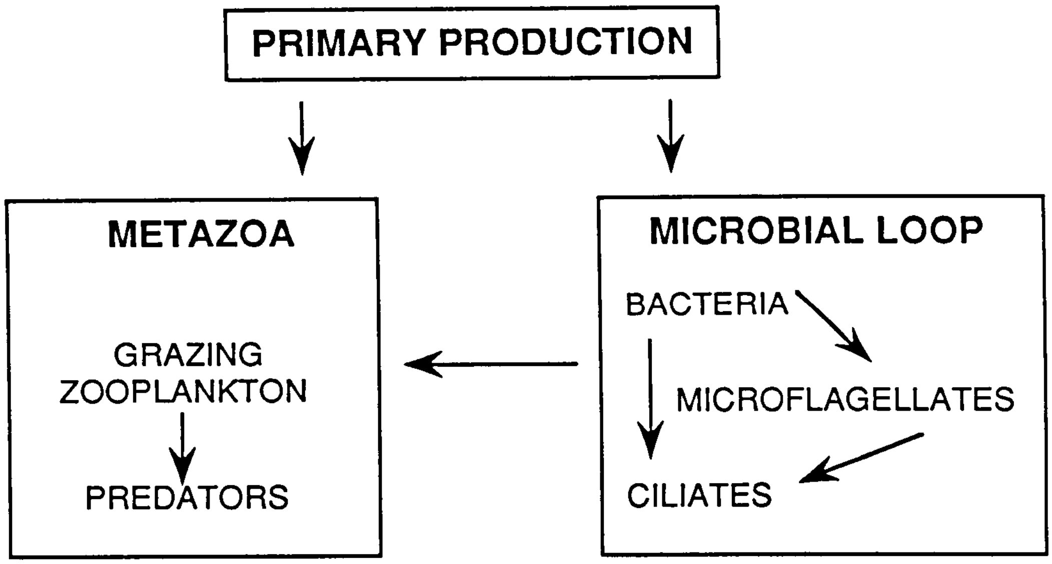

Figure 1. Division of energy flux between metazoans and microbial portions of the marine food web. From Pomeroy and Weibe, 1988.

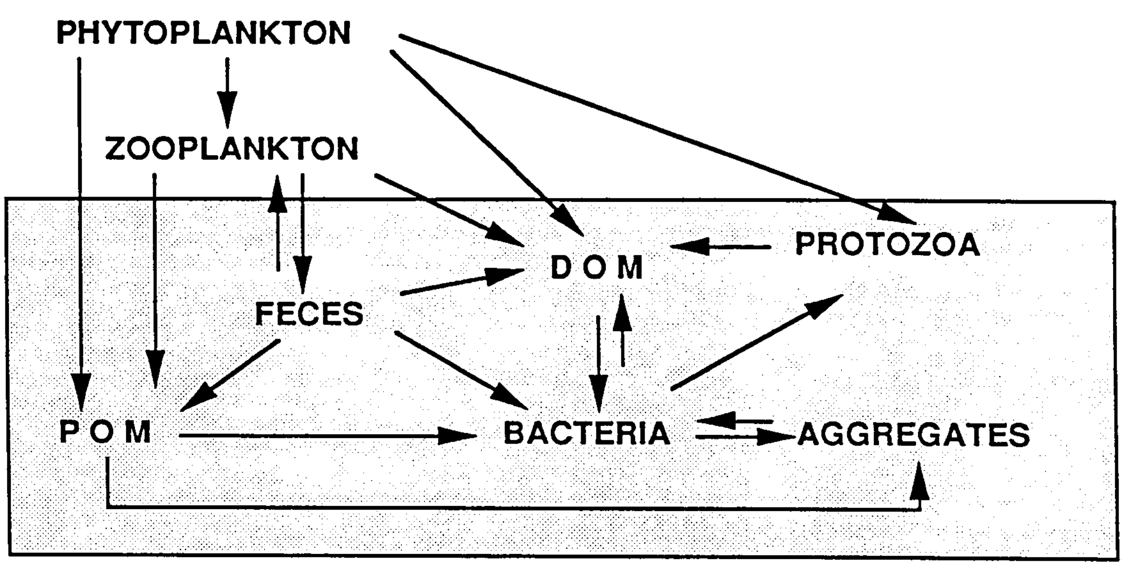

Figure 2. Detail of microbial loop (shaded portion).

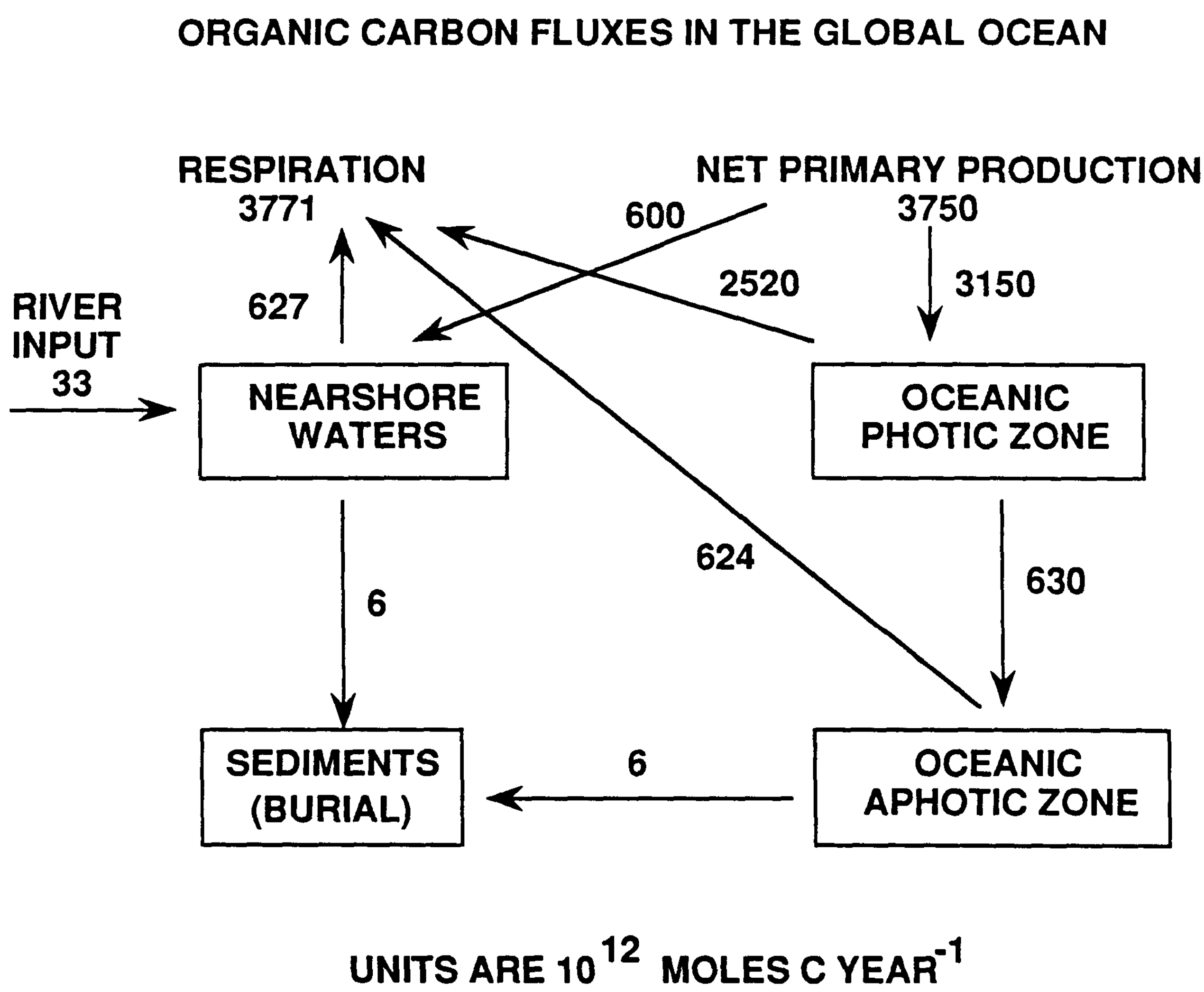

Figure 3. A simple model of organic carbon flux in the sea.

complex. As I have indicated, many major features of these systems have only recently been discovered. Naturally, we now think we know it all, but probably we do not. A substantial part of the observed variability in ocean systems can be filtered out by recognition of the mesoscale physical processes that drive much of the primary production. Recognition of the physical variability in the system at the time of biological sampling will substantially reduce variability of the data. Recognition of mesoscale features that influence biological stocks and rate processes (e.g., river plumes, intrusions of underwater, eddy-induced upwelling, or storms) is an important consideration. Biologists need to know in real time the physical conditions under which samples are being taken, so sampling can be related to those events. If biologists cannot be with physical oceanographers on the same cruises, then relevant physical observations, satellite imagery, CTD casts, underway S, T, Chlorophyll must be a part of the biological program, so there will be assurance that the physical regime is understood and documented.

Sampling all state variables and rates in a marine food web as it is now conceived is daunting and potentially costly. While we can be selective in collecting data on the basis of experience, a better approach is some preliminary modeling, even of a highly condensed kind. Modeling during planning should seek (1) scant or missing data that are essential and (2) state variables or rate processes that will be most sensitive and therefore cost-effective to procure. Further modeling during or following the field program should be more predictive, and there should be an opportunity to both refine the model and validate it with field observations. Some recent biological models that incorporate microbial processes are Pace et al. (1984), Fasham (1985) and Moloney (1988). These are probably more elaborate than necessary for the purposes of Minerals Management Service (MMS), although they are simple enough to be run on software packages such as STELLA (High Performance Systems) which require little modeling experience and no programming.

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2.2.4

THE BENTHIC MIXED LAYER

Dr. Donald C. Rhoads
Science Applications International Corporation
Maritime Technology Group
89 Water Street
Woods Hole, MA 02543

INTRODUCTION

The benthos are the focus of many monitoring studies because they are long-term integrators of water column and benthic processes. My approach to benthic monitoring is similar to that of Pearson and Rosenberg (1978); species assemblages are treated as seres in benthic succession (Rhoads and Germano 1986). In the words of Johnson (1972): " The community is....a temporal mosaic, parts of which are at different levels of succession....the community is a collection of the relics of former disasters."

Application of these ideas to real-world monitoring problems involves mapping of successional mosaics on the seafloor and relating them to Johnson's "disasters". In addition, if we know the ecological functions of each sere, this approach allows us to address certain management issues. For example, predicting how disposal activity might affect successional correlates such as secondary production, geochemical cycling, etc.

SUCCESSION AND THE BENTHIC MIXED LAYER

As another example, I will chose organic enrichment as a variable that can cause successional reorganization of benthic communities (Figure 4). First, we will look at the biological features of the seres that develop over space and time along a hypothetical enrichment gradient and then describe the processes which accompany such changes. The generalizations made in the following paragraphs are supported by more than 10 years of world-wide coastal and shelf monitoring experience.

Biological Features

Zone 4 in Figure 4 represents the ambient bottom where organic sedimentation rates are on the order of 200 gm C/m^2/yr or less. Most of the labile organic matter is consumed near the sediment surface by low population densities of filter or deposit-feeding organisms. Most of the biomass is represented by deeper feeding infauna that feed head-down. These infauna circulate water and advect particles over vertical distances of several centimeters. This deep bioturbating assemblage feeds on the breakdown products of relatively refractory organic matter by stimulating microbial decomposition through benthic mixing (Hylleberg 1975; Yingst and Rhoads 1980; Carney 1989; Rice and Rhoads 1989).

It is important to note that deep head-down deposit feeding assemblages are best developed in relatively oligotrophic sediments. They have relatively long mean life spans and conservative recruitment. Their presence means that the seafloor has not experienced massive physical disturbance, extended hypoxia, or organic enrichment in the recent past. The thickness of the biologically mixed layer will vary depending locally on the profile (inventory) of refractory and labile detritus (Rice and Tenore 1982) but the mixing depth is usually greater than 10 cm and may extend to several decimeters.

Zone 3 is closer to the source of organic input and therefore sedimentation rates of organic matter are higher (say, 300-400 gm/m^2/yr). The increased inputs of detrital food result in increased biomass of all species, species richness may increase, and bioturbation depths may also increase.

In Zone 2, rates of organic input approach a kilogram or more of organic carbon/m^2/yr. Above a critical organic loading rate, (specific for the system of interest), the deep subsurface deposit-feeding faunal element is lost. Only near surface feeding taxa (mainly a few species of enrichment polychaetes) remain, albeit in high densities. The biologically mixed zone may be reduced to only one or two centimeters in thickness. Deep feeding and mixing is absent. The gradient between Zone 3 and Zone 4 communities may be very sharp.

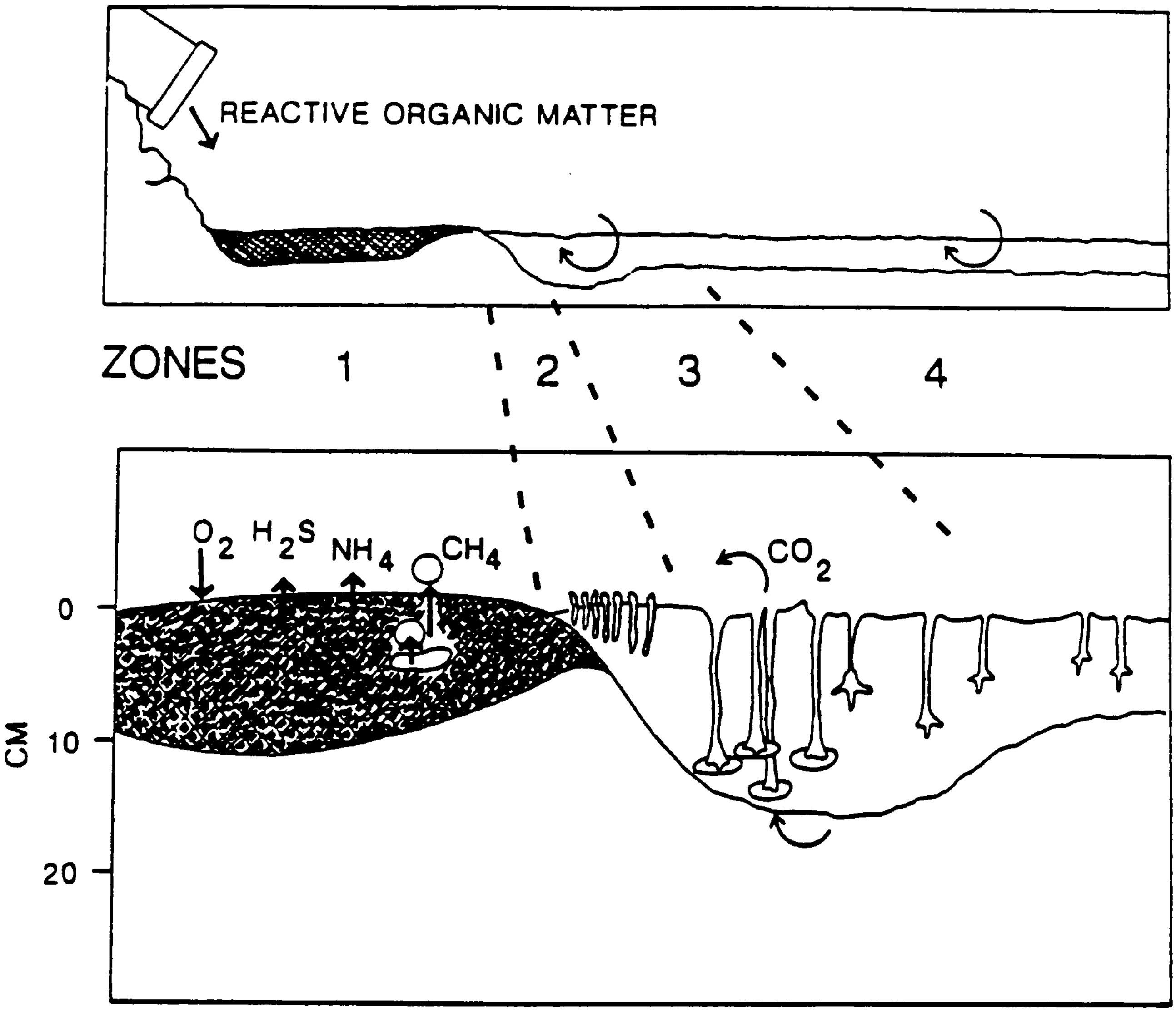

Figure 4. Organism-sediment relationships along a hypothetical enrichment gradient. Zone 1: Azoic, bioturbation is absent, high sediment oxygen demand (SOD) and release of anaerobic metabolites. Zone 2: High densities (low species richness and productivity of polychaete opportunists, bioturbation depth is surficial, SOD is high. Zone 3: Area of enhanced carrying capacity, peak species richness and deep bioturbation, reduced SOD. Zone 4: Ambient community living in relatively oligotrophic sediment, reduced diversity and biomass relative to Zone 3, very low SOD, deep bioturbation.

Zone 1, represents the input of several kilograms of reactive organic matter m^2/yr. The high flux of sulfides and absence of oxygen in the benthic boundary layer eliminates all metazoa. The biological mixing depth is zero.

Associated Processes and System Attributes

The deep benthic mixing (bioturbation) in Zones 4 and 3 serves to prevent the build-up of reactive organic matter in the sediment. Rather, organic matter is respired as CO_2. Nitrogen, phosphorus, and silica are recycled back to the water column where they may be used by plants (Aller 1982). The sediment therefore has a low inventory of sulfides and methane (anaerobic metabolites) and the sediment has a low oxygen demand.

The importance of physical stirring for digestion of organic matter is understood by sanitary engineers; physical stirring and aeration are designed into tertiary treatment plants. A major attribute of deep bioturbation is that it prevents the build-up of labile organic matter in sediments that might otherwise cause high sediment oxygen demand. Bioturbation is a natural form of "tertiary" treatment.

The sediment column in Zone 2 has a high inventory of labile organic matter and anaerobic metabolites. The sediment oxygen demand is high and such areas are candidate sites for developing bottom hypoxia. The inventory of organic matter is high both because the sedimentation rates are high and dense tube mats of enrichment polychaetes or amphipods may serve to trap organic particles (Rhoads and Boyer 1982). High organic content of the sediment also reflects the absence of deep biological mixing that would otherwise contribute to efficient aerobic decomposition, i.e. "tertiary" treatment (see above).

One positive attribute of Zone 2 type seres is that the density and productivity of small opportunistic polychaetes and amphipods can be very high because of the high input of easily metabolized (labile) detrital food. These seres can serve as important food sources for demersal species (many of commercial importance) (Becker and Chew 1983). It is interesting that benthic fish or crustacean food resources may increase just before the benthic system collapses (e.g., reverts to Zone 1) (Rosenberg et al. 1987).

Zone 1, representing extreme organic loading, has a zero benthic mixing depth. All digestion is via anaerobic bacterial pathways. Such areas are unproductive in terms of fisheries and are sources of anoxic, hypoxic, and/or sulfitic water. This water may outwell away from such sites and adversely affect far-field water quality.

In summary, in situ field mapping of organism-sediment relationships (particularly benthic mixing depths) allows one to identify successional mosaics on the seafloor. The mapped patterns can frequently identify the sources of disturbance that formed them. For example, the above type of survey was successfully conducted off the Louisiana coast around four production platforms to identify the effects of these platforms on benthic processes (SAIC 1985).

Once mapped, inferences about geochemical processes can be made in the context of the successional model outlined here. Each sere is associated with benthic processes that have important implications for overall ecosystem functions. This paradigm has particular utility for addressing management questions about how oil and gas activities (or any other disturbance) may affect benthic succession, secondary productivity, and geochemical processes.

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2.2.5

STABLE ISOTOPE TRACERS OF BIOLOGICAL PROCESSES IN THE GULF OF MEXICO

Dr. Brian Fry
Ecosystems Center
Marine Biological Laboratory
Woods Hole, MA 02543

The shelf of the northwestern Gulf of Mexico is a region of contrasts. The Louisiana shelf receives large sediment and nutrient inputs from the Mississippi River and the many relatively open bays that line the coast. In contrast, the Texas coast receives little river input, and its bays are generally contained seawards by long barrier islands. The fisheries productivity of both areas is high, but the Louisiana shelf is the more fertile of the two areas. The causes of this high productivity include river inputs, export from shallow bays, and upwelling of deep Gulf water. Tracer studies are needed to show which of these processes are locally most important for fisheries production.

Geochemists have used stable isotope tracers to study the patterns of river and estuarine influences in the Gulf of Mexico. Carbon isotope del^{13}C studies show widespread deposition of terrestrial-derived carbon into sediments of the Gulf of Mexico. For example, an early study in the Mississippi Sound east of the Mississippi River showed that terrestrial carbon measuring about -26 ppt. del^{13}C was dominant in nearshore areas, but that carbon derived from plankton and measuring about -21 ppt del^{13}C became more important offshore (Sackett and Thompson 1963). Subsequent studies of sediments off the Louisiana and Texas coasts showed that the deposition of terrestrial sediments was linked to river inputs, with del^{13}C values close to -26 ppt being found off the Mississippi River, the Atchafalaya River, and Trinity River (Gearing et al. 1977). In general, however, terrestrial carbon inputs decreased rapidly with increasing distance offshore, and were detectable only in a narrow nearshore zone of 2-30 km. Carbon from common salt marsh *Spartina* plants did not seem to influence shelf sediments, although sediments can be found in certain marsh areas that do have -16 ppt del^{13}C values close to those of -13 ppt. *Spartina* (Chmura et al. 1987).

Transect sampling has also proven valuable in stable isotope studies of food webs in estuaries and river plumes. One study examined the possible influence of the Mississippi River in fertilizing the offshore Gulf of Mexico. No large isotopic differences were detectable along transects off Southwest Pass during low-discharge winter months (Thayer et al. 1983). The effects of Mississippi River plumes are being reexamined with samples collected at peak river discharge in April 1989. A recent study has shown that algal blooms associated with river plume water can have distinctive stable isotopic compositions (Cai et al. 1988). Large algal blooms were present in Mississippi River plume water in April, and collections of phytoplankton and zooplankton are being analyzed for del^{13}C and del^{15}N. The goal of the research is to use isotopic tracers to follow the biological importance of the plume for the Louisiana shelf.

The isotopic tracers have also been used to discern the food web coupling between estuaries and the nearshore shelf, primarily through studies of common fish and shrimp. One survey of benthic shrimp and stomatopods from the northern Gulf of Mexico showed that offshore resident species that do not enter estuaries have fairly constant del^{13}C values of -14 to -16ppt (Fry 1983). However, pink, brown, and white shrimp that migrate offshore from estuaries as juveniles showed large regional differences in isotopic compositions, reflecting their estuarine past (Fry 1983).

It is not known how far seawards the estuarine food web extends along the Louisiana and Texas coasts. The gradients of isotopic change in estuaries are often much sharper in estuaries than offshore (Fry 1983), and need to be defined with close-interval sampling along the Louisiana and Texas coasts.

In summary, several biological processes important for the shelf of the northwestern Gulf of Mexico have been studied with stable isotope measurements. Transect sampling has shown that estuarine export often declines sharply with distance offshore. Future studies might combine carbon stable isotope measurements with nitrogen and sulfur isotope measurements to obtain a wider food web analysis of important fisheries species (Macko et al. 1984; Peterson et al. 1986; Fry 1988). One could assess the importance of estuarine export and river plumes for fisheries production in the northwestern Gulf of Mexico by making C, N, and S isotopic measurements along transects away from estuaries and river mouths.

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2.2.6

FLORIDA APPROACHES TO MARINE MONITORING

Dr. Sandra L. Vargo
Florida Institute of Oceanography
830 First Street
South St. Petersburg, FL 33701

The Florida Institute of Oceanography (FIO) is an administrative umbrella organization of the State University System of Florida representing the geographically dispersed marine science research community in Florida. The consortium members are the nine public universities, the private University of Miami, Florida Department of Natural Resources, and the Florida Sea Grant College. The Institute provides a forum for initiating and coordinating research vital to the State's responsible conservation and management of the marine environment utilizing the wealth of expertise of its membership and other educational and research organizations. In fulfilling its mission the FIO has long recognized the value of sustained ecological research. This research is necessary for understanding the functioning of ecosystems and for distinguishing natural variability from man-induced impacts. This research must be done on a time and geographic scale appropriate to the ecosystem in question. Funding cycles rarely encompass the time course of natural phenomena such as storms, diseases, and oceanographic-atmospheric events such as ENSO and processes such as global warming trends and sea level rise. Additionally, research at a single site cannot be extrapolated to draw conclusion about the broader system as a whole.

These considerations of scale lead to an integrating concept in Florida. This concept is based on the design of Florida's water management districts which were determined by hydrological zones. The goal of this design was to manage water resources in a manner appropriate to the geographic scale of the resource. The FIO proposes to extend this concept to coastal ocean management with management zones based on biological and physical factors (Figure 5) allowing for common research methodology and a coordinated management strategy.

In initiating this plan the FIO has targeted two areas in Florida for pilot studies - the West Florida Shelf and the Florida Keys reef tract. The West Florida Shelf program is in the preliminary stages of development and is not yet funded. However, the need is apparent when one considers the high productivity of the region (including periodic red tides with major ecosystem impact), its great areal extent, and the relative paucity of information available. The major studies in the region were funded by Minerals Management Service to evaluate potential environmental impacts of oil and gas exploration and production activities in the region. These studies were primarily descriptive in nature and not process oriented. In addition, there was no linkage between the water column and the benthos.

The FIO has received funding for the program in the Florida Keys from the John D. and Catharine T. MacArthur Foundation. The program will focus on the reasons for the decline in live coral coverage along the reef track in the past ten years, keeping in mind that the reef track is the down stream element in a mosaic of ecosystems commencing at Lake Okeechobee. At least four hypotheses have been advanced to date to account for the decline of live coral and are as follows.

- nutrification due to agricultural runoff and increased population;
- input of trace metals and pesticide from the same sources;
- stress from the coral bleaching events in 1983 and 1987;
- some combination of the above.

The research team has designed a program taking into account the time and geographic scales necessary to evaluate these various hypotheses. The establishment of five core research sites (Figure 6) is central to the program. Initial plans are to utilize the National Oceanic and Atmospheric Administration (NOAA) Marine Sanctuary system and other protected areas where possible. The tentative sites planned are Biscayne National Park, Key Largo Marine Sanctuary, Tennessee Reef, Looe Key Marine Sanctuary, and Fort Jefferson National Monument. Each of these sites will be subject to long-term continuous monitoring of environmental parameters such as incident and submarine irradiance, air temperature, wind speed, tide and wave height, water temperature at several depths, fluorescence (chlorophyll a), turbidity, and conductivity. These monitoring stations will be

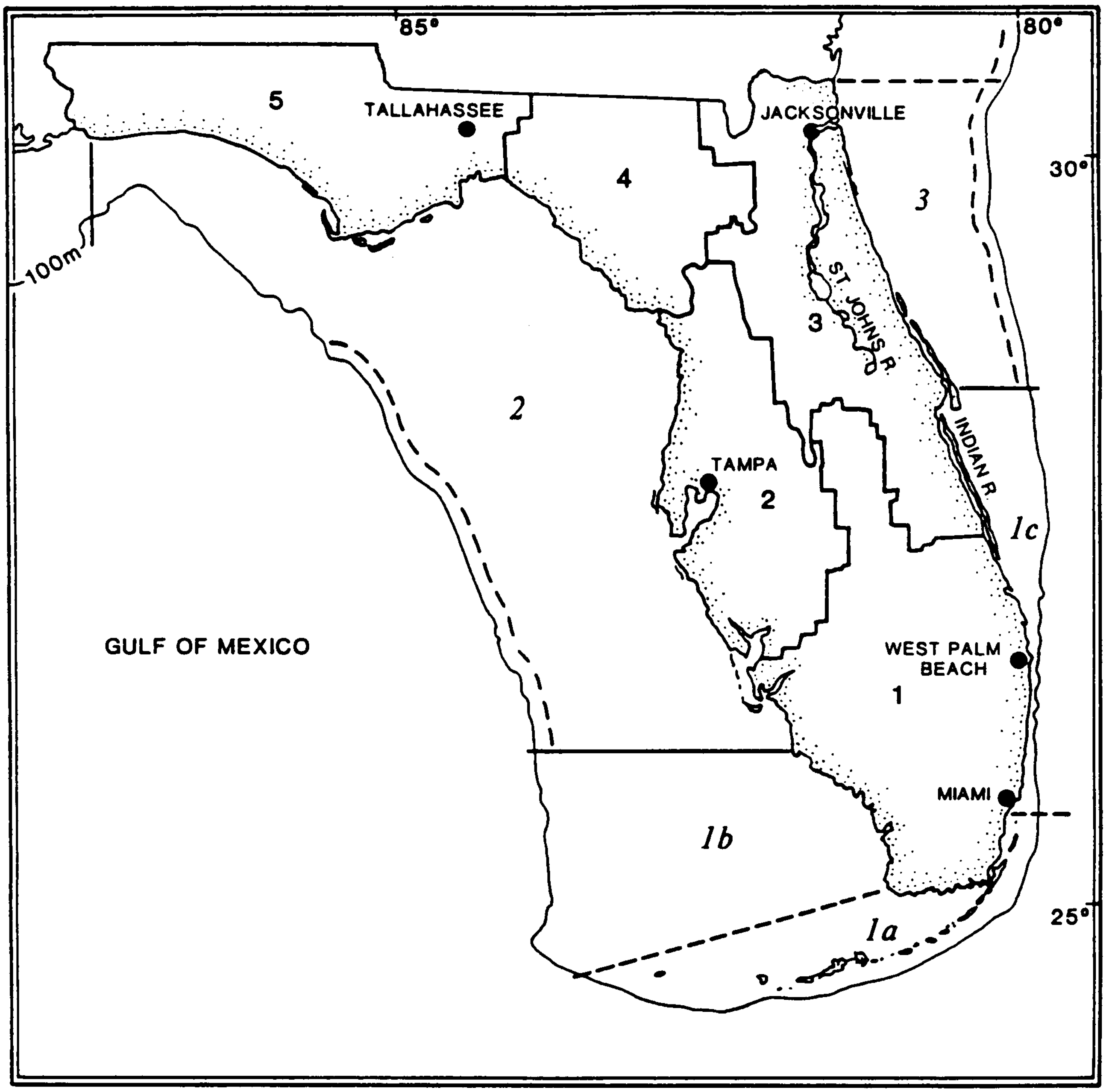
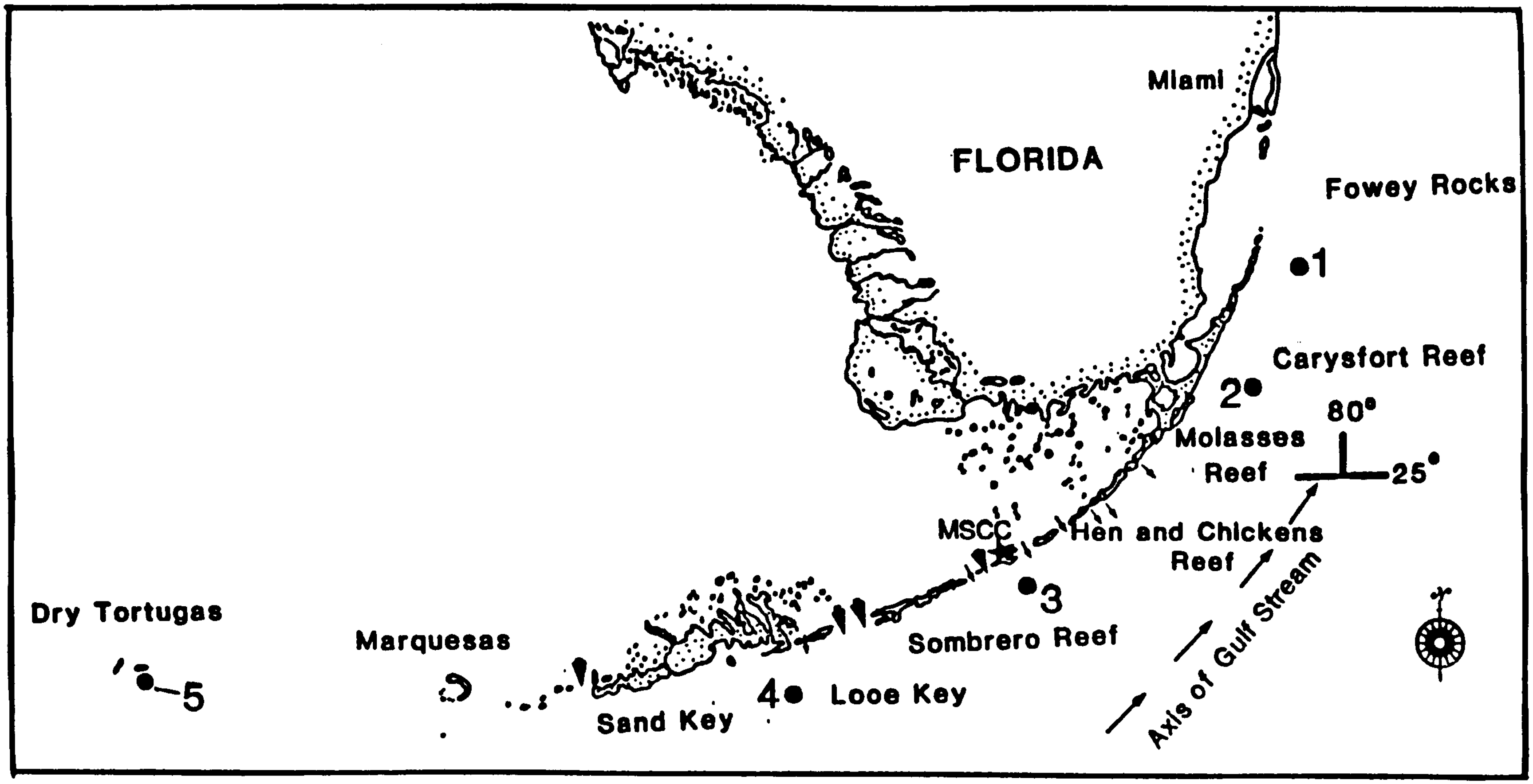


Figure 5. Hypothetical coastal management districts.



5. Fort Jefferson National Monument

4. Looe Key National Marine Sanctuary

3. Tennessee Reef

2. Key Largo National Marine Sanctuary

1. Biscayne National Park

Figure 6. General locations of core sites along the Florida Keys reef tract. Water flow from Florida Bay out toward the reef tract is shown by the arrows. The site of the arrows denotes the relative volume of the flow.

automated and data transferred by satellite transmission to the main support facility, the Marine Science and Conservation Center on Long Key, roughly midway in the chain of islands. The data will be used to establish long-term trends along the geographic scope of the reef tract and as support information for the more site specific studies designed to fill in known data gaps.

Four site specific studies are planned to fill these data gaps and are as follows.

1. Water circulation and transport (N. Smith, Harbor Branch Oceanographic Institution)

   The water circulation and transport studies will focus on quantifying water exchange (tidal and non-tidal) between Florida Bay and the reef tract. Secondarily, net transport from the island chain to the reefs will be determined.

2. Coral reef dynamics (J. Porter, University of Georgia; W. Jaap, Florida Department of Natural Resources)

   The coral dynamics portion will use photographic recording of quadrants to determine long-term changes in coral coverage and growth. This will build on an existing five year library for Key Largo and Looe Key. The process will be automated to make it more suitable for management purposes.

3. Ecological and physiological indicators of coral health (A. Szmant, University of Miami)

   This portion of the program will evaluate a variety of factors influencing coral growth such as incidence of disease, biomass of zooxanthellae, and recruitment. Coral growth will be measured directly using Alizarin Red techniques.

4. Nutrient dynamics (A. Szmant, University of Miami)

   The integrated effect of increased nutrients will be assessed using settling tiles (caged and uncaged) to determine the growth of macroalgae. Additionally, macroalgae will be plotted in selected quadrants at the core sites and assessed quarterly to determine seasonal and longer term trends.

While the environmental monitoring stations and site specific studies will provide much needed information to develop effective management strategies for the Florida Keys reef tract, none of these strategies will be effective without broad based public support. It is quite likely that any effective management will involve further restriction of activities on the reef. Therefore, we have incorporated in this program a means of public education via a videotape explaining the relationship of the reef to the larger seascape and how man's activities affect this ecosystem.

2.2.7

THE DESIGN AND EXECUTION OF A LARGE OCS MONITORING PROGRAM

Dr. Gary D. Brewer
Environmental Studies Section
Mineral Management Service
Pacific OCS Region
1340 West Sixth Street
Los Angeles, CA 90017

The California Monitoring Program (CAMP) is a multidisciplinary evaluation of the long-term environmental effects of oil and gas development and production platforms. Sponsored by the Department of Interior, Minerals Management Service (MMS), the project is designed to (1) detect spatial and temporal changes in the soft bottom and hard bottom benthic communities in the Santa Maria Basin, California and (2) evaluate whether any such changes are related to drilling activities. Participants include biologists, chemists, and physical oceanographers from over a dozen consulting firms, academic institutions, and government agencies. A panel of independent experts has been retained as a Quality Review Board.

Planning for a platform monitoring program began in 1982 when a conference was held in Los Angeles to develop study needs and priorities (USDI, MMS 1982). Eventually, a three-phased program emerged that is expected to last well over a decade. Phase I began in 1984 with a reconnaissance of the Santa Maria Basin; results of the Phase I survey (Science Applications International Incorporated 1985; Piltz 1986) helped identify appropriate study sites and sampling protocol for Phase II (CAMP) monitoring, which began in 1986 and is ongoing (Brewer et al. 1987; Hyland and Neff 1988). The knowledge gained during Phase II should provide the insight for additional, innovative studies during a projected Phase III. To give you some idea of the relative commitment to these studies, to date, MMS has committed about $12 million, not including potential funding during Phase III.

The Santa Maria Basin (Figure 7) was selected as a study region because the area had been free of oil development drilling before our studies began. In addition, the coastal area offshore south-central California is free of the potential confounding influence of major sewage outfalls and large rivers.

Two sites of proposed oil and gas development drilling are being monitored. Soft bottom communities are being studied at a series of site-specific stations around the proposed site of Platform Julius (145-m isobath) and at a series of nine regional stations (depth range 90-565 m) (Figure 8). All soft-bottom sites are sampled in triplicate with a 0.25 m^2 box corer for analysis of macrofauna and meiofauna. Representative species of both macrofauna and meiofauna are given detailed life-history analysis, such as egg production and growth. X-rays have been taken of special box core sections to examine the vertical structure of the burrowing organisms.

Hard bottom communities are being studied at nine deep water reefs adjacent to Platform Hidalgo (Figure 9). Hidalgo is located on the 130 m isobath and the stations range from roughly 100 to 250 m depth. Each of the nine study reefs is sampled with a remotely operated vehicle (ROV) called Recon IV on a seasonal basis both before and after drilling was initiated. A high resolution color video camera enables the pilot to guide the ROV to and over each site, where random, standardized photoquadrats are collected. Counts and density estimates of rock epifauna are made by projecting the color slides onto a screen. The reproduction and growth of selected reef species are being studied.

In addition to the biological studies, the chemistry of platform discharges, sediments, and animal tissues are examined; concurrent studies are underway of currents, sediment transport, and sediment resuspension. Complementary laboratory work is comparing larval settlement in natural sediments versus sediments contaminated with drilling waters.

The original experimental rationale was to sample all regional and site-specific stations (i.e., for biological, chemical, and sediment parameters) during the fall of each year, both before and after platform drilling was initiated, for a period of five years. In addition, seasonal variability in all parameters was to be evaluated during

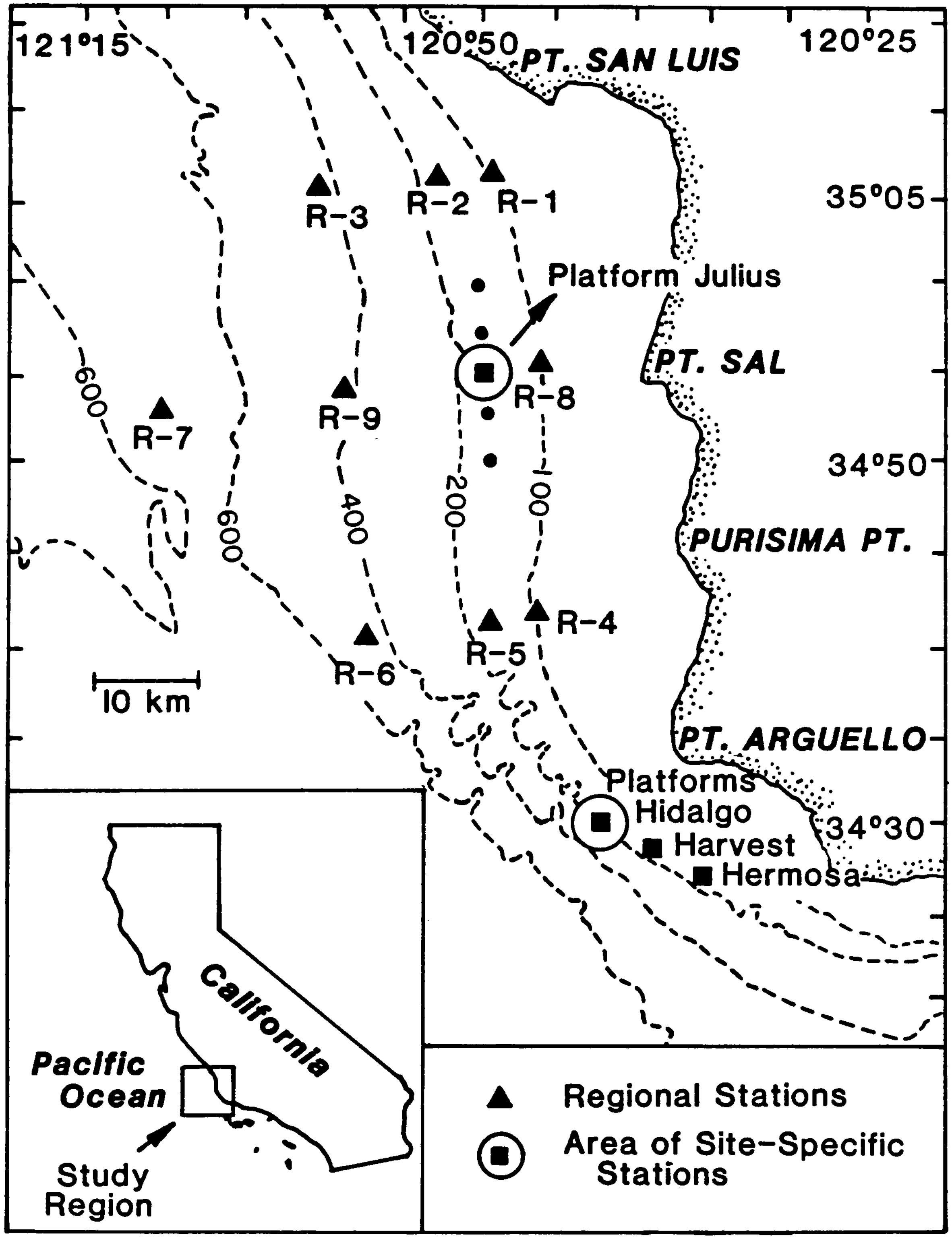


Figure 7. Location of CAMP study region, including Platforms Hidalgo, Harvest, and Hermosa and proposed Platform Julius.

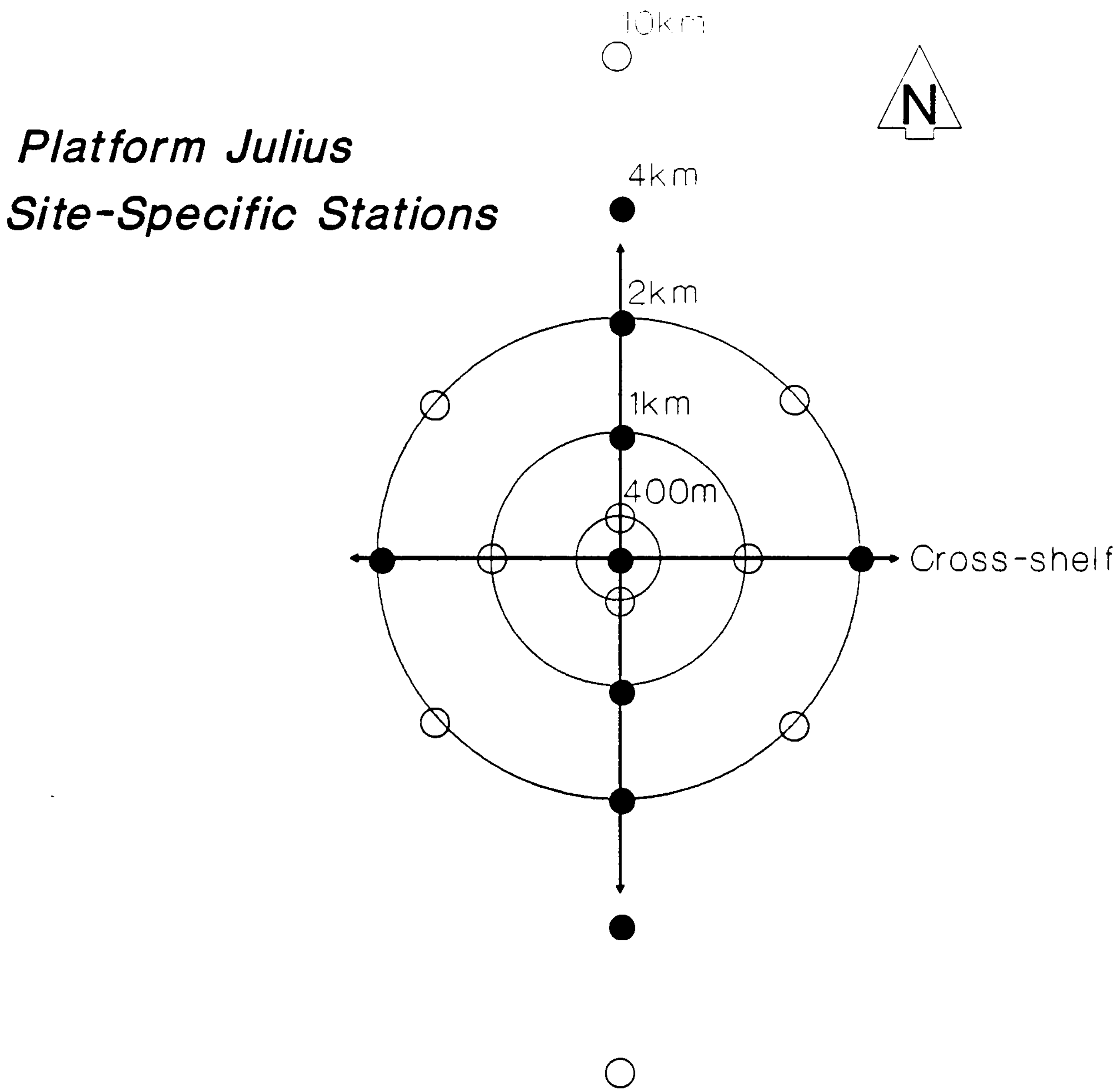


Figure 8. Diagram of the site-specific, soft bottom sampling array around proposed Platform Julius.

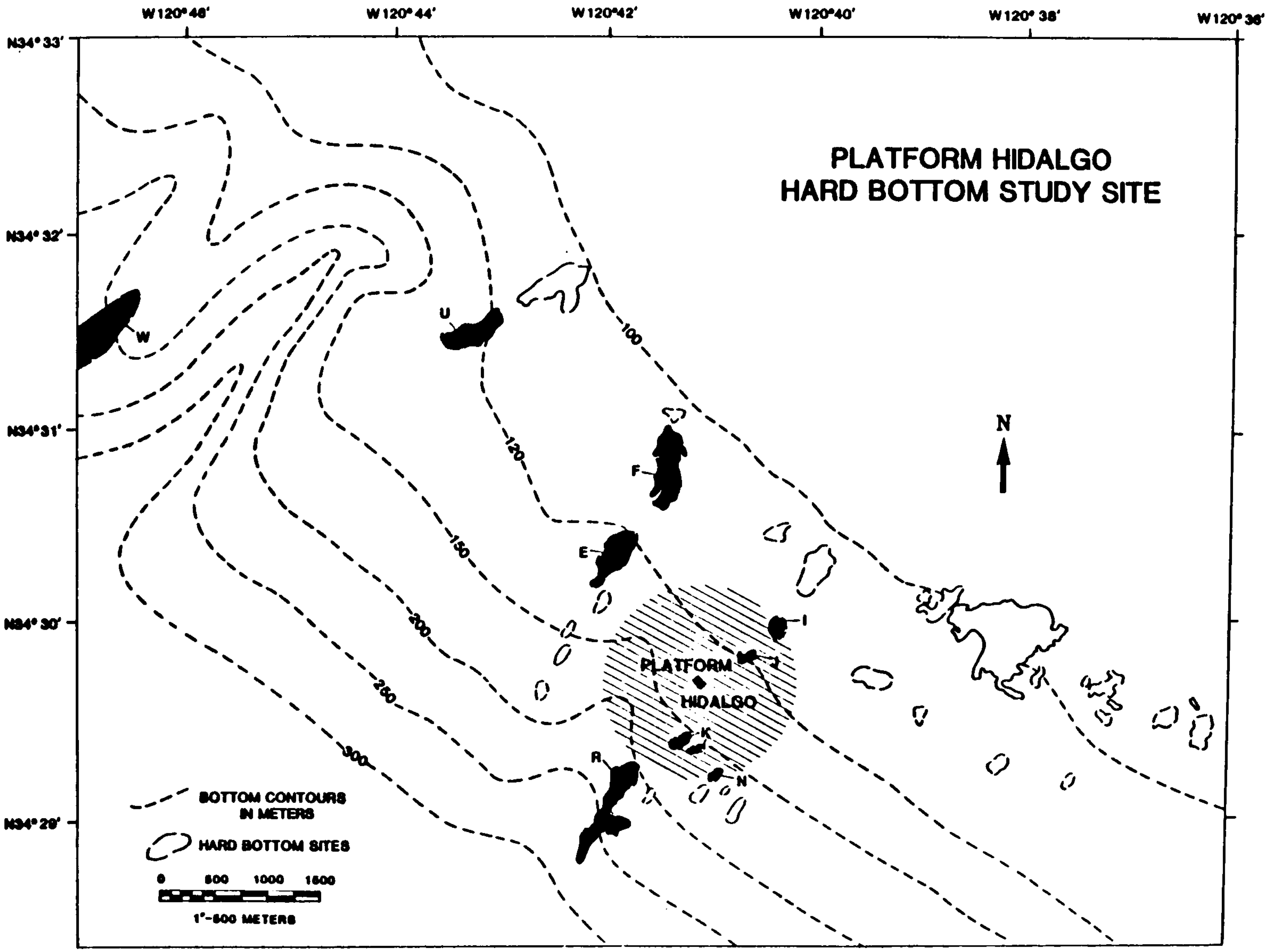


Figure 9. Location of hard substrate (reef) stations around Platform Hidalgo. Reefs selected for long-term monitoring are designated as sites W, U, F, E, I, J, K, N, and R.

at least a one-year period, both before and after drilling commenced. Potential dose-response relationships would be tested by assessing biological changes in benthic assemblages together with concurrent physical or chemical changes in the sediments that were specifically linked to platform discharges.

What specifically are the potential impacting agents or factors associated with offshore drilling that might alter these hard bottom communities? Other than the obvious physical presence of the platform (i.e., an artificial reef) biological communities at some variable distance around oil and gas development and production platforms are exposed to a variety of platform-associated contaminants (Table 5). The most significant discharges, in terms of volume and composition are drill muds and cuttings (Table 6). Produced waters may be important at some installations, but have not, and will not, been discharged in the Platform Hidalgo region.

Table 5. Permitted discharges and effluents associated with offshore oil development.

Drill cutting	particles of sedimentary rock (up to 900 metric tons per well)
Drilling fluids	primarily barium sulfate, clay, ligno-sulfonates, sodium hydroxide with some trace metals and hydrocarbons (up to 1000 metric tons per well)
Cooling water	deck drainage, ballast water (treated)
Domestic sewage	treated
Sacrificial anodes, anti-fouling paints, pipe dope	small amounts of Al, Cu, Hg, Pb, Sn, Zn
Produced water	saline "fossil water" (up to 1.5 million liters per day)

Table 6. Ingredients of water-based drilling muds.

Barite (barium sulfate)	used as a weighting agent
Bentonite clay	seals bore-hole and maintains gel strength
Lignosulfonates	organic polymers from wood lignin, used to control viscosity
Lignin	a soft coal used as a clay deflocculant
Sodium hydroxide	maintains pH between 10 and 12, which is needed optimum clay deflocculation
Sea Water	
Total = 99 + %	
Other Additives	

Studies at Platform Hidalgo that are dedicated to fishes will begin in the fall of 1989. Entitled "Effects of an OCS Oil and Gas Platform on Rocky Reef Fishes and Fisheries," the project will supplement the CAMP project by adding studies of spatial variation, sublethal effects, and ecological relationships of fishes. In planning for these studies, we recognized that experimental design is limited by having to collect data at depths of 100 to 250 m, by the lack of unbiased sampling techniques, and by high sample variance. The mobility of fishes makes the study problematical. For example, conclusions regarding the uptake (or lack of uptake) of contaminants from a point source discharge are tenuous if the distributional history of the species under study is unknown. Nevertheless, MMS is supporting these studies because the perception persists that commercially valuable finfish may be at risk as a result of platform placement or routine platform discharges.

We selected Platform Hidalgo and the adjacent reefs for the fish studies in part because fishes are known to aggregate on or over rocky outcroppings and topographic features. Such behavior, i.e., a limited home range, should provide the opportunity for tenable hypothesis testing on platform effects to reef associated species. We plan to use a combination of high quality video, still photos, commercial fishing, and tagging to evaluate fish abundance, distribution, and movements among the reef and between the platform and the reefs. Studies of sublethal impacts will examine the uptake, accumulation, and/or metabolism of metals and hydrocarbons. A variety of sensitive biochemical measures will be used; life history and recruitment variability among reefs that are exposed to platform contaminants will be compared to unaffected reefs. Foods/feeding and predator/prey relationships of fishes will be examined and compared between the platform and the reefs. To date, three-years of pre-drilling CAMP data has been collected at site-specific Platform Julius soft bottom stations and regional soft-bottom stations.

The installation of Platform Julius has been stalled by permitting delays, and as a result, CAMP has suspended sampling at all soft bottom stations until a definitive date for Platform Julius installation and first-drilling is determined. At Platform Hidalgo, the first well was drilled in November 1987, providing the opportunity to collect one-year of pre-drilling, seasonal sampling as originally planned. However, after seven wells were drilled at Platform Hidalgo, drilling was suspended, pending approval of an onshore processing facility. Nevertheless, sampling at Platform Hidalgo will continue, at least through October 1990, and additional sampling beyond 1990 will be considered, depending upon the timing and extent of additional drilling.

Finally, the design of the MMS Pacific Outer Continental Shelf Region's long-term monitoring project has received considerable interest and critical review; the project has benefited from a knowledge of the mistakes and shortcomings of previous platform monitoring projects. Unfortunately, the execution of what we believe is a well-designed study has been clouded by unforeseen delays in the approval of development and production permits.

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2.2.8

MONITORING FOR SOFT BOTTOM EFFECTS

Dr. Paul A. Montagna
The University of Texas at Austin
Marine Science Institute
Port Aransas, TX 78373-1267

It is very difficult to detect long-term impacts of oil and gas activities in the marine environment. Part of the problem is in identifying and defining quantitative measures of impact. The most difficult aspect is to assess the cumulative and chronic impacts of low-level effects.

Three recent studies, California Monitoring Program (CAMP), Group of Experts on Effects of Pollution (GEEP), and SEEP have added substantially to our current knowledge on how to detect and measure impacts, and are relevant to the purpose of this workshop. Each study defined potential impacts and implemented study elements to detect those impacts. CAMP is a well-designed, long-term monitoring program on the California continental shelf, and I will summarize the soft bottom studies to date. GEEP is a European study of a pollution gradient which covered all aspects of the ecosystem. SEEP is a study of long-term chronic impact on benthic processes at a southern California oil seep. I will review these programs and try to draw some conclusions and perspectives on how to detect and measure long-term impacts.

CAMP PROGRAM

The CAMP program (Brewer, section 2.2.7) was conceived to determine the long-term impact of oil and gas development and production in a pristine environment. The work is being performed by Battelle (the prime contractor) and many subcontractors (I am the subcontractor for the meiofauna studies). Work at the hard bottom site (south of Point Arguello) has progressed nicely. There were two cruises before spudding at Platform Hildalgo in November 1987. There have been five cruises since then to perform long-term monitoring. Unfortunately, work at the soft bottom site (west of Point Sal) has terminated after nine cruises. Platform Julius was to be installed by Shell Western Exploration and Production in July 1987, but has been postponed until late 1992 or perhaps indefinitely.

The objectives of the soft bottom program were to detect and measure long-term (or short-term) environmental changes around oil and gas platforms in the Santa Maria Basin, and to determine whether the changes were caused by drilling-related activities or were natural events. To achieve these objectives three null hypotheses were formulated: (1) there are no differences in biological, chemical, or physical variables between platform and comparison sites; (2) there are no changes in biological, chemical, or physical variables with time at the monitoring sites; and (3) observed changes in biological, chemical, or physical variables at the monitoring sites are not related to drilling-related events.

The plan at the soft bottom site was to distinguish between local and regional effects. Regional stations were selected to cover broad geographic and bathymetric zones, and to sample sites visited in an earlier reconnaissance survey by Science Applications International Corp. We employed three transects with stations at depths of 90, 150, and 410 m. One additional station was added at 750 m to the central transect which is known locally as the mud patch. This was added since it is apparently a depositional environment, and therefore the most likely area to be impacted of any deeper sites. To determine near-field effects at the site of the platform a "Site Specific" array was developed. We employed a semi-radial station pattern to determine near field impacts in any direction. Concentric rings at 0.4, 1.0, and 2.0 km intervals were sampled to determine the spatial scale of detectable impacts. This design was inspired by a successful monitoring program conducted on Georges Bank by Battelle and the Woods Hole Oceanographic Institution.

Sampling was designed to span 5 years. Sampling was to be performed three times annually for one year pre- and post-spud, and then annually thereafter. Because of the drilling delays, we started sampling biannually in May 1988, but cruises for the fourth and fifth year have been postponed indefinitely.

Samples are taken with a 0.25 m^2 Hessler-Sandia box core. The box core is fitted with 25 subcores so that synoptic measurement can be made for biological (macrofauna and meiofauna), chemical (trace metals, particularly barium, hydrocarbons), and sedimentological (grain size, TOC, carbonate, shear stress) properties.

The central California shelf is rich in meiofauna. Meiofaunal continental shelf densities around the world span two orders of magnitude with the Pacific being among the highest and the Gulf of Mexico being among the lowest (Table 7). In the USA, the west coast has higher densities than the east coast. The east coast estimates are remarkably similar to one another. Arctic and North Sea densities are as high as east Pacific densities. But, the eastern Atlantic off Africa is also low. The southeastern Texas shelf of the Gulf of Mexico is very depauperate in meiofauna.

Table 7. Continental shelf meiofauna densities.

Location	Density $10^3/m^2$	Depth m	Author
Santa Maria Basin	90-140	1900	Montagna 1990
Santa Maria Basin	750	197	Montagna 1990
SE USA	100-400	670	Tietjen 1971
SE USA	11-500	360	Coull et al. 1982
SE USA	> 400	670	Coull et al. 1977
NE USA	250-750	117	Wigley & McIntyre 1964
North Sea	101-146	1480	McIntyre 1964
North Sea	117-141	2050	Faubel et al. 1983
Norwegian Sea	250-750	870	Thiel 1975
Barents Sea	226-405	2550	Pfannkuche & Thiel 1987
Barents Sea	854	1330	Pfannkuche & Thiel 1987
W Africa	40-750	1000	Thiel 1978
Gulf of Mexico (STOCS)	10-82	200	Pequegnat & Sikora 1979
Gulf of Mexico (STOCS)	91-134	50	Pequegnat & Sikora 1979

The most interesting outcome to date in the CAMP program is that macrofauna and meiofauna densities exhibit little correlation with one another (Hyland 1988). Whereas, macrofauna densities decrease with increasing depth, meiofauna do not. Also, macrofauna diversity decreases with depth, but meiofauna diversity increases with depth. Both macrofauna and meiofauna exhibit some temporal trend but it is not seasonal. This indicates that meiofauna and macrofauna probably have different roles in benthic shelf ecosystems. We know this to be true in shallow water ecosystems (Coull and Bell 1979; Coull and Palmer 1984). Meiofauna, because of their small size and shorter generation times, can have similar or higher productivity values than macrofauna (Gerlach 1971, 1978). Meiofauna, because they share similar spatial scales to microbes, also play important role in nutrient cycling (Gerlach 1978). The CAMP study demonstrates the importance of studying both meiofauna and macrofauna because they probably indicate different kinds of effects on the benthic ecosystem.

Given the obviously low densities of meiofauna in the Gulf of Mexico, it is imperative that we develop an understanding of food limitations in benthic webs in the Gulf. This will require understanding the benthic microbial food sources that support meiofauna and macrofauna populations.

GEEP Workshop

The GEEP workshop was convened to perform a practical inter-calibration study and evaluate techniques for the assessment of pollution in the sea (Bayne et al. 1988). All levels of biological organization were studied from the molecular to the community, and all biological components from bacteria to macrofauna were included. Both mesocosm and field experiments were performed. In the GEEP mesocosm experiment Warwick et al. (1988)

found meiofauna to be very sensitive to the treatments. Harpacticoids exhibited a graded response of decreasing diversity with increasing exposure to pollutants, but diversity profiles for nematodes were virtually unaffected. Diversity was not useful in detecting the pollution gradient in the field study, but community differences were distinct and species level data gave no more information for discrimination than did higher groupings (Heip et al. 1988). Macrofauna phyla groupings also were just as adequate for distinguishing the pollution gradient as were species level data (Warwick 1988a). Based on the field and mesocosm studies Warwick (1988b) came to the following list of conclusions on the relative utility of meiofauna and macrofauna in detecting environmental impacts.

- Macrofauna:
  - widely studied, and there are many species which are known stress indicators;
  - longevity results in community structure exhibiting integrated responses over the long-term;
  - world-wide taxonomic literature means they are easy to investigate;
  - methodologies for sampling and analysis are well developed.

- Meiofauna:
  - sampling is inexpensive and less labor intensive;
  - lower levels of taxonomic discrimination produce results which are as good as species analyses (macrofauna also);
  - short generation times mean fast response potentials;
  - because of short generation times, small size, and direct benthic development, community responses are measurable at temporal and spatial scales which can be reproduced in experiments (e.g., mesocosms);
  - copepod species were most sensitive to discriminate polluted sites than other meiofauna or macrofauna species.

The most remarkable result from these studies is that identifications at higher taxonomic levels are as good as species identifications. This indicates that it may be possible to obtain up to 80% of the information one needs with the expenditure of the first 25% of the funds. The results also indicate that meiofauna and macrofauna can indicate impacts at different levels of the ecosystem of interest. Finally, harpacticoid copepod species are the most sensitive indicators of stress in both field and mesocosm studies.

SEEP STUDY

Southern California has an abundant amount of natural hydrocarbon seeps. Curiously, it was found that there are higher densities of benthic macroinvertebrates living in seep sediments than in normal sandy sediments (Spies and Davis 1979; Davis and Spies 1980). Organic enrichment, via heterotrophic hydrocarbon degrading bacteria and chemoautotrophic sulfide-oxidizing bacteria and nematodes, was hypothesized to explain the high densities of macroinfauna at the Isla Vista seep (Spies and DesMarais 1983). We investigated mechanisms that control tropho-dynamic benthic processes as a function of active petroleum seepage (Spies et al. 1988). Meiofaunal, bacterial, and microalgal populations were followed over two annual cycles to determine if they were responding to fluctuations in the abundance of bacterial and microalgal food.

Bacterial biomass and productivity exhibited a strong graded response, increasing with increasing hydrocarbon seepage (Table 8). Nematode density was also greater at the station with the most active seepage rates. On temporal scales, when bacteria biomass and production decreased from the first to second year, so also did nematode density (Table 8). These strong links between nematodes and bacteria indicate that seeping petroleum has an enhanced effect on the detrital (bacteria based) food web. Benthic metabolism increased sharply along the petroleum gradient (Montagna et al. 1986; Bauer et al. 1988). Although the nematode:copepod ratio is controversial, it increases with the increasing petroleum gradient. Harpacticoids and Chl a are more dense and abundant at the comparison site than at the seep sites (Table 8). When Chl a decreased, harpacticoid density decreased (Table 8). These strong links between harpacticoids and microalgae, and decreases in both populations with increasing seepage indicate that seeping petroleum may have a deleterious effect on the grazing (microalgal based) food chain.

Table 8. Santa Barbara hydrocarbon seep microbes and meiofauna parameters means by year and station (Montagna et al. 1987, 1989).

Year	Station	Chl	BAC	2nd	NEM	HAR	OTH
84-85	o	14.5	2.14	211	1767	326	136
86	o	12.7	1.05	185	1069	27	170
o	A	11.1	2.22	381	2184	89	163
o	B	14.1	1.40	213	1051	109	141
o	C	18.8	1.23	119	1224	345	165

Chl = chlorophyll a (mg/m^2).
BAC = bacterial biomass (ug C/m^3).
2nd = bacterial secondary production (mg $C/m^2/d$).
NEMatoda,
HARpacticoida,
OTHer (29 taxa) = meiofauna density ($103/m^2$).
Sampled: Dec 84, Apr 85, Jul 85, and Apr 86, Jul 86, Dec 86.
Gradient of seepage at stations = A > B, and no seepage at C.

As well as organic enrichment by the petroleum, we also studied potential sublethal toxic effects on benthic recruitment. Harpacticoid copepods were used for the reproductive study. They undergo six naupliar and six copepodite stages, the adults are sexually dimorphic, and females brood their eggs. Thus a number of reproductive parameters can easily be counted and measured for size differences. We found that life history strategies were different in the three sites. Species which were restricted to the heavy hydrocarbon seepage site had very high rates of egg production relative to the number of surviving juveniles (10:1). Species away from the seep had ratios of eggs to juveniles approaching 2 or 5:1 (Spies et al. 1988). Similar life history responses of harpacticoids to the AMOCO CADIZ spill in France have been reported by Bodin (1989).

The SEEP study demonstrates the usefulness of measuring benthic tropho-dynamic processes to determine the long-term cumulative impacts of petroleum on benthic communities. Harpacticoid copepods were especially useful to elucidate sublethal effects on population recruitment.

Conclusions and recommendations based on CAMP, GEEP and SEEP studies: All three studies point out the importance of studying both macrofauna and meiofauna to detect short- and long-term impacts on soft bottom ecosystems. Regardless of whether the goal is to design a monitoring study, chronic impact study, or an ecosystem study one should:

- develop a prior null hypotheses;
- use community structure to determine effects on habitat structural degradations;
- use rates of processes to determine effects on habitat functioning degradation;
- use life history and reproductive data to indicate sublethal or chronic impacts;
- design work so natural influences can be easily segregated from man's impact on both local and regional scales;
- choose the target group with the best attribute for the question; this may generally require knowledge about bacteria, meiofauna, and macrofauna;
- explore the use of higher taxonomic levels to detect impacts, rather than identifying everything to the species level;
- measure trophic dynamic structure and processes to indicate impacts which might result in organic enrichment.

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2.2.9

BIOLOGICAL EFFECTS OF PETROLEUM HYDROCARBONS

Dr. Jay C. Means, Professor
Environmental Studies Institute
Louisiana State University
Baton Rouge, LA 70803

The study of the toxicological impacts of petroleum hydrocarbons has been the focus of literally hundreds of research articles. It would be impossible to summarize these in even a cursory way in the abstract. However, the reader is referred to two recent compilations (Boesch and Rabalais 1987; National Research Council 1989) which do encompass the wealth of information available. The vast majority of this article involves assays of acute, short-term effects on various species of organisms representing several phyla. While these studies have established the acute toxicity of petroleum hydrocarbons, integrated long-term studies which take into account what is known about the physical-chemical processes which determine contaminant distributions in sediment-water systems have not been performed. Recent research has produced predictive models of exposure for benthic organisms in contact with contaminated sediments (McElroy and Means 1988). Further, studies which attempt to show the relationships of benthic infaunal activities and contaminant transport are also beginning to appear in the literature. What is still lacking are integrated, holistic studies which take into account both physical and biological processes which are occurring on longer time scales (e.g., six months to two years). The following are a series of recommendations for research in the areas of long-term effects of petroleum hydrocarbons.

RECOMMENDATIONS

1. Detailed investigation of the chemodynamics of oil and gas production associated normal aromatic, and heterocyclic aromatic hydrocarbons with special emphasis on the role of chemodynamic processes in regulating bioavailability to benthic and demersal organisms and in contributing to the persistence of these chemicals in sediments.

2. Investigation of the effects of petrogenic aromatic hydrocarbons and selected trace elements upon the intermediary macromolecular processes in benthic and demersal species with special emphasis upon processes associated with growth, reproduction, and energy utilization in these organisms.

3. Develop more rigorous analytical methodologies for the evaluation of the fate and transport of biologically active aromatic hydrocarbons including heterocyclic compounds and metabolites of aromatic and heterocyclic compounds.

4. Investigate the long-term effects of genotoxic compounds and metabolites upon the genome of benthic and demersal species.

5. Investigate the potential for tropic exchanges of accumulated compounds or metabolites of those compounds with respect to their chronic toxicological impacts on organisms.

6. Investigate the relative sensitivity of early developmental stages of benthic and demersal organisms with respect to their responses to chronic exposure to petrogenic hydrocarbons during long periods of development.

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2.2.10

UPDATE OF DRILLING WASTES FATE AND EFFECTS STUDIES IN THE MARINE ENVIRONMENT

Mr. Maurice (Mo) Jones, Director
ENSR Environmental Laboratory
Houston, TX

To assist the Minerals Management Service (MMS) in designing offshore studies to detect impacts associated with long-term oil and gas activities, it would be useful to review selected papers from the recently released proceedings of the 1988 International Conference on Drilling Wastes (Engelhardt et al. 1989). Several conclusions should be considered by members of the workshop charged with identifying needs of the MMS Gulf of Mexico Environmental Studies Program.

Of the forty papers presented at the symposium, half dealt with the marine environment. Of these 20 papers, nine were concerned with the fate and effects of oil-based muds (OBM), which were discharged under international regulations (typically prohibited by U.S. Environmental Protection Agency regulations). The 11 water-based muds (WBM) papers were roughly half field and half lab studies, with a few additional papers discussing modeling (two papers) and testing protocols (four papers). Only three fate and effects papers concerned Gulf of Mexico sites specifically. While the WBM studies are the most relevant to this workshop due to the prohibitions on discharging OBM in the Gulf, OBM studies are possibly pertinent when considering long-term, low-level hydrocarbon contamination. In the short time allotted today, clearly all 20 papers cannot be thoroughly reviewed, but selected issues relevant to designing long-term monitoring are noted as follows.

Boothe and Presley's study (1989) was exemplary because they developed good retrospective data on the discharges including amounts and types, then tied this operational data to assessment survey data through a mass balance approach in sediments within 500 m of six offshore drilling sites (exploration, development, and production) in water depths ranging from 13-102 m in the Gulf of Mexico. An improved "bulls-eye" sampling strategy was employed. Using barium as a mass balance tracer, they found that deep-water development and production sites had by far the largest barium and other trace element (Zn, Cd, Cu, Pb) retention. Presumably, other mud constituents behaved similarly. Shallow water sites retained $<1.5\%$ total barium. Few large scale MMS fate studies, such as are being discussed here today, have placed adequate emphasis on first describing the inputs to the system and the comparing inputs to remaining levels. I heartily recommend that the workshop adopt a similar approach and consider mass balance approaches when feasible.

The relatively efficient dispersal mechanisms observed by Boothe and Presley (1989) in shallow waters was also observed by Jones (1989) in Galveston Bay. Precisely measured doses of drilling wastes to enclosed in situ mesocosms resulted in barium enrichment in the sediments up to 40,200 ppm at the highest dose. Within six months, these elevated levels, comparable to values found around production sites offshore, were reduced to background levels in this shallow estuary (<2m). The authors speculated that a combination of resuspension, bioturbation, and density transport into deeper sediments were the dispersal mechanisms that accounted for the rapid decrease. A precise understanding of these dispersal mechanisms, their relative importance, the associated biotic (e.g., tube dwelling polychaetes), and abiotic (e.g., weather events) elements, are critical to understanding the processes that govern fate and effect. I recommend that the workshop incorporate into its planning consideration of investigating these mechanisms.

Jenkins et al. (1989) found elevated barium levels down current of an exploratory well offshore California. Using an improved "bulls-eye" sampling pattern, he also identified statistically significant bioaccumulation of barium in two benthic species (clam and polychaete). Jenkins went further than most similar studies in that he tried to determine the potential significance of the bioaccumulation observed to the population. His group fractionated the organisms and studied the form of the accumulated barium. They determined that the barium remained as insoluble $BaSO_2$, that very little became bioavailable, and thus no toxicity was observed or expected to occur. This study is good in that it seeks to understand the meaning of an observation and, again, its implication for the health of the population and community. Similarly, we should look for ways to understand the significance of our findings.

These three studies confirm earlier observations by the National Research Council (1983) and other reviewers that the MMS is correct in its strategy to emphasize development and production sites rather than exploration, except in unique environments, and to look further into water column impact studies such as preoccupied our interests early on.

One very interesting study by Thompson et al. (1989) on the effects of drilling wastes offshore Florida in the Big Bend seagrass bed area did find significant effects on *Halophila* from an exploratory rig. They postulated that physical smothering and decreased light penetration may have been the underlying mechanisms. Fortunately, they revisited the site some two years later and found recolonization by the seagrass in affected areas. This brings up the interesting question of recovery rates and mechanisms for recovery. It may be most useful for MMS to focus on understanding the natural recovery mechanisms and rates as well as detecting areas of impact. I recommend again that the workshop incorporate these ideas for discussion.

Many papers addressed both diesel and mineral oil contaminated cuttings and drill solids in international waters: Beaufort Sea (Erickson et al. 1989); the North Sea (Reierson et al. 1989; Bakke et al. 1989a and b; Grahl-Nielsen et al. 1989); and the Canadian offshore in general (Chenard et al. 1989). These field studies found that hydrocarbons were degraded through time by microbial and weathering mechanisms and that the degradation rate was largely an inverse function of hydrocarbon concentration, composition (high or low aromatic content), and environmental factors (e.g., temperature, nutrients). Erickson et al. (1989) did find that low molecular weight ispoprenoids, as detected by GC fingerprinting, were particularly useful to follow the fate of a specific mineral oil (VISTA ODC), which is widely used, along with other mineral oils, in the Gulf of Mexico. This study emphasizes the importance of monitoring the right parameter to determine fate. I would like to point out that due to the increased drilling of deviated holes in the Gulf of Mexico as platforms have more wells to develop a field, the use of mineral oil lubricants and spotting fluids may increase during the projected MMS timeframe. U.S. Environmental Protection Agency (EPA) toxicity restrictions and sheen prohibitions are strong motivators to find substitute products for oils, but few completely hydrocarbon-free product substitutes have reached the market at this time.

The Erickson study (1989), as well as the study by Sauer et al. (1989), focused on organic components of drilling wastes rather than inorganics. Sauer was interested in using the most prevalent organic constituent of muds, lignosulfonate, as a possible tracer. Organic constituents may behave somewhat differently than barium in areal distribution and eventual fate because of significant differences in specific gravity (i.e., >4.2 for barite, ≤ 1.0 for most organics). Sauer found that lignosulfonate components could be useful as organic tracers, depending on the background ambient levels of lignin-type compounds.

The subject of organic constituents of drilling wastes is an area for discussion or consideration by this group for several reasons. First, the frequency and total amount of organics, particularly polymeric compounds such as polyacrylates, polyacrylamides, and biopolymers, are increasing to become a far more significant part of the waste. The need for inhibitive systems as industry drills through unstable shales, particularly in the Gulf of Mexico, and the considerable problem of using traditional potassium based systems due to EPA toxicity regulations, is putting increased emphasis on polymers. While these various types of polymers are typically of low toxicity, they may cause some changes in mud dispersion. Some of the newer polymer systems have the consistency of liquid "silly putty" with potentially different dispersion behavior. These polymers may be potential new tracers also as we look for key parameters to monitor. An important point to make is that EPA is consistently showing more interest in the organic constituents of drilling fluids as evidenced by the onshore drilling waste study which monitored for 229 organic compounds, 29 elements, and 22 conventional analytes (DeNagy and Telliard 1989).

One paper concerning organic contamination of the North Sea, based on a 14 year long-term review and study, had specific suggestions for what should be the key components of a six year long-term monitoring. Riererson et al. (1989), which is noted by the editors as being controversial in nature, conclude with a biological and chemical list of parameters that should be monitored with a schedule for monitoring based on North Sea degradation rates for oil contaminated sediments. I recommend that the workshop review Reierson critically to see if any of their long-term monitoring suggestions are relevant to MMS studies.

Last, there are several papers included that look at toxicity and bioaccumulation in the laboratory. Neff's two papers (1989a and b) look at longer term lab studies (99 days) on bioaccumulation and foodchain transfer. They found limited bioaccumulation and little bioavailability with minimal toxicity. More importantly, Neff started initial measurements on sublethal effects, such as growth and metabolic effects, that are critical to making population productions. I suggest that today's workshop participants keep in mind the direction EPA is taking in biomonitoring of effluents, specifically the emphasis on chronic effects, where growth and fecundity of specific keystone organisms are being measured as indicators and possible explanations for population effects. While these specific EPA procedures may not be useful to MMS programs, the increased need for designed studies to understand population dynamics suggest that we should consider these approaches.

The proceedings, which are 867 pages, is an excellent source of data pertinent to this workshop. I believe the program committee did an excellent job in selecting the papers and the editors did an excellent job of reviewing the papers. My only criticism is that many studies, which had excellent QA/QC programs, did not describe those programs or results to help us understand the data. We must have good QA/QC data with each study to fully appreciate the data, and MMS and our workshop must emphasize this aspect similarly.

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2.2.11

SOURCES OF LONG-TERM VARIABILITY IN THE NORTHERN GULF OF MEXICO CONTINENTAL SHELF ECOSYSTEM

Dr. R. Eugene Turner
Department of Marine Sciences
Louisiana State University
Baton Rouge, LA 70803

Dr. N.N. Rabalais
Louisiana Universities Marine Consortium
Chauvin, LA 70344

Variability in the ecosystem of the northern Gulf of Mexico continental shelf occurs, in part, because of changes in the water quality of the Mississippi River. Water quality has changed considerably this century and these changes are reviewed. The concentration of suspended sediments has declined this century due to flood protection and navigation improvement efforts. Further, channel shallowing below New Orleans and channel deepening in the Atchafalaya Basin have contributed to varying amounts of suspended sediments being delivered to offshore. These changes affect the light regime, thus influencing phytoplankton production rates.

The various estimates of light transparency using secchi disk measurements are summarized for the northern Gulf of Mexico continental shelf, especially near the Mississippi River delta. These data include results from in situ studies, monthly across shelf transects, plume surveys at the river deltas, and continental shelf surveys from Mobile Bay to Texas.

Concurrent measurements of light transparency (submarine photometer) and extinction coefficients estimated from secchi disk depths (SDD) are very similar, especially in well-mixed water columns. In addition, the extinction coefficients estimated from secchi disk data and estimated from in situ phytoplankton production are also strongly correlated. SDD varied between 0.2 cm and >30 meters and were, of course, lowest in low salinity waters located near sediment sources. SDD changed slightly in the Mississippi River turbidity maximum and substantially increased around 20 ppt. It appears as if SDD increased from the 1950's to the 1980's.

Nitrate, silicate, and phosphate concentrations in river water have also changed, probably reflecting the general increased eutrophication of fresh waters through increased fertilizer usages. These changes undoubtedly have resulted in increased phytoplankton production on the continental shelf, perhaps influencing hypoxic conditions, presently widespread and severe.

Additional sources of variation are eustatic sea level rise, climatic cycles (many of which operate over periods longer than decades), river discharge, and solar radiation. All of these sources of variation, and others, will cause measurable variability in the aquatic communities offshore, and complicate discernment of impacts due to Outer Continental Shelf activities.

2.2.12

PROCESSES OF THE SHELF ECOSYSTEM IN THE TEXAS-LOUISIANA REGION

Dr. Gilbert T. Rowe and Dr. Rezneat M. Darnell
Department of Oceanography
Texas A&M University
College Station, TX 77843

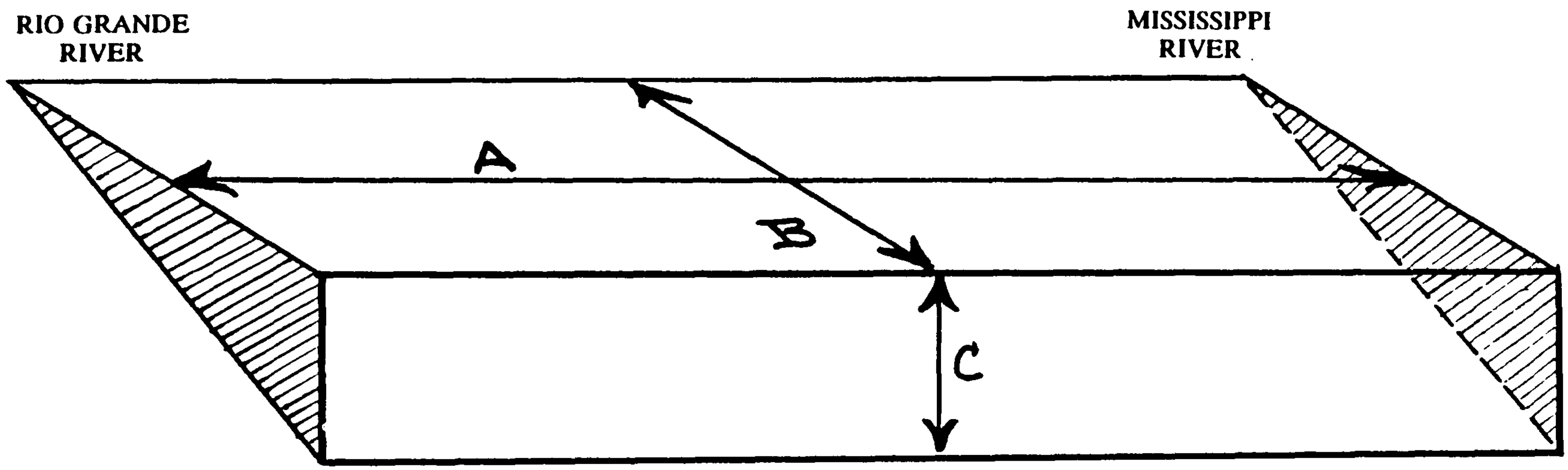
Major previous ecological investigations of the TEXLA shelf include the following: South Texas Outer Continental Shelf Study, Strategic Petroleum Reserve Study, Buccaneer Gas and Oil Field Study, East and West Flower Garden Banks Studies, Offshore Ecology Investigations (off Timbalier Bay, LA), Central Gulf Platform Study, and Biofouling Community Studies. Additional investigations have dealt with the distribution of plankton, nekton, the demersal invertebrates, fishes, and with physical oceanography. There has been amassed a large inventory of the species present and their distribution patterns, primarily off the eastern half of Louisiana and on the southwestern half of the Texas shelf. Much is also known about the distribution of sediment types and of the various chemical species (including hydrocarbons, pollutants, and trace metals). Although very little quantitative information has been accumulated concerning ecological processes of the area, a great deal may be inferred from the historical studies.

The dominant influence on the TEXLA shelf is the Mississippi-Atchafalaya River System. Freshwater, nutrients, and sediments brought to the shelf by this system effectively set up a series of biological and ecological gradients as shown in Figure 10. Phytoplankton standing crops and primary productivity are highest near the Mississippi River and lowest down-coast, and they are highest nearshore and lowest offshore. The same general situation applies to the meiofauna, macrofauna, and demersal species. A surface-to-bottom gradient exists in relation to phytoplankton and the biofouling species.

Existing data point to the importance of the element nitrogen as the factor limiting phytoplankton growth on the TEXLA shelf. Components and processes of the nitrogen cycle in the region are shown in Figure 11. Nitrogen exists in both organic and inorganic forms. It enters the shelf waters through river runoff, upwelling of deep Gulf water, hydrocarbon seeps, and local regeneration. These processes are most intense in the eastern half of the shelf.

A related set of processes of importance on the TEXLA shelf are those which lead to the development of hypoxic nearshore bottom waters off Louisiana and eastern Texas. High phytoplankton productivity followed by bacterial decay, coupled with vertical stratification and poor bottom circulation, lead to oxygen depletion during summer months when the temperature is elevated.

These and other processes which are known in general terms require detailed explanations. All involve coupling of physical and biological processes and they cannot be resolved by the examination of species inventories and distribution patterns. Our focus must shift, as it were, from anatomy to physiology.



A. Along-shelf gradient
B. Inshore-offshore gradient
C. Depth gradient

Figure 10. Freshwater, nutrients, and sediments brought to the shelf effectively set up a series of biological and ecological gradients.

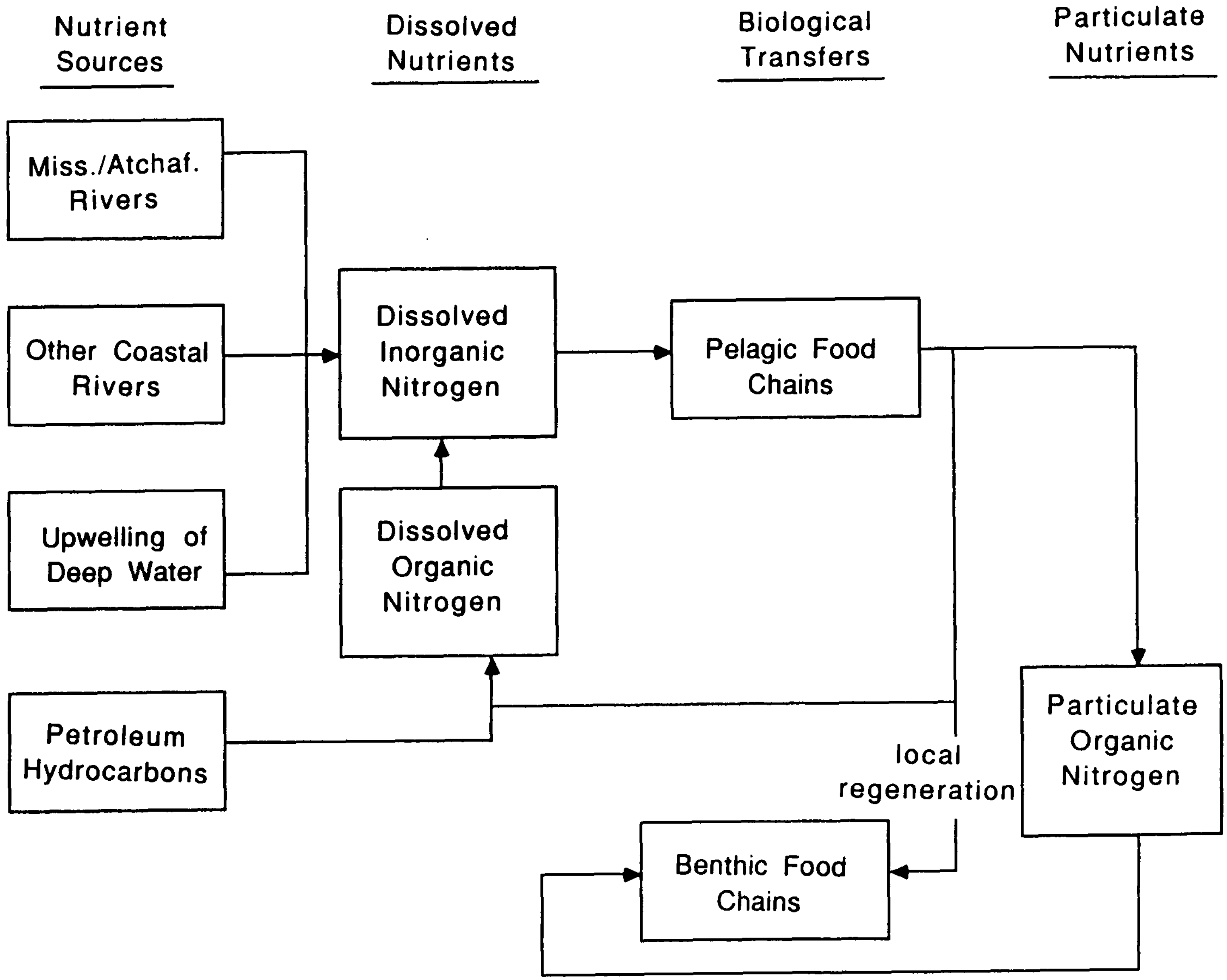


Figure 11. Existing data point to the importance of the element nitrogen as the factor limiting phytoplankton growth on the Texas-Louisiana shelf.

2.2.13

PHYSICAL OCEANOGRAPHY OF THE TEXAS-LOUISIANA SHELF

Dr. William J. Wiseman, Jr.
Coastal Studies Institute
Louisiana State University
Baton Rouge, LA 70803

Circulation on the shelf west of the Mississippi River Delta is strongly influenced by the relative strengths and phasing of river runoff and seasonal meteorological changes. Immediately following the spring flood of the Mississippi River, discharge from both the bird-foot delta and the Atchafalaya Delta combine to form a well-developed coastal boundary layer of low salinity water which hugs the coast, is isolated from the mid-shelf waters by a strong salinity front, and flows at least as far south as the Texas-Mexican border. There is good evidence that it flows much further southward along the Mexican coast. As the winds over the western Gulf of Mexico become more southerly in the late spring and early summer, the coastal winds along the south Texas coast become upwelling favorable. Flow within the coast boundary layer reverses direction and flows northward and eastward. A convergence develops somewhere along the TEXLA coast and low salinity water flows offshore. A mean eastward flow over the outer shelf and upper slope appears to be present throughout the year. Cochrane and Kelly propose the existence of a series of ephemeral counter rotating gyres over the shelf.

On shorter time scales, atmospheric frontal passages drive strong currents over the shelf. On time scales of two to ten days, much of the current variance over the shelf can be explained as a simple wind-driven sloshing of water along the shelf.

A potentially important mode of shelf break exchange is driven by air-sea interactions during winter cold front passages. Mid-shelf waters over the western Louisiana shelf are rapidly cooled by the atmosphere. The shallow inshore waters are cooled even more. Being fresher, though, these inshore waters remain lighter than the mid-shelf waters. The outer shelf waters lose nearly as much heat as the mid-shelf waters, but they are deeper and the resultant temperature drop is less. Furthermore, the salinity gradient between the mid-shelf waters and the outer shelf waters is weak. Consequently, the mid-shelf temperature change is often sufficient to result in mid-shelf waters being denser than the outer or inner shelf waters following a cold air outbreak. These mid-shelf waters sink and flow offshore carrying suspended and dissolved material with them.

2.2.14

ENVIRONMENTAL HYDROCARBON MEASUREMENTS IN ECOSYSTEM STUDIES

Dr. Mahlon C. Kennicutt II
Geochemical and Environmental Research Group
Texas A&M University
Ten South Graham Road
College Station, TX 77840

The measurement of various chemical parameters are often only seen in a support mode for biologically driven programs. In fact these measurements are often invaluable factors in interpreting and modeling ecosystems and their response to man's activities. In particular the direct measurement of an innate property closely associated with the process of interest is most directly applicable and unambiguous, i.e., hydrocarbons and OCS oil and gas activities. The use of hydrocarbon measurements and the ultimate program objectives can be addressed on the basis of four conceptual approaches. Environmental hydrocarbon measurements can be used (1) to assess baseline values, (2) as tracers of inputs, (3) to establish temporal variations and trends, and (4) as supporting ancillary data. These concepts are summarized and potential benefits are discussed.

Probably the most direct approach for hydrocarbon measurements is the "baseline concept". In simplest terms the natural and/or presently occurring hydrocarbon levels are measured in an inventory-like mode. This approach attempts to define natural or existing background concentrations in various pools (sediments, tissue, water, etc.) and areal variability is defined. This approach documents existing contamination and aids in differentiating contaminant processes, both those of interest and contributions from other sources. The data base produced is also necessary in order to recognize future man-related perturbations over and above natural variations. This approach is particularly important in the northern Gulf of Mexico for two reasons. First, the Gulf has a long history of man-related activities and no pristine or pre-drilling data for a given area may exist. Secondly, natural seepage, an important process in the northern Gulf of Mexico, tends to contaminate with the same petroleum potentially released by OCS activities.

The "tracer" concept relies upon unique fingerprints that can be used unambiguously to recognize inputs derived from multiple sources, i.e., terrigenous (land) versus plankton (water column). These studies lend clues to processes affecting a given area and provide a basis to assess the fate, and ultimately the effect, of by-products of various activities. The "tracer" concept can be pursued at many levels of detail depending on project goals.

Time dependent variations have become recognized as a significant feature of continental shelves, thus hydrocarbons can be used to assess "trends". These studies determine the cyclic or episodic nature of inputs and suggests the time-scale and magnitude of variability within a system. The physical-chemical environment can be quite variable and it is important to determine if man's activity could accentuate or moderate cyclic or episodic events or vice versa.

In a more support-oriented mode, hydrocarbon measurements can be determined as "ancillary" data. It is important to provide a chemical framework not only to support the biological interpretations but also in evaluating the relationship between biological variability and definable chemical environment changes. This also provides a broader framework to compare a given study area with existing environmental data bases to determine the severity of contamination or pristineness in relation to world wide pollutant trends.

These approaches to hydrocarbon data provide significant input and information to ecosystem studies. Program and sampling design for the assessment of hydrocarbon sources, fates, and distributions must be considered in light of the ultimate program's goals. The Gulf of Mexico northern continental shelf long-term monitoring effort would benefit from all four hydrocarbon approaches and hydrocarbons are seen as an integral and important component of any ecological study to be proposed.

2.2.15

ECOSYSTEMS OF THE TEXAS-LOUISIANA OCS REGION

Dr. Nancy N. Rabalais
Louisiana Universities Marine Consortium
Chauvin, LA 70344

The oil and gas development scenario for the Gulf of Mexico is expected to continue as in previous decades with over 90% of all offshore drilling and production occurring there (Ray 1987). In the area of the TEXLA shelf, exploration of deeper waters on the continental slope will predominate, but a large number of wells will continue to be drilled on the inner and mid-shelf. Most of the drilling and production will take place in the Minerals Management Service (MMS) central planning region, but activity will also increase in the western Gulf lease area, with new exploration occurring both inshore and offshore. An understanding of the ecosystems in the above mentioned areas is necessary for the proper development and management of oil and gas resources within the context of the biological resources of the area.

The summary that follows provides a brief description of the dominant features and processes of the continental shelf environments of Texas and Louisiana and a focus on the benthic communities. Without diminishing the importance of water column communities or populations of larger demersal sea bed fauna, this review emphasizes the macroinfaunal communities for several reasons. The benthos has received emphasis in studies of the effects of oil spills and other discharges because of their susceptibility, longevity, and relative immobility. Future studies will likely concentrate on the benthos. The benthos of parts of the TEXLA shelf have been extensively surveyed; still other areas have received no attention. An outline of the studies completed or ongoing in the area of interest are given in Table 9 and located in Figure 12. A large area of the southwestern Louisiana and upper Texas continental shelves has not been investigated with regard to the benthic communities. Off the southeastern Louisiana coast, the outer shelf ecosystem is unknown as is the shelf break and upper slope for the entire area. Features of the benthic nepheloid layer, as illustrated from the east Texas shelf (Sahl et al. 1987), and the potential for transport of sediment-adsorbed contaminants further illustrate the need to understand these ecosystems.

A matrix comparing the dominant features and processes of U.S. continental shelf areas, including those from the Mississippi River delta to the Texas-Mexico border, has been compiled by Rabalais and Boesch (1987). The region is not directly influenced by major ocean currents, except for the passage of anticyclonic gyres which spin off the LOOP Current and travel westward along the outer shelf. Circulation on the shelf proper is more affected by wind forcing, tides, and river discharges (Murray 1972, 1976). A net westward (Louisiana) and southwesterly (Texas) flow along the shelf characterizes the predominant conditions from fall to early spring (Smith 1980). In summer, the flow is to the west and southwest form Louisiana to about 95°W where it converges with an opposing flow to the north and northeast. A clockwise eddy is frequently found just west of the Mississippi River delta. This eddy advects part of the river's effluent back toward shore where it may be entrained in a coastal boundary layer. An easterly flowing counter current and energetic cross-shelf currents were also observed near the shelf break by McGrail and Carnes (1983). The large freshwater discharges of the Mississippi and Atchafalaya Rivers influence the hydrography of the northwestern Gulf shelf. The influence is especially prominent in the reduced salinity of inner shelf waters as far west as Galveston (Nowlin 1971) and occasionally down the Texas coast (Smith 1978). Related to the density stratification influenced by late spring river discharges and the nutrient inputs is the development of depressed levels of dissolved oxygen in bottom waters of the inner shelf during summer (Turner and Allen 1982; Rabalais et al. in press). Hypoxia in bottom waters is recurrent but ephemeral off the southwestern Louisiana shelf (Gaston 1985; Pokryfki and Randall 1987) and is known to occasionally extend at least to Freeport, Texas (Harper et al. 1981a).

The continental shelf from the Mississippi River delta to the Rio Grande is gently sloping and wide, over 200 km off the TEXLA border (Emery and Uchupi 1972; Shepard 1973). There are many more physiographic irregularities in the central part of the shelf than to the east and southwest. Topographic features include many channels, most of which are associated with longitudinal ridges, and largely filled extensions of large rivers across the shelf. The topography of the northwestern Gulf north of Matagorda Bay is marked by numerous protuberances which have been shown in most cases to be caused by salt or shale diapirs (Emery and Uchupi 1972; Rezak et al. 1983). The stage of sedimentary evolution (Curray 1965) grades from allochthonous at the

Table 9. Studies with soft-bottom benthic component.

BASELINE STUDIES:	
1975-77	South Texas Outer Continental Shelf (STOCS)
1976-80	Texas Submerged Lands Studies (Bur. Econ. Geol.)
1983-86	Northern Gulf of Mexico Continental Slope Study
OIL AND GAS RELATED ACTIVITIES STUDIES:	
1972-74	Offshore Ecology Investigation (OEI-GURC)
1978-79	Central Gulf Platform Study
1976-80	Buccaneer Gas and Oil Field Study
1977-82	DOE Strategic Petroleum Reserve Program Bryan Mound West Hackberry (currently being sampled) Big Hill Texoma and Capline
1976	Rig Monitoring Studies
1979-80	IXTOC and BURMAH AGATE Spills Effects
1981	Louisiana Offshore Oil Port Studies (LOOP)
1985-86	Produced Water Discharges (API)
1989	Influence of Petroleum Activities in Areas of Hypoxia (MMS University Initiative, LUMCON)
ADDITIONAL STUDIES:	
1960	Parker, Macroinvertebrates of the Northern Gulf of Mexico
1985-86	Effects of Hypoxia on the Benthos (LUMCON)
1987	Benthos of a Continental Shelf Influenced by the Mississippi River (LUMCON)

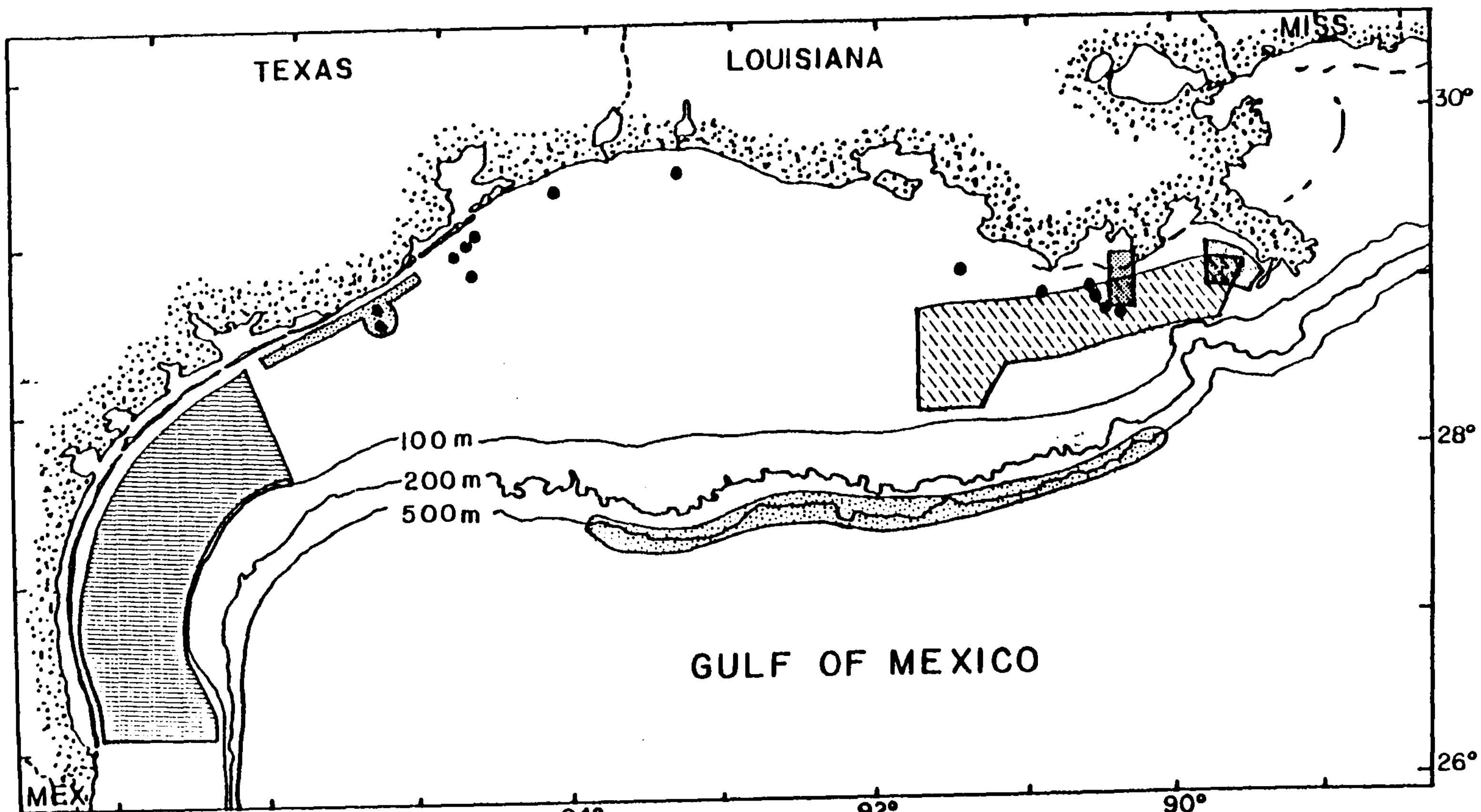


Figure 12. Location of studies with a soft-bottom benthic component.

Mississippi River delta area to a climax grade on the south Texas continental shelf. The result is a complex of sediment regimes with a decrease in the silt/clay content in the nearshore regions to the west and south where the percentage of sand increases (U.S. Dept. of the Interior, Minerals Management Service 1983). In general, the sediment sand content decreases across the shelf. There are exceptions to this, associated mostly with topographic features and the allochthonous sedimentary regime near the Mississippi River delta.

Baker et al. (1981) studied the benthic macrofauna and Fitzhugh (1983) re-examined the polychaete fauna around oil and gas platforms on the Louisiana shelf in an area extending 320 km west from the Mississippi River delta in 6 to 98 m depth. Information on the benthic fauna of the inner shelf of the northwest Gulf (10 to 20 m depth) is available from brine disposal monitoring studies (Harper and McKinney 1980; Weston and Gaston 1982) and the Buccaneer Gas and Oil Field study (Harper et al. 1981b). The macroinfauna of the south Texas shelf is described by Flint and Holland (1980), Flint (1981) and Flint and Rabalais (1981). More recently the benthic fauna of the inner shelf off southeastern Louisiana has been examined by Neff et al. (1989) and Rabalais et al. (in press). Polychaetes dominate the macrobenthos in all of the areas studied. Several genera (*Paraprionospio*, *Sabellides*, *Magelona*, *Mediomastus*) are numerically dominant. In most of the areas studied, benthic community composition closely corresponded to sediment patterns and depth zonation. Variability in the community structure was attributed to spatial variability due to the patchiness of macrobenthic organisms and temporal variability due to a period of larval recruitment. Hypoxic events account for significant changes in the benthic community structure (Harper et al. 1981a,b; Gaston 1985; Rabalais et al., in press).

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2.2.16

ECOSYSTEMS OF THE MISSISSIPPI-ALABAMA OCS REGION

Dr. William W. Schroeder
Marine Science Program
The University of Alabama
Dauphin Island, AL 36528

The Mississippi-Alabama shelf is one of the five major continental shelf subprovinces in the Gulf of Mexico. It is separated, to the west, from the TEXLA shelf by the Mississippi River delta while to the east it extends to the western rim of the DeSoto Canyon and abuts the West Florida shelf north of the head of the DeSoto Canyon. The shelf break occurs at depths ranging from 60 to 100 m.

From east to west the sediment regime grades from the extensive MAFLA sand sheet through a transitional zone to the north-south trending silts and clays of the St. Bernard prodelta deposit through another transitional zone and back into sands of the Chandeleur Islands. South of Mobile Bay and Mississippi Sound the inner shelf is covered with a complex of barrier island sands and silts and clays from the adjacent estuaries. To the southeast along the outer shelf and shelf break, surficial sediments consist of a mixture River birdfoot delta region delta-front silt and silty-clay deposits merge with the adjacent shelf deposits.

Polychaetous annelids dominate the macroinfaunal taxon and constitute the majority of biomass in most areas covered with unconsolidated sediments. An unusual characteristic of this shelf area, compared with other shelf regions of the northern Gulf of Mexico, is the lack of dominance by any one species within given depth zones. The numerically dominant macroepifaunal taxon (excluding heart urchins) is most often Crustacea.

Topographic features of a hardbottom nature are common on this shelf. They range from low relief (<2 m) northwest trending linear ridges constructed of sand and shell gravel and occasional rock rubble to isolated outcrops or erosional remnants of indurated materials on the inner shelf to low to high (up to 15-18 m) relief patch reefs, linear ridges and pinnacles on the outer shelf and shelfbreak. These hardbottom features provide substrate for sessile epifauna not ordinarily found on the more extensive areas of unconsolidated sediment.

2.2.17 POSSIBLE EFFECTS OF OIL AND GAS PRODUCTION ON PLANKTON PROCESSES IN THE PLUME OF THE MISSISSIPPI RIVER

Dr. Quay Dortch
Louisiana Universities Marine Consortium
Chauvin, LA 70830

The production and transport of oil and gas can release chemicals into the environment which may affect plankton processes (National Research Council 1985; Capuzzo 1987; Spies 1987). In general terms, both inhibitory and stimulatory responses can be observed. Two responses appear to be cited most often; changes in phytoplankton species composition to smaller, often flagellate, species and decreases in zooplankton grazing rates on algae. It has been presumed that the actual impact on the plankton in the coastal and open ocean was minimal because of the short generation times of planktonic organisms, the likelihood of rapid reseeding of impacted populations with unaffected organisms, and the difficulty of detecting impact in populations subject to high natural variability. However, this ignores the possibility that although effects on any one group of organisms may not be observed, processes within the ecosystem and its overall functioning may be impacted. Furthermore, the Mississippi River plume may not be as open a system as many coastal and open ocean areas, and may be impacted as if it were an enclosed estuary.

As described by Wiseman (section 2.2.13), the flow of the Mississippi River plume is generally to the west between the coastal boundary layer and the TEXLA coast. Some effects of the river input may be observed all the way to the Mexican border. By analogy with upwelling areas (MacIsaac et al. 1985; Wilkerson and Dugdale 1987; Dortch and Postel 1989), the river plume can be described as a conveyor belt (Figure 13). At the mouth there is very high nutrient input, but due to turbidity-induced light limitation, phytoplankton biomass remains low. After the sediment drops out, phytoplankton take advantage of the high light and nutrients, growing very rapidly. Down plume, a chlorophyll maximum is usually observed at about 25% salinity, made up almost entirely of large diatoms. At this point nutrients supplied directly by the river are depleted, but regeneration by zooplankton, bacteria, and benthic organisms continues to supply nutrients. In fact, despite high river input of nutrients, this system is uniquely dependent on regeneration for maintaining its high productivity. However, much of the biomass sediments out below the chlorophyll maximum (probably as phytodetritus) and down plume (probably as zooplankton fecal pellets), so that eventually biomass of all organisms, nutrient concentrations, and nutrient regeneration rates decreases to very low levels. This model can be used to assess the potential effects of a decrease in grazing ranges or a change in species composition. Many factors, which cannot be assessed here, would modify these impacts.

A decrease in zooplankton grazing would increase the flux of carbon to the benthos. This would exacerbate the hypoxia which already exists on the shelf during periods of strong stratification and which may be related to increasing eutrophication. Because nutrients would be sequestered in the sediments or in hypoxic layers, regeneration downstream would be decreased, resulting in lower overall productivity of the system, especially down plume. Finally, there would be decreased transfer of carbon to higher trophic levels in the water column, leading to decreased production of commercially important species depending on planktonic food chains.

Large diatoms, which unlike most other phytoplankton, require silicon (Si) for growth and are the major component of the algal biomass which develops in response to nutrient input from the river. Furthermore, they play a vital role in the planktonic food web and flux of carbon to the benthos in the plume. Over the last 40 years riverine input of Si has decreased, while that of other nutrients has increased (Turner et al. 1987; Turner, section 2.2.11). There is evidence that in the plume in the region of the chlorophyll maximum, concentrations of Si could be growth limiting for diatoms. Thus, eutrophication may already be changing the phytoplankton species composition to smaller, flagellated phytoplankton, which do not require Si. This will certainly affect trophodynamics and flux of carbon to the benthos, but precise predictions are not possible. If substances released by oil and gas production and transport affect phytoplankton species composition in similar ways, major changes in the ecosystem could occur as a result of multiple, human-induced stresses.

While the foregoing discussion is general and speculative, it does suggest a number of processes which deserve further attention because they are critical to the ecosystem and vulnerable to impact. These include at a

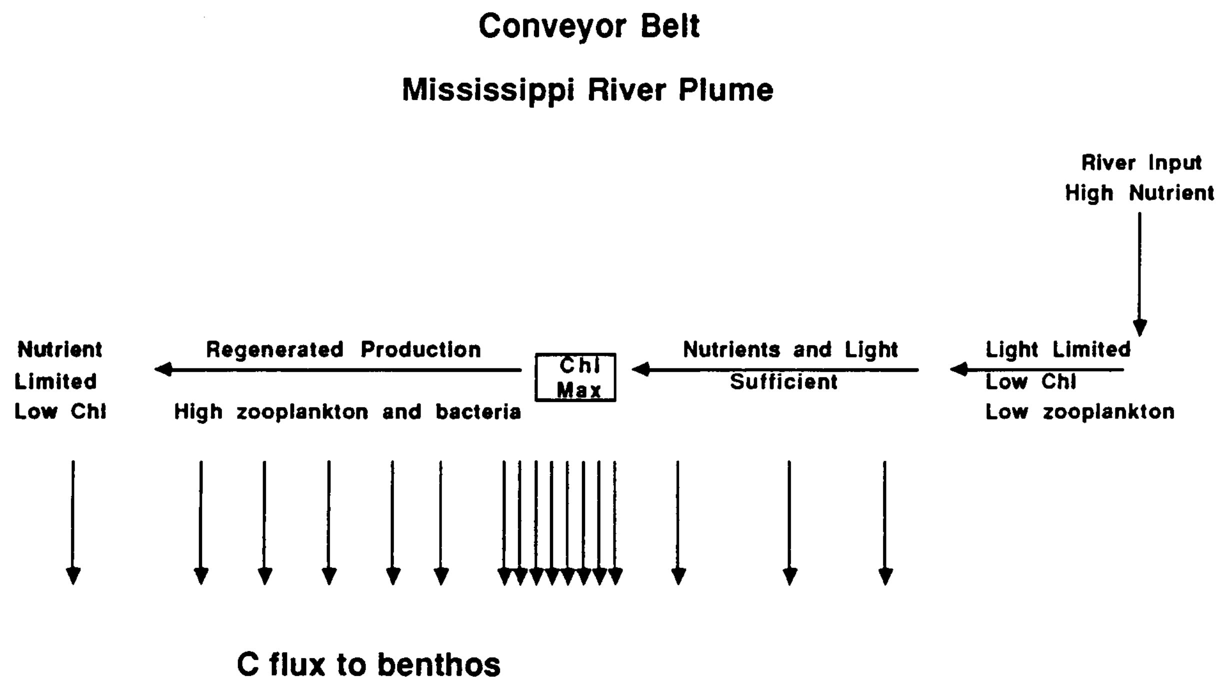

Figure 13. Conceptual model of the Mississippi River plume as a conveyor belt.

minimum primary production, bacterial production, zooplankton grazing, benthic and water column nutrient regeneration, flux of carbon to the benthos, and water column and benthic respiration. These must be measured at the same time as the usual measurements of nutrient input, standing stocks, and hydrography.

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3.0 WORKSHOP CONCLUSIONS: MEETING NEW INFORMATION NEEDS

3.0 WORKSHOP CONCLUSIONS: MEETING NEW INFORMATION NEEDS

In the preceding sections (2.1-2.6) of this workshop report, it has been established that Minerals Management Service's (MMS') information needs are changing in response to a change in program emphasis. It is no longer acceptable to manage the Outer Continental Shelf (OCS) simply on the basis of description and subjectivity; we must understand how the OCS ecosystems function and develop objective management criteria. It has also been established (sections 2.2.1-2.2.17) that existing scientific approaches hold great potential for meeting the new needs. However, there is no proven model for drawing on this developing expertise to achieve MMS' new needs.

Before examining the academic community's ideas and suggestions, it is very important to understand that changes in MMS' needs and the research community's capabilities have followed separate paths. Over the past 30 years, coastal oceanographers have changed both their method of conducting research and the primary questions which are asked. In contrast, MMS has adopted only the newer research techniques while keeping its questions directly focused upon the anticipation and detection of impacts.

If there has been a single theme in coastal oceanography for the past three decades, it is that process oriented studies and experimentation are more informative about the functioning of coastal systems than traditional descriptive studies. Species composition, zoogeographic patterns, and other descriptive studies at the population level are rarely considered high priority academic questions in OCS regions. Rather, new questions address ecosystem processes such as rates and controls of primary and secondary production, nutrient cycling, etc. It should be noted, that closer to shore in the rocky intertidal, population studies are still the primary emphasis. However, these are of limited utility in the Gulf of Mexico OCS.

In contrast to the academic change in emphasis away from populations, MMS has retained a need to know about species and populations. It is difficult to imagine a situation in which environmental impact will be defined in other than a species or population level change. Therefore, academic advocacy for process oriented studies is reasonable only when a connection can be made between understanding the process and better understanding population and species level changes. Drs. Turner and Rowe (section 3.1) present a strong case for the process oriented ecosystem approach.

The key to any impact study in the OCS is understanding the overwhelming natural variation so that low level impacts can be detected. This critical understanding of natural variation will never be achieved via long-term monitoring which only documents and describes changes in populations and species. Changes in populations must be driven by success of larval recruitment, long-term survival on bottom, the pattern and rates of productions, and other related ecosystem processes. Therefore, natural variation can only be understood if faunal variation of importance to MMS is understood in the context of natural processes of production and transport.

This workshop faced three challenges: a major new ecosystem study, a major new long-term monitoring study, and a renewed effort to look for impacts in the vicinity of long-term oil and gas activities. The level of academic experience in each area differs, and this is reflected in the nature of advice from the scientific community.

- TEXLA Ecosystem Study - The oceanographic community at large is now highly experienced in planning, conducting, and successfully completing regional ecosystem studies. The area calling for special innovation is the definitive linking of ecosystem level processes with benthic population structure and variation.

- Long-Term Monitoring at Selected Marine Ecosystem Sites - The oceanographic community has virtually no experience at large scale regional monitoring of ecological systems for more than a few years. The simple suggestion that such programs can be accomplished by extension of traditional sampling over long durations is dangerously flawed. Considerable thought and innovation will be required to design an efficient program which will lead to a better understanding of natural variation of the kind and scale relevant to MMS.

- Detection of Impacts Associated with Long-Term Oil and Gas Activity Sites - On first examination, there is an illusion that the oceanographic community has, by far, the greatest experience in this area. There have been numerous studies conducted and then submitted for careful scrutiny and productive criticism. However, our experience really lies in efforts to detect gross, acute impacts. As we move to less obvious, chronic impacts, there is just as great a demand for innovation, as there is for careful consideration of past attempts at design, execution, and final analysis.

3.1

TEXAS-LOUISIANA MARINE ECOSYSTEM STUDY

Dr. R. Eugene Turner
Department of Marine Sciences
Louisiana State University
Baton Rouge, LA 70803

Dr. Gilbert Rowe
Department of Oceanography
Texas A&M University
College Station, TX 77843

3.1.1 Introduction

The tasks of this workshop were to "identify the important elements needed in a marine ecosystems study of the Texas/Louisiana (TEXLA) Outer Continental Shelf (OCS)." The workshop began with a general meeting reviewing goals and deadlines and ended with writing assignments to be presented the next day. Minerals Management Service (MMS) personnel were present during all discussions, which involved 10-20 persons at any one time. Participants were allowed two weeks to submit materials to the co-chairs before this draft was prepared jointly. The draft was mailed to non-MMS personnel for review and revised by the co-chairs before submission in this form.

Purpose of the Workshop

The guidelines for the workshop were adopted and generally understood to be:

- identify study elements, discuss appropriate methodological approaches,
- establish sequences and priorities, and
- justify the anticipated study findings in terms of the mission needs of MMS.

We began the process of developing technical advice with the assumptions that:

- the scientific ideas put forward will be judged on their overall value to the study goals without initial consideration of funding limitation, relevance to other programs, or the personal research interests of the participants,

- due to the accepted expertise of the participants it would not be necessary to dwell on the merits of methodology, rather than establishing the priority of the study elements which should receive the greatest consideration.

Geographical Extent of the Study Area

The general study should include three areas: the Mississippi River plume, the continental shelf break where Loop eddies interact with the shelf waters, and the continental shelf proper from the Mississippi River delta to Brownsville, Texas. The river plume is important as a major driving force for continental shelf variability in terms of freshwater and new nitrogen, the location of the most intense metabolic rates in the water column, and where freshwater-seawater interactions are most conveniently studied. The Loop eddies are an important focus for interactions of shelf and deep Gulf of Mexico waters, especially with regards to upwelled water. The continental shelf is the location of the majority of OCS oil/gas recovery efforts, and nationally-important commercial fishing resource. While complete shelf coverage is recommended, highest priority should be assigned to the northern Gulf of Mexico in the area of the plume and at the shelf break and then be evenly distributed southward down the Texas shelf.

3.1.2 Discussion: Value of a Process Oriented Ecosystem Study?

Since the development of process oriented ecosystem studies are a new undertaking for MMS, it is appropriate that we consider the overall value of this approach. A process study is markedly different from previous MMS ecosystem studies which stressed comprehensive species inventory rather than system function. Ecosystem inventories are of limited overall value since it is impossible to determine the importance of component species and there are no objective criteria for setting the scope of the study. By contrast, process studies dispense with efforts to be comprehensive and devote all resources to determination of the most important functional components of a system. Properly done, a process oriented study will have greater management value than a description.

The primary intellectual tool of process studies is systems analysis or general systems theory. Systems analysis can be characterized as an approach to research in which the objective is to gain a predictive capability about the behavior of complex systems. Rather than structuring research around an often artificial dichotomy in which a null hypothesis is either proven or not proven false, system analysis seeks to partition complex systems into more tractable natural subdivisions. While simpler than the whole system under analysis, the subsystems usually retain too much complexity for dichotomous hypothesis testing. Therefore, research is designed to estimate parameters associated with state variables and state transitions. Typically, the goal of developing predictive capability is achieved in the form of an environmental systems model.

Systems analysis contributes to ecosystem management in several ways: (1) differentiating between natural variability and anthropogenic environmental stress (and thus minimizing incorrect assumptions about impacts where none exist, or uncovering impacts where none are obvious), (2) in the efficient use of study resources, (3) answering specific questions about target species (e.g., important fisheries or important food resources), (4) predicting the severity of proposed oil and gas impacts, and, (5) offering substantial predictions (hindcast and forecast) about the behavior of the system under varying natural and man-imposed regimes. For example:

- Variability - What is the explanation for the observed variability? Will it be assigned to the wrong cause? All previous monitoring studies on this shelf have led to the conclusion that the natural long-term variability and influence of the river make definitive causal relationships between ecosystem behavior and OCS impacts impossible to detect. In the present absence of understanding how the ecosystem works, there is a sure and significant risk that actual impacts are either left undiscovered, or that inconsequential relationships are assumed to be severe impacts. The relationship between the observed variability and true impacts may be of three types: coincidental (either causal or non-causal), random, or partially related (see Figure 14). One may incorrectly assume that causal relationships are absent if the natural variability is disguised by the natural noise in the system.

- Experimental design - Building the best sampling protocol depends on how and what questions are asked. For example, general impacts on community primary production may be important concerns of interest. However, knowing how production changes due to variability of physical, toxicological, or river-nutrient related processes involves an understanding of how biological communities integrate all three driving forces, not just one of them. Simple toxicological studies (single species) are not usually sufficient to answer questions about the community behavior, because of the integrated nature of ecosystem parts.

- Prediction - Monitoring alone is not prediction; prediction, needed for management, requires knowledge of how the whole ecosystem works, not of just the parts.

- Interdependence - A system is a set of interacting interdependent units, of which an ecosystem is an example. Only by investigating the key components, e.g., nutrients and phytoplankton, can we expect to understand what causes variations of the benthos in time and space, and ultimately the fisheries resources that might be affected by offshore oil and gas recovery activities. The result is understanding how the TEXLA shelf functions, rather than stochastic relationships that are empirical and behind which there is no insight into how one part of the system affects another.

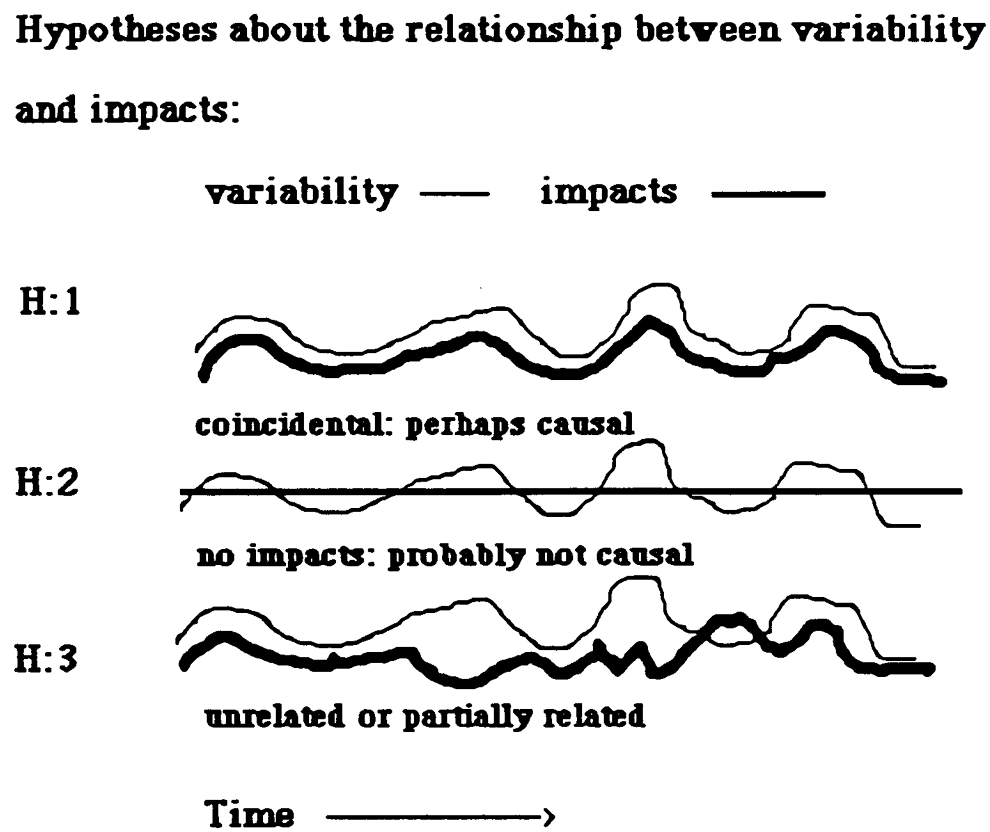

Figure 14. Hypotheses about the relationship between variability and impacts.

Historical Data

Historical results can be examined for two purposes. First, we can seek examples of process studies dealing with impacts. Second, we can seek out existing information which will help design the study in the TEXLA region. In the first case, we find little of immediate utility. None of the previous MMS "Ecosystem Studies" (see Avent, section 2.1.5) were process oriented. Even the most recent large MMS studies on Georges' Bank and the Santa Maria Basin were based upon time-series monitoring with little attention to the processes behind the measured parameters. The Department of Energy has supported major coastal ecosystem studies, but none of these were designed to produce information similar to MMS' practical management needs.

While no major ecosystem studies have been conducted in the TEXLA region, several important programs have contributed markedly to our ability to design and execute successful ecosystem studies in this region (see Rabalais and Turner, section 2.2.11; Darnell and Rowe, section 2.2.12; and Rabalais, section 2.2.15). Most notably, these include ongoing research on the Mississippi River plume, regional hypoxia, and the dynamics of ring-shelf interactions.

3.1.3 Recommended Goals & Objectives

The general goals of this proposed study should be to (without any implied order of importance):

- begin the study with the construction of a heuristic ecosystem model to serve as a design guide, to be used during the study for heuristic and experimental probing, and to test hypotheses using the data collected during the study and simulation;

- link processes and species populations, the model should include explicit representation of stocks and processes to be measured to understand structure and function of benthic and pelagic communities. This would include: (a) quantified standing stocks, with identification of the dominant (10 most abundant) species of phytoplankton, zooplankton, epifaunal fish, megafauna, infaunal macrofauna, and meiofauna and, as appropriate, bacteria, and (b) quantified roles of each functional assemblage, its production, and consumption of organic matter;

- linkages between system components and geographic regions should focus upon quantification of the sources and fates of organic matter, including riverine, upwelling, eddy, and shelf regions from the Mississippi River delta to Brownsville, Texas;

- physical studies should seek to determine transport mechanisms and forcing functions of biological processes;

- the regional importance of the Mississippi/Atchafalaya River plumes will be determined, especially of nutrients of presumed importance to phytoplankton;

- the regional importance of hypoxia will be examined to understand (quantitatively) what natural phenomena contribute to hypoxia and understand hypoxia sufficiently well to separate its effects from other natural and man-made influences, especially those activities regulated by the MMS;

- all components shall be designed to characterize and determine the effects of variability on ecosystem processes (biogeochemical), including the effects of eddies, river, winds, water level, insolation, and riverine derived nutrients and sediments that have varied significantly this century.

It is necessary to draw some limits upon the scope of inquiry so as to keep the project within reasonable limits. It was the consensus of the participants that regions within the span of the barrier islands could be safely omitted so long as major fluxes to OCS waters were estimated and included in models. Special habitats such as seagrasses warrant independent study, and commercial species such as fishes also warrant separate study.

3.1.4 Important Questions and Approaches

The actual design of the TEXLA study should be such as to answer seven key questions. These questions are detailed below along with the approaches that a final design might embrace. It is important to note that these questions are phrased so as to give high priority to traditional MMS needs concerning benthic populations and variation.

- Question #1: Physical - Biological Linkages - How does the physical oceanographic circulation affect the structure and function of the biological communities on the TEXLA shelf?

  Background: The central TEXLA shelf is an area of high fisheries productivity, moderate phytoplankton production, and freshwater discharge of the largest river in the U.S. Natural variation in the shelf ecosystem in time and in space (horizontal and vertical) is anticipated to be driven by variations in river flow, wind, currents, estuarine exchange, and eddies. These relationships are unquantified and should be described, if not understood, in order to comprehend the biological system and how oil and gas recovery activities affect the biological system. However, it is impossible to clone this system for experimental treatments and so studies must make use of the natural variations to derive conclusions regarding their influence.

  Approach: Recognize four oceanographic provinces (plume, coastal boundary currents, outer shelf and gyres, mid-shelf) and develop information on ecosystem processes and structure for corresponding biological components while simultaneously deriving physical oceanographic measurements. These physical measurements need not be as comprehensive as in the MMS Physical Oceanography Program. Build a data base for primary productivity and benthic community structure, especially on the Louisiana shelf, and use natural gradients, storms and disturbances, and temporal salinity development of gyres as experimental treatments in testing for the effects of circulation on biological processes. The role of the river plume, wind-induced sediment resuspension, and upwelling as sources of nutrients and fixed C and N needs to be evaluated. How much is imported from the coastal boundary layer? Are food webs especially compact and efficient in this area? The physical measurements of flux may then be compared to uptake rates to evaluate their relative importance.

- Question #2: Identification of Trophic Links - What is the food web structure of the continental shelf ecosystem?

  Background: Information is lacking on food web structure of this continental shelf community and cannot be adequately reconstructed synthetically using data/analyses from other continental shelves. We need to know if predation is an important determinant of community structure in benthic TEXLA communities, whether the food web is controlled by a "top down" or "bottom up" predation, or if it is dominated by productivity controls on population size and the resulting cascading trophic interactions.

  Approach: Control sites should be first studied, and then compared to probable locations of OCS impacts. Needed is background information on contamination accumulation (not intensive), growth rates of ubiquitous and/or abundant key species, how close community metabolism is coupled to organic input (cohort analysis; role of disturbance), and experimental studies on the effect of predation on structuring community production and biomass. Stable isotope analysis is one promising approach, but should not be used to the exclusion of experimental benthic studies (for example) with exclosure/inclosures, ship board experimentation, and various new microbial studies (e.g., dilution experiments, chemical inhibitors, isotope tracers, etc.).

- Question #3: Identification of Controlling Factors - What controls benthic community structure and function on the TEXLA shelf?

  Background: Benthic studies are important in MMS monitoring schemes but there are significant gaps in our knowledge of benthic community structure, especially on the TEXLA shelf. Needed are a mix of descriptive and experimental studies focused on the control of food supply, variations in growth rates, and the effects of disturbance by trawling, storms, and drilling muds/effluents. It is important to know if predation or food supply may regulate benthic community structure on this shelf, since the interpretation of the impacts of drilling muds, for example, may differ if a top predator, rather than key food supply, are stressed.

Approach: A mix of descriptive and experimental studies focused on control sites, measurements of changes in food supply (sediment traps, phytoplankton productivity), mapping (time series) of growth rates of important benthic animals, experiments on the effect of disturbance from trawls, storms, and drilling muds/effluents, and on predation, especially from shrimp and other abundant epibenthos. Separate studies are needed on the effects of resuspension and nepheloid layers. Previous studies indicate that abundant or ubiquitous benthic organisms should be used as indicators in these studies.

- Question #4: Identification of Contaminants - What are the hydrocarbon and trace metals contaminants (e.g., PAH, PCB, Hg) accumulating in TEXLA food webs? In which animals, trophic levels, and oceanographic areas are these accumulated?

Background: This is basic information required to address impacts.

Approach: Trace the fate of petroleum products in food chains using standard fingerprinting techniques, including stable isotope analyses. Synthesize target compounds with ^{14}C label and conduct uptake experiments at platform sites. Focus monitoring program on detecting dispersal. Complete a general survey of the shelf, but particularly at frequently-sampled stations.

- Question #5: General Variation and Covariance of System Components - What part of the biological variability is driven by natural (i.e., environmental) processes on the TEXLA shelf?

Background: There is great variability in the primary production and hence secondary production on this shelf, but the reasons for it are not well known. Are variations in primary productivity of the phytoplankton, which arise in response to variations in nitrogen input, driving the biological variability of the entire marine ecosystem?

Approach: Consider four mesoscale physical forcing functions and estimate their relative significance for (1) nutrient inputs from the Mississippi-Atchafalaya River plume and coastal boundary current; (2) upwelling of "new" nitrogen from interaction of Loop current eddies with shelf-upper slope topography; (3) upwelling of "new" nitrogen at other thermohaline surface fronts/mixing zones (e.g., bottom layers); and, (4) response to storms. Begin phytoplankton studies with the following caveats: (a) environmental measurements within each region of high and variable phytoplankton productivity must be of adequate resolution in time and space to create gradients as well as describe mean fields; (b) mesoscale physical features evolve through time, on a scale of days to weeks, so that plumes and/or eddies must be mapped synoptically; (c) the largest horizontal environmental gradients are at the mesoscale physical features and these should be mapped at time-space scales of days and kilometers.

- Question #6: Variation Due to Regional Hypoxia - Are there observed changes in the species abundance and individual numbers due to hypoxia? When does hypoxia start, how long does it last, what are the seasonal variations, can it be predicted in time and space, and is it disrupted by storms? Will it return after a tropical cyclone, and which species return first? What species survive hypoxia?

Background: Hypoxia on the TEXLA shelf is widespread, intensive, and persistent with demonstrated and catastrophic consequences to the biota. While much descriptive data has been collected and experimental work is presently underway, large gaps in our understanding remain. The extent to which oil and gas activities are influenced by or trivialized by hypoxic events is largely unexplored.

Approach: Supplement existing efforts at the necessary scale and initiate new ones. Construct an oxygen budget. Determine the vertical exchange coefficient across water column layers of different degrees of stratification. Complete a total carbon budget. Primary production measurements, sediment trapping, respiration rate measurements (water column and benthos) should be conducted concurrently. This should be a seasonal study for one year at one location (transect) near the Mississippi River, and then expanded to shelf-wide cruises in subsequent years during critical periods of hypoxic water mass formation, during the summer when strongest, and during breakup.

- Question #7: Variation Due to Storm Effects - What is the role of hurricanes on the biology of the shelf?

  Background: Hurricanes have a frequent and drastic effect on the shelf, stirring up pollutants, restructuring the ecosystem, distributing water masses, and causing enormous exchanges of shelf and estuarine waters in short time periods. Important questions are: How deep into the water column and into the sediments does mixing occur? What is a hurricane's effect on hypoxia? How long does it take for recovery after storms? How significant is organism burial or removal?

  Approach: Opportunistic sampling just before and after hurricanes, that "hitchhike" onto existing efforts by other parts of the study.

3.1.5 Biological - Physical Studies Linkages

Whether biological processes are being influenced by the river plume at the eastern edge of the TEXLA region or by decaying rings at the western edge, it is critical to the success of a process oriented study that biological-physical links be as well understood as possible. The existence of separate physical and biological components is unfortunate in that such separation discourages the needed coordination. So that the ecological utility of physical oceanography results be maximized, it is necessary for the following coordination to be undertaken.

3.1.6 Field Sampling

- Spatial Coverage - conduct about 10 regional scale surveys annually on a 'regular' grid, with special emphasis on coastal boundary layers, riverine and oceanographic fronts, and upwelling, with the below parameters measured continuously while underway between stations. Extended scale information can be obtained through the use of remote sensing (visual and thermal, image, retrospective analysis) to follow, for example, eddies and cross shelf features.

  - light measurements - measure insolation/total photosynthetically active radiation (PAR), split into upwelled and downwelled components of PAR;
  - micronutrient distributions, including urea and dissolved inorganic nitrogen (DIN), silicate, phosphate with a sampling resolution possible for every 15 minutes while underway and vertically at about 12 depths per station;
  - general parameters - measure temperature, salinity, nutrients, light transmission, and pigments continuously while underway during all biological data collecting surveys;
  - particle flux - sediment trap measurement concurrently with current meter moorings of the Physical Oceanography Program to quantify the flux of sinking particulate matter across the shelf, including particulate organic carbon (POC), particulate organic nitrogen (PON), and pigments.

3.1.7 Coordinating Analysis

Large MMS and similar studies have a history of fragmenting during the final analysis phase to the extent that very little effort goes into seeking linkages among system components. This must be avoided if a process oriented study is to be successful. Therefore, the analyses of the physical and biological components must be linked in the following manner:

- integrate the biological modeling with physical modeling, i.e., at gridded, vertically resolved simulations of long-term circulations and associated parameters of biological importance (>10 years);

- using both system state estimates and transport information, estimate the flux of N from the system through their transport off the shelf, through denitrification and burial.

3.1.8 Assigning Priorities

Some examples of areas of priority in reviewing the various proposed components were noted during discussions. Higher priority should be given to studies that:

- include model construction before field studies, for heuristic purposes at first, to identify unknowns and what does not need to be done, and to use before field work to set effort and justify sampling;
- determine the organic inputs, probably with sediment traps, and to conduct shelf-wide measurements of the rates of production, preferably at previously sampled sites;
- determine the biomass of meiobenthos and macrobenthos (but not necessarily of fish);
- determine rate measurements, e.g., community respiration rates, as opposed to standing stock measurements;
- investigate microbial turnover/uptake, in particular, because this functional component probably turns over at least 25 to 50% of the energy;
- include regeneration rate measurements.

Moderate priority should be given to studies that include:

- sulfate reduction, sedimentation rates on a geological time scale.

Lower priority should be given to studies that include:

- pollutant reservoirs,
- burial rates of POC,
- sediment physical properties such as grain size, mineral composition, porosity , etc.

3.1.9 Management Suggestions

Even though management issues are beyond the charge of this workshop, it is important that a few comments be made. As stressed in the presentations, increased emphasis upon process studies is a new venture for MMS. As well expressed by Dr. Pomeroy (section 2.2.3), the use of process oriented ecosystems to meet management needs is also a new departure for coastal oceanographers. Therefore, it is critical that study planning and management be structured to help both MMS and the participating scientists as they jointly undertake this new endeavor. There must be mechanisms in place which encourage innovation, which avoid locking in unproductive efforts, and which discourage attempts to revert to descriptive based studies. The following steps should help bring about the needed mechanisms.

- encourage carefully planned components.
  - synthesize/analyze pockets of existing information through, for example:
    a) solicitation for small competitive awards,
    b) workshops on specific topics,
    c) data summaries and technical reports,
    d) provide small amounts of money ($30-$100K) for highly leveraged efforts, especially where on-going or long-term data samples are available and crisp statements of work can be put forward.

- strive for a mix of institutional responses rather than one institution award, thus maximizing expertise and cooperation within the scientific community.

- stipulate or rate proposals on the basis of the anticipated publication of data in refereed publications (for example, on the established publication record of proposing scientists).

- phase-in planning should last longer than three months to maximize integration within and among subprojects.

- outside advisors should be involved to tighten scientific effort and to encourage timely summarization of results. These advisors should have some influence on the future funding success of individuals within the longer-term project.

- encourage/incorporate contingency plans for examining the effects of hurricanes and major, or otherwise unusual, events.

- force coordination
  - insist on a plan to promote data sharing within the project to maximize use of an anticipated expensive sampling scheme, to produce the best science, and to cross-calibrate results;
  - add a position at MMS for a coordinating scientific program officer. He/she should be responsible for running programs, developing Request For Proposals (RFPs), and reviewing proposals;
  - integrate efforts with proposed physical oceanographic efforts via, for example, cooperative efforts in planning amongst the separately funded efforts sharing/assignment of ship space and time on the PO cruises, using the same types of gear, methods, and people on the biological cruises.

3.2

DETECTION OF IMPACTS ASSOCIATED WITH LONG-TERM OIL AND GAS ACTIVITY SITES

Dr. James J. Kendall
Minerals Management Service
Gulf of Mexico OCS Region

Dr. James P. Ray
Shell Oil Company
Houston, Texas 77210

3.2.1 Introduction

The study(s) to be conducted concerning "Effects of OCS Development and Production Activities, Northwestern Gulf of Mexico," are intended to elucidate the chronic (persistent), low-level (sublethal) stresses and long-term effects thereof associated with developmental drilling and production activities, particularly in an area with a long history of oil and gas development, production, and transportation. In particular, sites in the Western and Central Gulf of Mexico are far enough west to be outside the perpetual influence of the Mississippi River plume. The fiscal year (FY) 1990 effort is conceived as the first of several study years, to be funded in recurring 3-year cycles. The continuation of this study, or suite of related studies, over a multi-year period will allow the Minerals Management Service (MMS) to define these chronic, low-level, long-term stresses of Outer Continental Shelf (OCS) activities.

This program will build on the findings of past rig and platform monitoring studies conducted in the Gulf of Mexico, Pacific, and Atlantic OCS Regions, as well as other ecosystems studies in the northwestern Gulf previous to, or concurrent with, this effort. This program will complement the companion study concerning "Long-Term Monitoring at Marine Ecosystem Sites", but will differ by focusing on production sites where impacts may have occurred due to offshore oil and gas development activities, as compared to studies of natural variability at sites believed not to have been impacted.

The importance of this study to the decision making process of the MMS is that the Environmental Studies Program(ESP) has recently shifted its focus to studies of chronic, low-level, long-term environmental stress due to offshore oil and gas activities. Ecosystem processes and functions will also be examined in an attempt to explain the mechanisms at work causing the observed impacts.

The development of an offshore oil and gas field may have a variety of effects on the marine environment. Effects studies have concentrated on both the usual or unusual agents/activities associated with OCS development. Unusual events/activities would include disastrous events or major unanticipated shifts in program activity.

While most research shows that the effects resulting from acute, short-term stresses associated with oil and gas structure are localized and ephemeral, there is less certainty regarding the impacts which may result from low-level, sublethal, chronic stresses. As early as 1981, the National Marine Pollution Program Plan (Interagency Committee on Ocean Pollution Research, Development, and Monitoring), concluded that the most significant unanswered questions for the offshore oil and gas industry are those concerning the effects on ecosystems of chronic, low-level exposures resulting from discharges, spills, leaks, and disruptions caused by development activities.

In keeping with the theme of long-term environmental effects, an attempt was made to focus the discussions here on those effects which were perceived to be long-lasting (possibly longer than two years) and significantly deleterious to either resources (e.g., fisheries) or ecosystem integrity. Finally, it was repeatedly stressed that drilling and production facilities are evolving entities, and that future structures might be expected to have different environmental interactions and effects.

3.2.2 Discussion: A Strawman of Potential Impacts

To stimulate the discussion a straw-man was presented in the form of a list of "impacts" to the marine environment which could "potentially" result from the development of an OCS oil and gas field (Kendall, section 2.1.4, Table 3). By no means was this list meant to be complete, rather, it was intended to stimulate and focus the discussions. The participants prioritized those items to be addressed. These concerns included: historical data; areas for study; activities potentially causing effects; parameters to measure, methods, quality assurance and quality control (QA/QC); areal designs; and time frames.

Historical Data

Historical data includes both general and specific well information. General historical data would include dates (in/out), depth drilled, volumes discharged, and drilling mud types used. The locations of the platforms and individual wells would also be critical and would most likely be the most accurate, probably within a few feet. It was felt that while MMS has this data (computerized), it may be difficult to retrieve in a form that would be immediately usable.

Specific historical well data would include the actual compositions and volumes of the additives used in the formulation of the drilling muds. While some of this information will be available from daily mud logs, in some instances stockpiled materials may have been used and accurate records not kept (e.g., diesel fuel for a stuck pipe).

Other historical data sets (and sources) which may be helpful include: discharge rates and depths; National Pollution Elimination System/EPA discharge records; records of other activities (e.g., fishing/trawling); meteorological records; records on produced waters, including volumes of discharges, composition, additives (some of which could be used as tracers); produced sand; treatment processes; air quality data; base-line data; records of pipelines; the use of antifouling materials; and the types and numbers of sacrificial anodes. Of particular concern was that the baseline data, particularly biological, collected by the industry itself should not be overlooked.

Locations of Study Sites

Referring to the study profile, the following restrictions were reiterated: "Appropriate sites in the Western and Central Gulf of Mexico; probably far enough west to be outside the constant dominance of the Mississippi River plume."

Depth

The depositional characteristics of a site are intimately associated with the energy of the environment and consequently its depth. Shallow areas are typically high energy environments exhibiting cycles of deposition and erosion. Long-term impacts resulting from the deposition of materials would most likely be minimal. Deep areas are likely to remain undisturbed, however, the dilution of materials discharged at the surface may be sufficient so that little if any deposition occurs. It is at the moderate depths where there is the potential for accumulation leading to detectable impacts.

Central vs. Western Gulf of Mexico

The central vs. the western regions of the Gulf of Mexico (GOM) will be a criteria in study site(s) selection. The central Gulf of Mexico (offshore Louisiana) is more frequently associated with oil production while western areas (offshore Texas) with natural gas. This would, for example, influence any study examining the impacts of produced waters: produced waters are more commonly associated with oil rather than gas production.

Differences in geographical locations will also result in variations of the physical and biological characteristics. For example, differences in the texture of the benthic sediments (e.g. hard bottoms verses soft bottoms--see Rezneat M. Darnell, section 3.3, Figure 15).

Activities Potentially Resulting in Impacts

- First Priority - drilling muds and cuttings, produced waters, produced sands, spills (crudes and refined materials), the physical structure of the platform itself, structure removal, fish population displacement, and synergistic effects;
- Second Priority - deck drainage, anodes and anti-fouling materials, domestic/sanitary wastes, pipelines (metals & test fluid), geomagnetic disturbance (fish navigation), noise, completion/work over fluids, and trash;
- Third Priority - air impacts, hydrostatic test materials, and sand blasting/paint chipping activities.

Parameters to Measure

- Physical - water, produced waters (composition, verify mixing models, examine microlayers, etc.);
- Biological - benthic communities only, water column work should be avoided except in specific cases such as resident fish communities associated with a structure;
- Chemical - standard parameters;
- Miscellaneous - analysis of all discharges.

Effects and Parameters to Measure

- Chemical - While it first appeared that the parameters to be examined were a repetition of past work, these previous studies dealt almost exclusively with short-term, acute stress. These same parameters may now require re-evaluation in terms of long-term, chronic stresses and effects thereof.

  Metals - selected metals should be examined as to their toxicological effects as well as their potential use as tracers.
  Barium - a major component of drilling muds and possibly be a particularly good tracer;
  Mercury - found in drilling muds, sacrificial anodes, and some paints, and often in pipe dope; Zinc - pipe dope, sacrificial anodes;
  Miscellaneous - Chromium, Cadmium, Copper, Arsenic, Tin, Vanadium, Nickel

  Radionuclides - particularly the radioactive isotope of barium which has been previously used as a tracer.

  Silicon (i.e. silicate) and sulfur - may have use as indicators of primary production and deposition.

  Organics - Polynucleated aromatics (PNA's), naphthalenes, dibenzenes, benzene, heterocyclics, lignosulfonates and their derivatives (it was pointed out here that they are not very sensitive because they are extremely difficult to detect), steranes-triazanes, petroleum hydrocarbon ratios, isopenoids, and the total organic content, Carbon/$CaCO_3$ ratio, bactericides, and treatment chemicals. From the toxicological point of view, alkalated analogs, particularly the ratios of specific position isomers (standards are now available for such new techniques), were also added to the list of organic compound which should be considered. With the interest in microbial processes the nutrient content (e.g., phosphate and nitrate) of the interstitial waters will also need to be examined.

- Physical Parameters - Benthic

  Standard Measurements - sediment shear strength; mineralogy; total organic carbon; interstitial waters; REDOX potential/discontinuity layer; isotopes, particularly short-lived species (e.g., Radium, Thorium) in the sediment which may be of value in examining mixing rates and fluxes; and grain size distribution (e.g., fine verses whole sediment ratios) must be conducted. While most contaminants are associated with fine grain sediments and examination of this component leads to good recovery of contaminants, we must not lose sight of the whole sediment so as not to skew the date.

Nephloid Layer Composition - for examining colloidal solids verses solid bottoms with respect to partitioning (see Means, section 2.2.9).

Surface versus Bottom Current Measurements - Resuspension transport is one of the biggest weaknesses in this topic.

Underwater T.V. and Video Surveys.

Regarding actual sampling techniques, there were "differences" of opinion as to whether or not to examine composite samples, or individual discharge streams. Individual streams would include discharges of drilling muds, cuttings, and domestic (treated) sewage. While some of this information will be available from historical records, such incidentals as the leachings from pipe dope and the paint chips from service boats sand blasting while on station will be difficult to quantify. The MMS Pacific OCS Region is presently utilizing composite sampling techniques in order to get a feel for the combined long-term effects of these releases.

- Biological Parameters - Concerning the biological parameters to measure, the participants agreed on three categories: classical techniques; state-of-the-art, but readily available; and "new technology," techniques available in the near future.

Classical Techniques - Standard measurements of abundance and diversity; recruitment, including biofouling and hard bank communities, this was particularly in reference to macro- and megafauna as opposed to meiofauna, there has been some recent advances in the latter which the participants felt justified listing it under category number 2; measurements of growth as used with mollusks, corals, and fish; bioaccumulation; fecundity/reproduction measurements, and studies of plants and seagrasses.

State-of-the-Art (readily available) - New techniques for use in meiofauna studies; histopathology techniques (e.g., neoplasms); the metabolism of contaminants; in situ exposure experiments; genetic techniques which might be used for in situ exposure experiments to examine the impacts to populations; biodegradation techniques; and techniques utilizing radionuclides. Concerning long-term development type studies, there is probably insufficient data on bioaccumulation and metabolism. Specifically, most work dealing with metabolism has assumed that there is a "leveling-off." However, this may not be the case when dealing with organics where there may be no limit to exposure because materials may be continuously metabolized and a steady state not achieved, but rather a chronic exposure whereby molecules are continuously being passed through the gut and reacting chemically. This is of particular interest when considering the amount of energy being utilized in metabolizing such contaminants and thus not available for growth and reproduction.

New Technology (available in the near future) - Behavior studies; bioaccumulation techniques, particularly those which may utilize skeletal parts (e.g., mollusks and fish [otoliths]); cytochrome P-450 techniques; metalthion; scope of growth studies; nitrogen metabolism; techniques utilizing changes in the concentration and composition of enzymes. As for genetic techniques, the Israelis are examining the relationship between mercury and allele frequency. Such a technique could be particularly useful in determing whether a population of organisms was not doing well over several generations (i.e., sublethal effect). Tracing the genetic composition of the organism could be useful. It was also noted that there are two levels of genetic response: (1) changes in gene frequency, and (2) actual changes in the DNA composition.

Examples of how biological/biochemical techniques could be tied into impact studies were explored in an attempt to utilize information and observations already available. For example, in sediments with elevated hydrocarbon levels there are microbial communities which naturally "biodegraded" the compounds. However, in areas which experienced hypoxic events, the rate of the degradation is reduced--what could be the ecological implications?

Laboratory procedures involving the testing of sediments might also be part of this study. For example, experiments examining growth and fecundity, bioavailability, and the partitioning of contaminants. While EPA protocols should be considered for such work, they were intended to examine the effects of compounds which are not metabolized. This is of concern because many contaminants are metabolized into more toxic materials (metabolites).

In situ experiments may also need to be designed which use the fouling organisms/communities themselves as the subjects of study of bioaccumulation, bioavailability, and genetic responses. For example, the Shell Oil Company has investigated the bioavailability of mercury from sacrificial anodes into mussels and scallops. While no deleterious effects were observed, very little of this type of work has actually been conducted.

3.2.3 Production Fields - A Historical Perspective, Concerns, and Recommendations

Early production fields were designed around central facilities each surrounded by satellites having one or two wells. Potentially, each satellite could have its own "impact" area with accumulations of drilling mud and cuttings, corrosion from anodes, etc. The "central" facility (where "production" takes place) might release significant quantities of produced waters. If studies are to take place in these older areas, it is critical that they be ground-truthed.

More recent production fields do not typically use the satellite design. There is a single large structure with multiple wells; up to 100 wells may be drilled from a single structure. The products of these multiple well structures are then channeled into a single pipeline feeding into the "trunk" line to shore. The shift towards this design has occurred during the past five years. While it may be easier to examine the latter type of "field," any effort to investigate long-term impacts may necessitate the use of "satellite" fields.

3.2.4 Recommendations: Analyses, QA, and QC

The level of analytical precision will be determined by whether a few sites or many sites are chosen and the bound on their respective ranges (i.e., sensitivities required). These analyses may include AAS, ICAP-MS (the method of choice for metals), neutron activation, and X-ray diffraction for mineralogy. It was also agreed that all physical, chemical, biological, and geological samples need to come from the same source. For example, in the CAMP program samples are taken with a Hessler-Sandia box core fitted with 25 subcores so that synoptic measurement can be made for biological, chemical, and sedimentological properties (Montagna, section 2.2.8).

In any bioassay type testing, efforts must be made to use sensitive life stages (e.g., eggs, embryo, and larvae) and only "realistic" concentrations for exposures. The latter would necessitate any bioassay testing be closely coordinated with fate and transport studies. Such work will also require up front quality assurance/quality control (QA/QC). However, while a central "core" of procedures and standards needs to be established, the overall study design should allow for enough flexibility to modify experiments as needed.

Finally, all of the information must be pulled together into a Hazard Assessment. Here models will be important because they pull all of the pieces together and while they may not actually represent the real environment, they often do supply something which can be just as important: "what pieces of information are missing?" That is, models may tell you what you don't know. Finally, laboratory testing should be used to verify field observations and data wherever possible.

3.2.5 Areal Designs for Sampling

The "matched design" or "paired t-test" whereby several platforms are examined at one point in time was agreed upon as the design most suitable for this type of study. This design involves sampling the parameter(s) of interest along a transect originating from the individual structures and making comparisons between the sampling locations along the transect (i.e., as opposed to examining just a few platforms and following them through time: the current status verses a time series change).

The "matched" or "paired t-test" design is of particular value because even in situations of large scale variability,it is still effective since comparisons are made within a transect originating from the individual structures. This design may fall under criticism, however, because it looks in one direction only. On the other hand, any design which would necessitate a more concentrated effort would result in a reduction in the number of platforms examined; the classic concern of site specific verses regional studies.

While the "matched" or "paired t-test" design was the strategy of choice, several of the workshop participants felt, for one reason or another, that several platforms need to be examined. The sampling density will continue to be an issue and the literature needs to be thoroughly reviewed to determine the most effective and economical sampling density. From the depositional standpoint, some participants felt that the local current regime may result in an irregular and/or heterogeneous deposition of material around a production facility. However, this may only really apply to the short-term; over extended periods, the distribution may be more homogeneous.

No matter which plan is used, some regional considerations will have to be considered. For example, eastern areas are generally associated with oil production and thus more likely to have impacts associated with produced waters, while areas to the west are generally gas producers typically not associated with produced waters.

The issue of sampling/study design may be summarized by the distinction of two approaches:

- multiple platforms with minimal number of sampling sites, or
- minimal platforms with maximum sampling density (the "bulls eye" approach).

Time Frames

The actual times at which any studies will be conducted will be important because of such phenomena as: seasonality of reproduction and recruitment (typically spring), late summer storms, hypoxic events, etc. Generally, the best time to sample will be in July and August--just after intense periods of reproduction and just prior to late summer, early fall storms.

3.2.6 General Management Concerns, Concepts, and Conclusions

During the workshop several points were discussed which fit under the category of "general concepts." It was felt that these were of a nature so as to be listed again separately and to serve as conclusions for the session.

- In order to maintain a consistent focus, the program should be based around a central core; however, it must also be sufficiently flexible so that techniques/designs/parameters could be deleted and added as required.

- Screening surveys must be incorporated into the overall plan and conducted before a definitive studies plan is chosen.

- Innovative, state-of-the-art techniques must be emphasized so as to avoid being locked into "standard methods" which may be incapable of providing the pertinent information.

- There must be close coordination of all data collection, particularly regarding stations and sampling techniques.

- A data quality objective (QA/QC) must be defined at the onset of the program.

- The program must utilized the appropriate standards and allow for over sampling. It is far cheaper to store samples than to resample.

- Before any real intensive sampling is conducted, the chosen sights must be groundtruthed.

- Coordinate all efforts in regards to data analysis and data storage.

- Moderate depths should be the center of attention: sites which are too shallow may be heavily influenced by natural cycles of deposition and erosion while extremely deep areas would be too diluted.

- Finally, as an initial step, a site specific approach should be considered to address specific questions, followed by a more general approach once the questions are refined.

3.2.7 Session Chairs Post Meeting Discussion

Following the workshop, the session chairs met to discuss a series of issues which were unable to be addressed during the limited time available. It was just not possible to cover all of the aspects of a topic of this complexity in only three days of discussion.

Before any study of this type can be initiated it is vital that the appropriate questions be asked. These questions will undoubtedly fall within the vague concern of "just what are the low level, chronic stresses which may be having long-term, subtle impacts on the OCS but which cannot be adequately examined, or even identified, in terms of acute impacts?" After individual, well-defined questions are asked, it will then be time to select those locations where these low level, chronic stresses may be resulting in these long-term impacts. Once the potential stresses and areas of impact are identified the next step will be to determine how these low level, chronic stresses might be impacting these areas over the long-term. These will obviously include such wide ranging issues as standing stocks, reproduction, competitive abilities, body burdens, bioaccumulation, fitness, biochemical pathways, etc. It is at this point that the actual questions to be addressed will finally be chosen.

Once the questions are defined we will be tasked to select the best techniques/methodologies available to address them. At this point it is not possible to list all of the options available but it is obvious that the study components will include not only the standard sampling and survey techniques but also state-of-the-art analyses and experimentation. One needs only to examine the Technical Contributions of these proceedings (sections 2.2.1-2.2.17) for an introduction to the cutting edge of these analyses.

Once the questions are defined, the study sites selected, and the methodology(s) chosen, the sampling regime together with the appropriate statistical considerations can be designed. While it is much too early to discuss the statistical approaches which will be used, it needs to be remembered that once individual questions are answered, the next step will most likely lead to a modelling of the chemical and biological pathways. This could lead to the establishment of a program specifically designed to monitor the health of the system.

3.3

LONG-TERM MONITORING AT SELECTED ECOSYSTEM SITES IN THE NORTHERN GULF OF MEXICO

Dr. Rezneat M. Darnell
Department of Oceanography
Texas A&M University
College Station, TX 77843

3.3.1 Introduction - Limits of Monitoring and a Strawman

Our purpose is to come up with a plan (or perhaps alternate plans) for a field research program for long-term monitoring in the Gulf of Mexico which contributes to Minerals Management Service's (MMS) efforts to increase the effectiveness of its Outer Continental Shelf (OCS) studies. This monitoring program would provide the ecological basis for:

- understanding the natural ecological systems (their structure, function, and natural variation), and
- understanding and interpreting potential human perturbations on the natural systems, particularly those changes arising from oil and gas developments.

In developing a plan which meets the above purposes, we are faced with the difficult task of drawing a meaningful distinction between descriptive characterization and monitoring. Is it sufficient to create monitoring programs simply by extending the time and space duration of existing characterizations? Or, does longer-term monitoring call for a different set of questions, approaches, and analyses.

Initially, we need to set some limits to the systems which we wish to monitor and then consider some of the most appropriate aspects to study. First, monitoring should be limited to depositional environments (although hard substrate environments should be considered) because this is the dominant habitat. Second, natural ecological systems should be the primary focus of monitoring (although other systems such as biofouling communities and impacted systems should be considered). Third, rather than attempt to monitor the full species inventory, key process and/or species indicators of system condition will be the primary focus of monitoring.

Since one of our purposes is to understand normal variation in parameters and causal relationships, monitoring time must be suitable to that task. To reduce the ambiguity of the term "long-term" we have to set initial time limits. Ideally, the temporal duration would be twice the periodicity of major low frequency events. In practice, such a duration is difficult to determine due to our lack of familiarity of low frequency events (i. e., storms and hurricanes, outflow of flood waters, major intrusion by the Gulf Loop Current, etc.). However, a long-term monitoring program of a decade would capture two to three major storms and provide information of the resulting variation. Setting the resolution of sampling (frequency within the 10 year program) must also be determined somewhat arbitrarily since we know little about short-term variation. Initially, we could sample quarterly, or according to the natural seasonal progression of events.

Since our second purpose is to provide useful information on impacts, it is appropriate that the sampling duration and frequency of this task also be considered. Here again, we are faced with poorly known long-term and short-term sources of potential impact, detection, and interpretation of both chronic and episodic human-imposed effects (especially those resulting from oil and gas activities). At least initially, it seems that a 10 year duration might allow tracking of impacts associated with regional population/industrialization increases. The randomness of short-term impacts, makes selection of an optimal frequency impossible. However, seasonal sampling might serve to detect any residual changes up to three months after an impact.

In order to avoid being too general in our conclusions, we should become fairly specific in our recommendations. We should localize on regions and depths to be sampled, numbers and types of samples to be taken at each station, and frequency of sampling. Although we cannot tell the agency how to do its job, our task is to provide approaches, strategies, and guidelines which will be useful to the agency in its own deliberations.

In our deliberations it will be quite helpful if we have a concrete proposal which can be examined and modified. Therefore, I will first explain our purpose and our focus and provide some of the specifics of our task. For the benefit of those who are not as familiar with the shelf, I will provide a brief overview of the northern Gulf shelf environments. Then I will consider problems of sampling including natural variability of the system, sampling locations, and sampling frequency. Types of samples to be taken will be discussed. Finally I will present a concrete proposal in order to facilitate our discussion. I have prepared hand-out sheets including a map, the proposal, and a suggested agenda for our discussions.

3.3.2 Defining Long-Term Monitoring

In the introduction the question was asked how long-term monitoring differs from site characterization by simply extending in time. Now that we have imposed some simple limits to our effort, it is possible to suggest a definition of monitoring. Monitoring should be the repeated measurement of variables according to a design which will allow determination of the causes behind any detected changes or apparent equilibria. Successful monitoring is that which leads to greater refinement of the understanding of controlling factors.

Certainly some of the sampling carried out for monitoring will resemble that carried out for characterization, and to the uninformed critic the two may be confused. However, characterization leads to a picture of stasis. Monitoring appropriate to MMS' mission needs must not be centered around the archiving of data typical of characterization. The analytical and synthesis aspects of monitoring must contain aspects of continuous prediction, testing of predictions, and improvement upon the predictive method.

3.3.3 Selecting Major Zones of the Northern Gulf Continental Shelf

A brief overview of the environmental types of the northern Gulf continental shelf is in order to provide background for our deliberations. It is clear that the continental shelf of the northern Gulf of Mexico consists of six major zones, three west of the Mississippi River delta and three east of the Delta (Figure 15). Therefore, a full monitoring effort would seek to study all six zones.

Considerable discussion was devoted to the relative merits of sample transects versus areal coverage sampling within the six major zones. Since it has been well established that continental shelf fauna is distributed in zones that parallel the continent, cross-shelf transects have been routinely employed to describe patterns over large areas. A long-term monitoring program built around such transects would provide an excellent description of the movement of these faunal zones through time. However, there is no evidence to suggest that long-term impact of oil and gas activities will ever be so pronounced and widespread as to alter these major faunal zones. As scientifically interesting as their long-term patterns may be, such information may be of minimal value in impact detection.

If cross-shelf transects represent monitoring at an inappropriate spatial scale, what then is the appropriate scale? It was suggested that the scale employed in all previous site specific studies be used. Such studies typically look for faunal change on an area of ocean bottom 2-4 km square. It is the faunal variation within these relatively small areas that has prevented definitive statements about impacts, not cross-shelf faunal zonation changes. However, intensive sampling over an area of a few square kilometers may have major problems. While on the appropriate scale relevant to MMS' mission, only a relatively small area may be studied. And the patterns of variation within such an area may not be generally applicable.

3.3.4 Determining Replication of Sampling

The sampling program should take into account three sources of variation:

- statistical variation due to sampling error; natural variation in the physical and biological phenomena and, imposed variation due to human activities. Sampling error may be reduced by taking an adequate number of samples at each station;

- natural variability in the ecological systems requires that the sampling sites be representative of the systems under study and that they be repeated with sufficient frequency to provide information

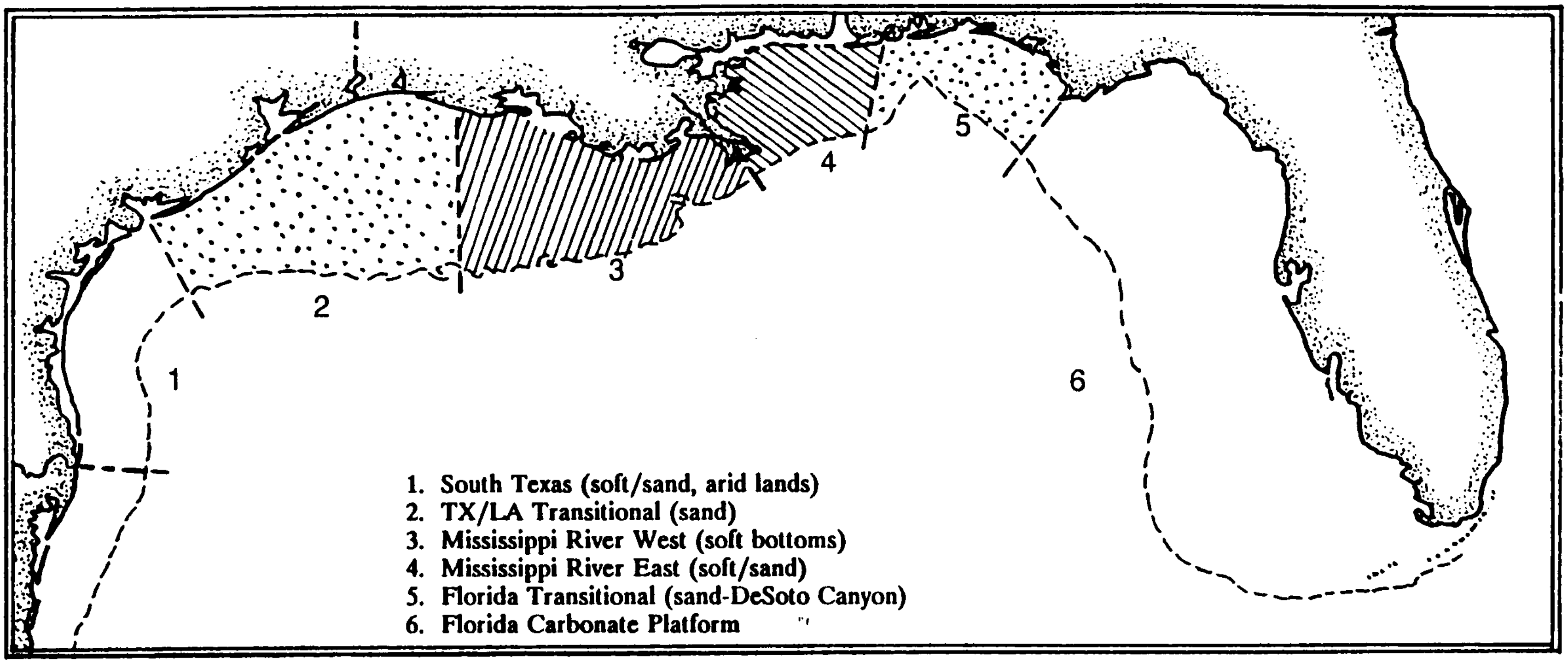

Figure 15. Major physical/biological zones of the northern Gulf continental shelf.

concerning the time-dependent phenomena. The types of samples to be taken should target those phenomena and biological species most likely to reveal changes in the systems;

- detection of changes due to human activities involves all of the above considerations, but it also involves study over a sufficiently long period to reveal more subtle changes associated with chronic effects. What types of symptoms of human perturbations are likely to be observed? These include: physical modification of substrates, hypoxia, accumulation of chemical pollutants in sediments or in biological tissues, accumulation and magnification of chemical pollutants up the food chains, pathological changes in tissues and organs, modification of the rates of physiological and ecological processes (photosynthesis, respiration, nutrient regeneration, etc.), and reduction in populations of sensitive species and replacement by more tolerant species.

3.3.5 Proposed Monitoring Program Structure

On the basis of our discussions, a strawman proposal was refined and areas where major design questions remain were identified.

3.3.5.1 Field Sampling Design

The trade off in selecting monitoring sites is easy to delineate. You either study up to six regions lightly or you study fewer regions more intensely. You are faced with the same trades within each region. You can study a long transect lightly, or concentrate sampling heavily in a tight region. Ultimately, anticipated patterns of oil and gas development both across regions and across the bathymetric transect could be used to identify the spatial coverage of greatest MMS mission value.

Sampling locations

- Zone-wise - Zones 2, 3, 4, and 5 are most relevant to oil and gas activities. Zones 1 and 6 are less relevant but represent different environmental and biological types, and they would be good areas for "control" studies.

  Recommendation: One complete transect for each of the zones, located near the mid-point of each zone.

- Depth-wise - Most physical and biological parameters are known to vary in relation to depth, and no particular depth can provide the information necessary to interpret what is happening all across the shelf. Transects are called for, and the only real questions are how many stations should be required per transect, and what should be their depth distribution.

  Recommendation: Each transect should contain six stations located at depths of 30, 60, 90, 120, 150, and 200 m.

Sampling frequency

- Sampling frequency would depend upon the degree of specificity required. It is important to establish the trends of time variability of the systems early in the study. Thereafter, sampling frequency could be reduced.

  Recommendation: During the first three years sampling should be carried out monthly at all stations in all zones. Thereafter, sampling should be conducted on a quarterly or seasonal basis.

Sample replications

- Replicate samples should be taken to provide a statistical basis for analysis of sampling error. The exact number of replicates would vary with the particular sample type.

Recommendation: A minimum of three replicates for each sample type is recommended.

3.3.5.2 Component Field Studies

The choice of study components must trade off the need to focus resources upon aspects which has greatest MMS mission relevance versus attempts to dilute resources in an effort to be comprehensive.

- physical - vertical profiles of temperature, salinity, dissolved oxygen, light penetration, and suspended sediments;
- geological - sediment samples for grain size analysis, total organic content, carbonate content, and hydrocarbon and trace metal analysis as well as for special pollutants;
- chemical - water samples for surface (floating) and water column (suspended) hydrocarbons; sediment samples for pollutant analysis; biological tissues for pollutant analysis;
- biological - macro-infauna, demersal invertebrates and fishes; samples for foodchain analysis; samples for tissue analysis for pollutants.

3.3.5.3 Special Integrative Studies

- Analysis, Modeling and Prediction - All analyses shall be designed and conducted so as to estimate time to time change in the variable. Models relating relationships among variables shall be created and refined on the basis of the data. As the data base develops, all continued sampling will be simulated and predicted in advance. Actual results will be used to suggest model improvements.
- Intensive Areal Sampling - Since cross-shelf transects may not provide information on variation at the appropriate spatial scale, it is important to include a program of sampling which intensively samples an area of approximately 4 square km. The analyses of samples should parallel those of the transect study with the addition of long-term environmental monitoring using moored platforms. This study should be conducted in conjunction with the TEXLA Ecosystem Study to assure the greatest availability of supportive process data.
- Process Oriented Studies - In order to maximize applicability of TEXLA Ecosystem studies seeking to link process and populations, at zones 3 and 4 in midshelf stations, process-related studies should be included.

3.3.6 Project Management and Organization

Given the lack of experience in long-term studies of this nature on the part of MMS and the coastal ocean community, it is appropriate to give some thought to the special management requirements. Both the regional coverage and time duration of the recommended study are unusual for most oceanographic work.

- It is envisioned that the six regional transects sampled will be studied by different organizations with a history and balance of expertise appropriate to each region.
- Design, coordination of field efforts, quality assurance, modeling, data management and data analysis must be vested in a single organization or team to guarantee effective execution of the study.
- Chemical analyses should be centralized at a single organization. For any other analyses conducted at other organizations, a program of blind standards must be applied to guarantee compatible results.

4.0 SUMMARY OF OBSERVATIONS AND RECOMMENDATIONS

4.0 SUMMARY OF OBSERVATIONS AND RECOMMENDATIONS

4.1 General Comments on Implementing New Directions

For many of the workshop participants, the deliberations were quite different from those experienced in other mission agency planning sessions. The unique aspect of this meeting can be found both in the unusual breadth of topics, three major studies, and the need to design studies which serve to take Minerals Management Service (MMS) along a new course. As a consequence, considerable time and effort was devoted to discussing and arguing the merits of the new departure rather than developing detailed plans.

In retrospect, these debates were beneficial in that they underscored both the scientists and the managers lack of experience in developing process studies of direct and immediate use to managers. The TEXLA Ecosystem Workshop was tasked with applying the new process oriented concepts of oceanography to an applied situation prior to their full basic development. The Long-Term Monitoring Workshop was tasked with developing a reasonable program of unprecedented duration and spatial coverage with direct MMS application more than a decade in the future. Finally, the Detection of Chronic Stresses Workshop was tasked with dealing with the elusive issue of never yet found, low-level and chronic impacts.

Three common themes were found in the deliberation of all three sessions. These are the need for innovation, the need for predictive models, and the need for a management structure geared toward fostering new approaches of direct value to MMS.

4.2 Study-Specific Recommendations

4.2.1 TEXLA Ecosystem Study

The TEXLA Ecosystem Study Workshop answered its charge of providing advise on the implementation of a process oriented study. With respect to the mission questions posed by MMS (section 2.1.5), it can be concluded that

- additional studies are needed because previous efforts have not led to definitive statements as to the presence of impact;
- process studies have the great advantage over descriptive studies in that an effort is made to understand natural variation, rather to simply be swamped by it;
- process studies should not be expected to produce a simple indicator of "health". They will allow for an understanding of variation. Indeed, there is no indication that descriptive studies in the Outer Continental Shelf (OCS) provide any indicator of health.

Implementation of the recommendations of the TEXLA working group will represent the greatest departure from previous MMS activities of all of the three studies. Past ecosystem studies, as listed by Avent (section 2.2.5), have all fallen in the category of descriptive inventories. Due to the emphasis upon benthic fauna, these previous efforts have typically omitted process relevant measurements such as productivity, nutrient fluxes, carbon fluxes, population recruitment, etc. In order to successfully adopt a process perspective, these omitted activities must now become the primary focus of the study!

Benthic population-process linkage is incorporated in the suggested ecosystem study, but is limited to the 10 most abundant species in the megafaunal, macrofaunal, and meiofaunal populations. In addition, dominant zooplankton and phytoplankton are to be included. These abundant species not only must be enumerated, but it will be necessary to determine their position in the food web, quantify their contribution to carbon flux, and relate their population dynamics to the varying physical environment.

The characteristics of the desired study include the following:

- Primary Processes

  - Primary Production
  - Carbon Flux to Bottom
  - Nutrient Cycling (Nitrogen)
  - Transport Phenomena

- Studies Based Upon Faunal Groups

  - Food Web Analysis - Stable isotope analysis and experimental benthic studies with exclosure/inclosures, ship board experimentation, and various new microbial studies (e.g., dilution experiments, chemical inhibitors, isotope tracers, etc.).

  - Benthic Process Studies - Descriptive and experimental studies focused on control sites, measurements of changes in food supply (sediment traps, phytoplankton productivity), mapping (time series) of growth rates of important benthic animals, experiments on the effect of disturbance from trawls, storms and drilling muds/effluents, and on predation, especially from shrimp and other abundant epibenthos. Separate studies are needed on the effects of resuspension and nepheloid layers. Previous studies indicate that abundant or ubiquitous benthic organisms should be used as indicators in these studies.

  - Phytoplankton Components - Phytoplankton productivity must be of adequate resolution in time and space to distinguish gradients as well as describe mean fields; mesoscale physical features evolve through time, on a scale of days to weeks, so that plumes and/or eddies must be mapped synoptically; the largest horizontal environmental gradients are at the mesoscale physical features and these should be mapped at time-space scales of days and kilometers.

- Studies Based Upon Chemical Aspects

  - Oxygen - Construct an oxygen budget. Determine the vertical exchange coefficient across water column layers of different degrees of stratification; of particular interest is hypoxia.

  - Carbon - Complete a total carbon budget. Primary production measurements, sediment trapping, respiration rate measurements (water column and benthos) should be conducted concurrently. This should be a seasonal study for one year at one location (transect) near the Mississippi River, and then expanded to shelf-wide cruises in subsequent years during critical periods of hypoxic water mass formation, during the summer when strongest, and during breakup.

  - Contaminants - Trace the fate of petroleum products in foodchains using standard fingerprinting techniques, including stable isotope analyses. Synthesize target compounds with 14C label and conduct uptake experiments at platform sites.

- Field Designs Employed

  - Regional Coverage - Based upon major physical regimes with sampling grids laid out to capture the events of these systems

    Mississippi/Atchafalaya plume
    coastal boundary currents westward
    outer shelf and gyres, mid-shelf westward

  - Frequency and Duration of Sampling - Approximately 10 regional cruises will be required per year for approximately five years.

- Station Selection - Due to complexity of region, true controls and treatments are not possible. However, contaminant distributions and placement within natural gradients can be employed to designate stations least likely to reflect various influences.

• Components Relating Process to OCS Impacts

  Control sites compared to probable locations of OCS impacts based on contamination accumulation, growth rates of ubiquitous and/or abundant key species, how close community metabolism is coupled to organic input (cohort analysis; role of disturbance), and experimental studies on the effect of predation on structuring community production and biomass.

• Links to Physical Oceanography - Determine importance of four mesoscale forcing functions for:

  - nutrient inputs from the Mississippi-Atchafalaya River plume and coastal boundary current;
  - upwelling of "new" nitrogen from interaction of loop current eddies with shelf upper slope topography;
  - upwelling of "new" nitrogen at other thermohaline surface fronts/mixing zones (e.g., bottom layers); and,
  - response to storms.

• Analysis and Synthesis

  - development of a Modeling Component - Systems models must be developed to test via simulation interrelations amongst system parameters. Such an effort must be initiated prior to adoption of final field design.

  - development of a Process Data Base - Build a data base for primary productivity and benthic community structure, relating natural gradients, storms and disturbances, and temporal salinity development to biological processes.

4.2.2 Detection of Chronic Stresses

The Detection of Chronic Stresses Workshop met its charge of considering the design of studies to detect the results of low-level chronic stress at oil and gas sites that had been in operation a long time. Previous studies to accomplish this have found only acute and spatially restricted impacts in the immediate vicinity of platforms. Beyond a few hundred meters from a platform, techniques used were unsuited for detection of impacts against a background of considerable natural variation.

An important outcome of the workshop was the realization that potential low-level chronic stresses must first be very well defined and then appropriate designs employed. Simply repeating the surveys of the past will prove fruitless. Of special importance is the incorporation of new field and analytical technologies to better search for the type of impact being tested.

Elements of a possible study could consist of the following:

• Primary Processes
  - chronic toxicology of contaminants
  - geochemical behavior of toxins
  - bioaccumulation

• Faunal Based Components
  - toxicology on selected species
  - composition of benthic and biofouling fauna
  - traditional indicators of biological status of the organisms (growth, recruitment, etc.)

- new indicators of biological status of the organism (histopathology, behavior, metabolism of toxins, skeletal growth records, allelic frequencies, etc.)
- biochemical indicators of toxin induced stress
- sensitive lifestage bioassay

- Chemical Based Components
  - metals as tracers and toxins
  - organics tracers and toxins

- Field Designs Employed
  - single transect at multiple platforms is the preferred approach
  - alternately, tradition intensive bullseye at a few platforms
  - single point in time sampling strategy in July/August

- Components Serving to Address OCS Issues
  - unlike other components, the entire project is of direct and immediate MMS relevance

- Links to Physical Oceanography
  - physical studies largely limited to benthic boundary layer transport and exchange of toxin between water and sediments

- Analysis and Interpretation
  - critical to develop appropriate techniques and initiate strong QA/QC program
  - modeling required for geochemical behavior of toxins and modes of long-term effects
  - analysis of field efforts tied closely to appropriate statistical design

4.2.3 Long-Term Ecosystem Monitoring

The Long-Term Monitoring Workshop met its charge by detailing the structure that might be taken to study natural and human impacts across the Gulf OCS for a period of 10 years. The trade offs of wide thin coverage versus intensive restricted programs was also established. An important definition was put forward distinguishing characterization from monitoring. The latter should be designed to detect and explain variation. The former produces only a static picture of no predictive value.

Due to the fact that such a monitoring program has never been attempted, the workshop was concerned that some special consideration must be given to program structure and management to assure success. First among these is a structure which will employ modeling and prediction to use rather than archive the data. Second is a structure which centralizes planning and analysis while allowing regional studies to be conducted by the most appropriate regional institution. Third is the quality assurance need to have all chemical analyses centralized.

A possible monitoring program might include the following elements:

- Primary Processes Studied
  - population changes
  - processes as identified in TEXLA Ecosystem Study

- Studies Based Upon Faunal Groups
  - dominant macro and megafauna
  - food web analysis of dominants

- Studies Based Upon Chemical/Geological Aspects
  - water column, surface, and sediment hydrocarbons/pollutants
  - tissue hydrocarbon/pollutant concentrations
  - descriptive sedimentology to detect past transport events

- Field Designs Employed
  - maximally, one cross shelf transect sampled seasonally at six depth intervals in each of six regions, with three replicates of each sample (typically box core)
  - minimally, two or more cross shelf transects at six depth intervals in only those two regions studied by the TEXLA Ecosystem Study

- Specifically Addressing OCS Impacts
  - initially, transects should avoid areas of existing contamination and focus upon future changes in natural systems

- Linking with Physical Oceanography and Other Studies
  - an intensive sampling and in situ monitoring program restricted to an area of approximately 4 km square shall be carried out within the TEXLA area; the data from this area would be used to establish physical links for the variables being monitored.

- Analysis, Synthesis and Modeling
  - program design and coordination shall rest in a single group even though field work may be multi-institutional
  - a predictive modeling component will be developed to employ analysis of each season's data and prediction of future results, continuing improvement of this model will be carried out for the duration of monitoring

4.3 Cross Project Coordination

4.3.1 Outside of MMS

The three studies considered during this workshop coincide with an overall increase in Gulf of Mexico research. National Oceanic and Atmospheric Administration (NOAA) is planning a major program as part of its Nutrient Enriched Coastal Ocean Productivity study (NECOP). The Department of Defense is planning to locate two Deep-Ocean Research Islands (DORIs) in the Gulf. And, various academic groups are considering submission of unsolicited proposals dealing with specific oceanographic processes.

Unfortunately, none of these planned efforts can be depended upon as a substitute for components of any of the three MMS studies. None has yet to be initiated, and none has the specific goal of understanding oil and gas-related impacts. Nevertheless, they can serve to enhance the scientific value of MMS supported studies by providing complementary data in terms of greater areal coverage or nature of the processes being studied.

4.3.2 Within-MMS Activities

It is obvious that certain aspects of all three studies can benefit from coordination and unnecessary duplication can be eliminated. This can be considered with respect to the selection of sites, the timing of sampling, and the scope of each separate project. For the most part, the TEXLA Ecosystem Study and the Long-Term Monitoring Study share the most needs in common.

- Site Selection - Conceptually, the two of the Long-Term Monitoring Program's six transects can be used as general locations for the TEXLA study. Since the Chronic Effects study must work close to possible sources of contaminants, its sites should be somewhat separate. If funding limits the breadth of the Long-Term Monitoring, then it could be restricted to the TEXLA region entirely.

- Sampling Interval - For the duration of TEXLA, its frequent sampling (10 times per year) exceeds the anticipated needs of the Long-Term Monitoring. Therefore, cruises could be combined for those transects in the TEXLA region.

With respect to the nature of components within each study, TEXLA and Long-Term Monitoring share the most tasks in common. The benthic studies of TEXLA could be combined with the more descriptive program of Long-

Term Monitoring in those regions where the projects coincide. Similarly, chemical, geological, and sedimentological sampling could be combined in the common region. Detection of Chronic Effects retains its identity and does not fit well with the other studies.

4.3.3 Physical Oceanography Coordination

The need for coordination with physical studies varies across the biological studies. The TEXLA Ecosystem Study absolutely must have information of transport, mixing, and transient events that affect biological processes. Both the Long-Term Monitoring and Detection of Chronic Impact Studies would benefit from information about environmental change, but close coordination is not required.

It is recommended that Physical Efforts coincide with the TEXLA Ecosystem Study in at least the following ways:

- common stations, regions, and schedules - within the TEXLA region, physical and biological data should be collected concurrently;
- common modeling efforts - ecological models dealing with transport or other biological physical interactions should be created in coordination with physical modelers;
- coordination of analysis and synthesis - common analysis of biological and physical data should be a contractual requirement.

APPENDIX A

AGENDA

AGENDA

MMS Northern Gulf of Mexico Environmental Studies Planning Workshop

Tuesday, August 15, 1989
SESSION I

The MMS Perspective and Needs for Scientific
Input to the Management Process

Co-Chairs:	Dr. Robert Carney	Coastal Ecology Institute Louisiana State University
	Dr. Robert Rogers	Minerals Management Service
8:30 - 8:35	Welcome, Announcements, and Workshop Objectives	Dr. Robert Rogers Minerals management Service
8:35 - 9:50	Changing Emphases in OCS Studies	Dr. Thomas E. Ahlfeld Minerals Management Service
9:50 - 10:05	The Gulf of Mexico OCS Regional Perspective	Dr. Richard Defenbaugh Minerals Management Service
10:05 - 10:20	Characteristic Ecosystem Site Monitoring Program	Dr. Robert Rogers Minerals Management Service
10:20 - 10:35	BREAK	
10:35 - 10:50	Detection of Effects at Long-Term Production Sites	Dr. James Kendall Minerals Management Service
10:50 - 11:05	The Texas-Louisiana Marine Ecosystems Study	Dr. Robert Avent Minerals Management Service
11:05 - 11:20	Status of the Texas-Louisiana Ecosystems Physical Oceanography Program	Dr. Murray Brown Minerals Management Service
11:20 - 11:40	A History of Efforts to Monitor and Detect Long-Term Impacts	Dr. Robert Carney Louisiana State University

MMS Northern Gulf of Mexico Environmental Studies Planning Workshop

Tuesday, August 15, 1989
SESSION II

General Concerns in Long-Term Designs
and the Application of Process Studies

Co-Chairs:	Dr. Robert Carney	Coastal Ecology Institute Louisiana State University
	Dr. Rezneat Darnell	Department of Oceanography Texas A&M University
	Dr. Robert Rogers	Minerals Management Service
1:00 - 1:05	Introductory Comments	Dr. Robert Carney Louisiana State University
1:05 - 1:35	A Generic Overview of Monitoring Designs for the Coastal Ocean	Dr. Donald Boesch Louisiana Universities Marine Consortium (LUMCOM)
1:35 - 2:05	Design and Statistical Concerns for Monitoring	Dr. Roger Green University of Western Ontario
2:05 - 2:35	Food Chain Approaches to OCS Ecosystem Studies	Dr. Lawrence Pomeroy University of Georgia
2:35 - 3:00	BREAK	
3:00 - 3:30	Benthic Processes and OCS Studies	Dr. Donald Rhoads Science Applications International Corporation
3:30 - 4:00	Biological Experiments & Sediment Transport Studies of Potential OCS Oil & Gas Development	Dr. Cheryl Butman Woods Hole Oceanographic Institution
4:00 - 4:30	Isotopic Tracers of Processes in the OCS	Dr. Brian Fry Woods Hole Marine Biology Laboratories
4:30 - 4:45	Florida Approaches to Marine Monitoring	Dr. Sandra Vargo Florida Institute of Technology
4:45 - 5:00	The Design and Execution of a Large OCS Monitoring Program	Dr. Gary Brewer Minerals Management Service

MMS Northern Gulf of Mexico Environmental Studies Planning Workshop

Wednesday, August 16, 1989
SESSION III

Detection of Impacts Associated with Long-Term
Oil and Gas Activity Sites

Co-Chairs:	Dr. James Ray	Shell Oil Corporation
	Dr. James Kendall	Minerals Management Service
8:30 - 8:35	Opening Comments	Dr. Robert Carney Louisiana State University
8:35 - 8:50	Looking for Long-Term Effects	Dr. James Ray Shell Oil Corporation
8:50 - 9:20	Monitoring for Hardbottom Effects at a Southern California Site	Mr. Dane Hardin Kinnetics, Inc.
9:20 - 9:35	Monitoring for Softbottom Effects at a Southern California Site	Dr. Paul Montanga Marine Science Institute University of Texas
9:35 - 9:50	Biological Effects of Petroleum Hydrocarbons	TBA
9:50 - 10:05	Drill Mud Effects	Mr. Maurice Jones ENSR Consulting and Engineering, Inc.
10:05 - 10:25	BREAK	

MMS Northern Gulf of Mexico Environmental Studies Planning Workshop

Wednesday, August 16, 1989
SESSION IV

The Texas-Louisiana Shelf Marine Ecosystem

Co-Chairs:	Dr. Eugene Turner	Coastal Ecology Institute Louisiana State University
	Dr. Gilbert Rowe	Department of Oceanography Texas A&M University
	Dr. Robert Avent	Minerals Management Service
10:25 - 10:55	Long-Term Changes in Coastal Systems	Dr. Eugene Turner Louisiana State University
10:55 - 11:10	Processes of the Shelf Ecosystem in the Texas-Louisiana Region	Dr. Gilbert Rowe and Dr. Rezneat Darnell Texas A&M University
11:25 - 11:40	Current Regimes of the Texas-Louisiana Shelf	Dr. William Wiseman Louisiana State University
11:40 - 11:55	Hydrocarbons of the Texas-Louisiana Region OCS	Dr. Charles Kennicutt Geochemical and Environmental Research Group Texas A&M University
11:55 - 12:05	Ecosystems of the Texas-Louisiana OCS Region	Dr. Nancy Rabalais Louisiana Universities Marine Consortium (LUMCON)
12:05 - 12:20	Ecosystems of the Mississippi-Alabama OCS Region	Dr. William Schroeder Dauphin Island Marine Laboratory
12:20 - 12:35	Factors Limiting Productivity on the Northern Gulf of Mexico Continental Shelf	Dr. Quay Dortch Louisiana Universities Marine Consortium (LUMCON)

MMS NORTHERN GULF OF MEXICO ENVIRONMENTAL STUDIES PLANNING WORKSHOP

Wednesday, August 16, 1989

Concurrent Workshops

2:00 - 5:00	Texas - Louisiana Marine Ecosystem Study	
	Co-Chairs:	Dr. Eugene Turner Louisiana State University
		Dr. Gilbert Rowe Texas A&M University
		Dr. Robert Avent Minerals Management Service
2:00 - 5:00	Effects of OCS Development and Production Activities	
	Co-Chairs:	Dr. James Ray Shell Oil Corporation
		Dr. James Kendall Minerals Management Service
2:00 - 5:00	Long-Term Monitoring at Marine Ecosystem Sites	
	Co-Chairs:	Dr. Rezneat Darnell Texas A&M University
		Dr. Robert Rogers Minerals Management Service

MMS Northern Gulf of Mexico Environmental Studies Planning Workshop

Thursday, August 17, 1989

Concurrent Workshops

8:30 - 12:00	Texas-Louisiana Marine Ecosystem Study	
	Co-Chairs:	Dr. Eugene Turner Louisiana State University
		Dr. Gilbert Rowe Texas A&M University
		Dr. Robert Avent Minerals Management Service
8:30 - 12:00	Effects of OCS Development and Production Activities	
	Co-Chairs:	Dr. James Ray Shell Oil Corporation
		Dr. James Kendall Minerals Management Service
8:30 - 12:00	Long-Term Monitoring at Marine Ecosystem Sites	
	Co-Chairs:	Dr. Rezneat Darnell Texas A&M University
		Dr. Robert Rogers Minerals Management Service
12:00 - 1:00	LUNCH BREAK	

MMS Northern Gulf of Mexico Environmental Studies Planning Workshop

Thursday, August 17, 1989

Concurrent Workshops

1:00 - 4:00	Texas-Louisiana Marine Ecosystem Study	
	Co-Chairs:	Dr. Eugene Turner Louisiana State University
		Dr. Gilbert Rowe Texas A&M University
		Dr. Robert Avent Minerals Management Service
1:00 - 4:00	Effects of OCS Development and Production Activities	
	Co-Chairs:	Dr. James Ray Shell Oil Corporation
		Dr. James Kendall Minerals Management Service
1:00 - 4:00	Long-Term Monitoring at Marine Ecosystem Sites	
	Co-Chairs:	Dr. Rezneat Darnell Texas A&M University
		Dr. Robert Rogers Minerals Management Service
4:00 - 5:00	Concluding Remarks	Dr. Robert Carney Louisiana State University

APPENDIX B

LIST OF ATTENDEES

ATTENDEES

Dr. Thomas K. Ahlfeld
Minerals Management Service
Branch of Environ. Studies
381 Elden Street
Herndon, VA 22070

Dr. Robert M. Avent
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Dr. R.C. Ayers
Exxon
Scientific Advisory Committee
P. O. Box 2189
Houston, TX 77001

Dr. James H. Baker
ENSR
C&E
3000 Richmond Avenue
Houston, TX 77098

Mrs. Mary R. Bartz
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Mr. Tony Bazile
Conoco, Inc.
NAE
600 N. Dairy Ashford
Houston, TX 77079

Mr. Richard T. Bennett
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Dr. Douglas Biggs
Texas A&M University
Dept. of Oceanography
College Station, TX 77843

Ms. Janice B. Blake
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Dr. Donald F. Boesch
Louisiana Universities
Marine Consortium
Chauvin, LA 70344

Dr. Gary D. Brewer
Minerals Management Service
Pacific OCS Region
1340 W. 6th Street
Los Angeles, CA 90803

Dr. Thomas J. Bright
Texas A&M University
Sea Grant College Program
College Station, TX 77843

Dr. James M. Brooks
Texas A&M University
Geochem. & Env. Res. Grp.
10 S. Graham Street
College Station, TX 77843

Dr. Murray Brown
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Dr. Robert S. Carney
Louisiana State University
Coastal Ecology Institute
Baton Rouge, LA 70804

Mr. Dennis L. Chew
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Mr. Duane Chisholm
LA Dept. of Environ. Quality
Water Pollution Control
P. O. Box 44091
Baton Rouge, LA 70804-4091

Mr. Joe A. Christopher
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Ms. Lauren Danser
Louisiana State University
4708 Chastant Street
Metarie, LA 70006

Dr. Rezneat M. Darnell
Texas A&M University
Dept. of Oceanography
College Station, TX 77840

Mr. Les Dauterive
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Dr. Richard Defenbaugh
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Dr. John deMond
LA Dept. of Natural Resources
Coastal Management Division
P. O. Box 44487
Baton Rouge, LA 70804

Dr. Quay Dortch
Louisiana Universities
Marine Consortium
Chauvin, LA 70344

Mr. Douglas Elvers
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Ms. Karen Foote
LA Dept. Wildlife & Fisheries
Marine Fisheries
P. O. Box 9800
Baton Rouge, LA 70898

Ms. Charlotte H. Fremaux
League of Women Voters
Jefferson Parish
305 Cuddihy Drive
Metairie, LA 70005

Dr. Norman Froomer
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Dr. Brian Fry
Marine Biological Lab
Ecosystems Center
Woods Hole, MA 02543

Mrs. Mary A. Garza
Geo-Marine, Inc.
1316 14th Street
Plano, TX 75074

Mr. Ruben G. Garza
Geo-Marine, Inc.
1316 14th Street
Plano, TX 75074

Mr. Gary D. Goeke
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Dr. Roger H. Green
University of Western Ontario
Dept. of Zoology
London Ontario, CANADA N6A 5B7

Mr. Sheldon R. Hall
Geo-Marine, Inc.
1316 14th Street
Plano, TX 75074

Mr. James Hanifen
LA Dept. Wildlife & Fisheries
Marine Fisheries
P. O. Box 98000
Baton Rouge, LA 70898

Dr. Donald E. Harper, Jr.
Texas A&M Galveston
Dept. of Marine Biology
5007 Avenue V
Galveston, TX 77551

Dr. Ken Havran
Minerals Management Service
Offshore Environ. Assessments
381 Elden Street
Herndon, VA 22070

Ms. Marietta S. Herr
League of Women Voters
New Orleans
59 Oriole Street
New Orleans, LA 70124

Mr. Charles Hill
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Dr. Bela James
Continental Shelf Associates
7607 Eastmark Drive
College Station, TX 77843

Mr. Jay Johnson
Conoco
New Orleans
3500 General DeGaulle
New Orleans, LA 70114

Ms. Michelle Kasprzak
LA Dept. Wildlife & Fisheries
Coastal Investigations
P. O. Box 98000
Baton Rouge, LA 70898

Dr. Mahlon C. Kennicutt II
Texas A&M University
Geochem. & Env. Res. Grp.
10 S. Graham Street
College Station, TX 77840

Mrs. Connie Landry
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Ms. Dianne Lindstedt
Louisiana State University
Louisiana Geological Survey
Box G
Baton Rouge, LA 70808

Mr. Patrick Mangan
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Mr. Scott Mettee
Alabama Geological Survey
Biological Resources
Tuscalousa, AL 35486

Mr. William Ibarra
Conoco, Inc.
3500 Gen. DeGaulle Drive
New Orleans, LA 70114

Mr. Douglas Johnson
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Mr. Maurice Jones
ENSR Corp.
2400 W. Loop South
Suite 300
Houston, TX 77027

Dr. James J. Kendall
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Dr. Herb Kumpf
EPA Gulf of Mexico Region
DOC/NOAA
3500 Delwood Beach Drive
Panama City, FL 32408

Mr. Dudley Lightsey
Texas General Land Office
Energy Resources
1700 N. Congress, RM 640
Austin, TX 78701-1495

Dr. Alexis Lugo
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Dr. Jay Means
Louisiana State University
Institute for Environmental
Studies
Baton Rouge, LA 70808

Mr. David L. Miller
Exxon Co. USA
Eastern Production Division
P.O. Box 61707
New Orleans, LA 70161

Dr. Thomas M. Mitchell
Science Applications
International Corp.
Marine Technology
13148 Coit Road
Dallas, TX

Dr. Paul A. Montanga
University of Texas
Marine Science Institute
P.O. Box 1267
Port Aransas, TX 78373-1267

Mr. David J. Murphy
Texas A&M University
Dept. of Oceanography
College Station, TX 77843

Mr. Russell G. Olivier
Freeport-McMoRan
Sulphur
P.O. Box 61520
New Orleans, LA 70160

Dr. Lawrence Pomeroy
University of Georgia
Dept. of Zoology
Athens, GA 30602

Dr. Nancy N. Rabalais
Louisiana Universities
Marine Consortium
Star Route Box 541
Chauvin, LA 70344

Ms. Gail Rainey-LeBlanc
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Dr. James P. Ray
Shell Oil Co.
Environmental Affairs
P.O. Box 4320
Houston, TX 77210

Dr. Larry A. Reitsema
ENSR
Consulting & Engineering
3000 Richmond Avenue
Houston, TX 77098

Mr. Jeffrey H. Render
Louisiana State University
Center for Wetland Resource
Coastal Fisheries Institute
Baton Rouge, LA 70803

Dr. Don Rhoads
Science Applications
International Corp.
Maritime Tech.
89 Water Street
Woods Hole, MA 02543

Mr. Adolph Ringen
Ringen Studio Design
518 Marigny Street
Mandeville, LA 70448

Dr. Robert M. Rogers
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Mr. Mark Rouse
Minerals Management Service
Offshore Leasing Management
18th & C Streets NW
Washington, D.C. 20240

Dr. Gil Rowe
Texas A&M University
Dept. of Oceanography
College Station, TX 77843

Dr. Ann Scarborough-Bull
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Dr. William W. Schroeder
University of Alabama
Marine Science Program
Dauphin Island Sea Lab
P. O. Box 369
Dauphin Island, AL 36528

Ms. Linda Shaw
LA Dept. Wildlife & Fisheries
Coastal Investigations
P. O. Box 98000
Baton Rouge, LA 70898-9000

Dr. Eugene A. Shinn
U.S. Geological Survey
Coastal Studies
600 4th Street S.
St. Petersburg, FL 33073

Mr. David Stanley
Louisiana State University
Coastal Fisheries Institute
Baton Rouge, LA 70803

Mr. Declan Troy
LGL Ecological Research Assn.
1410 Cavitt Street
Bryan, TX 77801

Dr. Sandra L. Vargo
Florida Institute of
Oceanography
State University System
830 First Street S
St. Petersburg, FL 33701

Dr. William Wiseman
Louisiana State University
Coastal Studies Institute
Baton Rouge, LA 70803

Mr. Joseph C. Souhlas
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Mr. Ted Stechmann
Minerals Management Service
Gulf of Mexico OCS Region
1201 Elmwood Park Blvd.
New Orleans, LA 70123-2394

Dr. Eugene R. Turner
Louisiana State University
Dept. of Marine Sciences
Baton Rouge, LA 70803

Dr. Barry A. Vittor
Vittor & Associates, Inc.
8060 Cottage Hill Rd.
Mobile, AL 36695

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