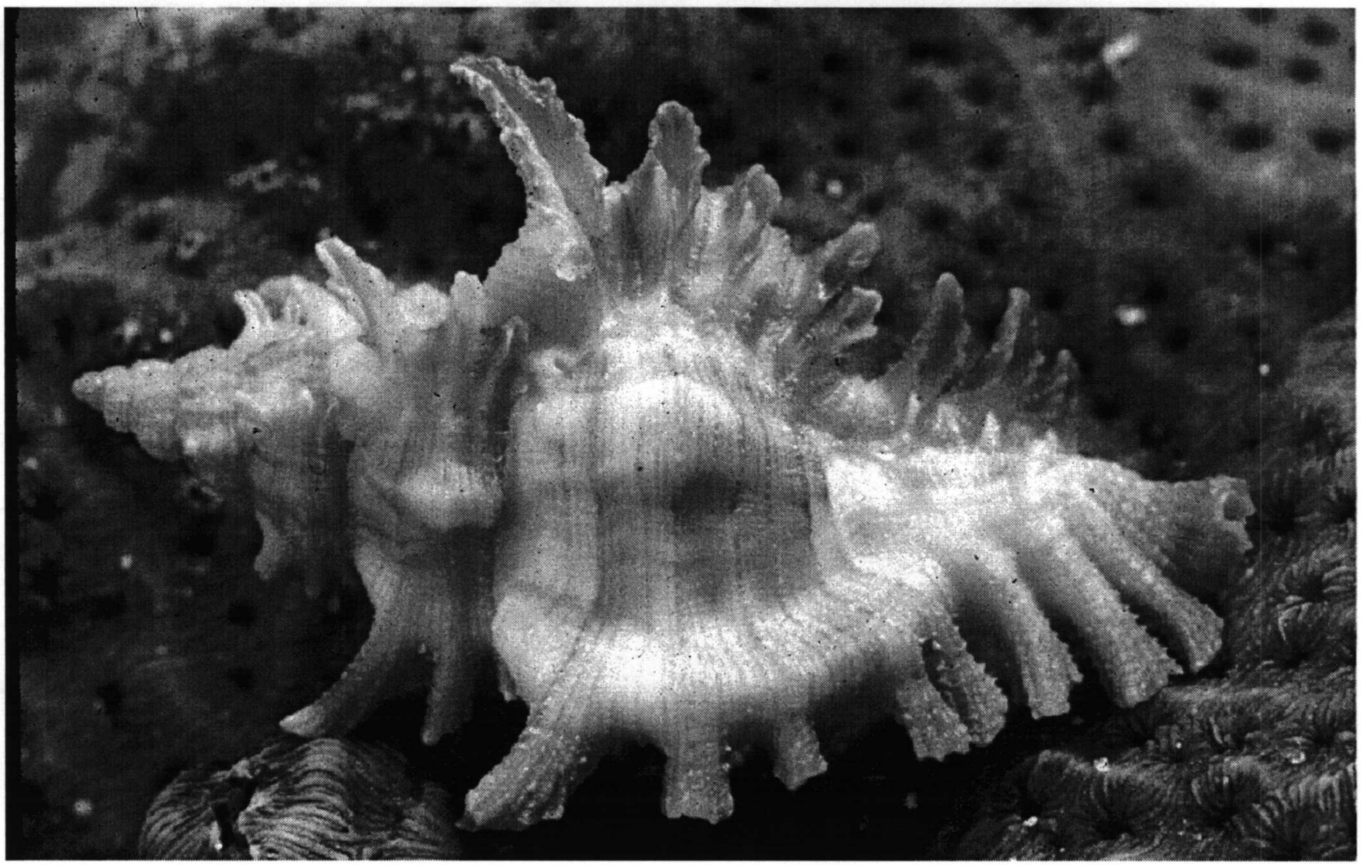
OCS Study
MMS 96-0024

Proceedings:
Fourteenth Annual Gulf of Mexico Information Transfer Meeting

November 1994



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

OCS Study
MMS 96-0024

Proceedings: Fourteenth Annual Gulf of Mexico Information Transfer Meeting

November 1994

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SUMMARY

The 1994 Information Transfer Meeting (ITM) was held by the Gulf of Mexico OCS Region of the Minerals Management Service (MMS) at the Clarion Hotel in New Orleans. The purpose of the ITM is to foster sharing of information among participants about current research, accomplishments, or issues of concern to the MMS. Presentations at the ITM pertained to the MMS Gulf of Mexico Outer Continental Shelf (OCS) oil and gas program, as well as regional environmental, social, or economic concerns, or current OCS industry activities or technologies. Once again, the ITM also served as an opportunity for the public to comment on the information base available for future oil and gas lease sales, particularly those proposed in the Western and Central Gulf of Mexico. The audience included scientists, managers, and laypersons from government, academia, industry, environmental groups, and the general public.

Technical sessions this year included University Research Initiative studies, Conservation and Environmental Awareness, Chemosynthetic Communities, Oil Spill Contingency Planning, GOOMEX studies, Marine and Energy Education, Coastal Marine Institute reports, Air Quality Issues, Aging Infrastructure, the LATEX-Seasonde Cooperative Experiment, Mariculture Associated with Oil and Gas Structures, MMS Environmental Studies reports, Distribution and Abundance of Cetaceans, and Subsalt Efforts on the Outer Continental Shelf.

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ACKNOWLEDGMENTS

The Minerals Management Service thanks all ITM participants. Special recognition goes to the speakers whose timely individual and panel presentations stimulated discussions and exchange of information. Authors are listed by name with their articles and again in an index at the back of this publication.

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

Appreciation is also extended to the University of New Orleans, Office of Conference Services, the contractor who handled the logistics for the meeting and compiled the proceedings.

OPENING PLENARY

Session: OPENING PLENARY

Chair: Mr. Gary D. Goeke

Date: November 15, 1994

Presentation	Author/Affiliation
Introduction	Mr. Gary D. Goeke U.S. Minerals Management Service Gulf of Mexico OCS Region Environmental Studies Section
Agency Welcome	Mr. Chris Oynes Acting Regional Director U.S. Minerals Management Service Gulf of Mexico OCS Region
Local Perspectives	Dr. Don Davis Administrator Louisiana Applied Oil Spill Research and Development Program
Federal/State Partnerships	Dr. Robert S. Carney Executive Director Coastal Marine Institute Louisiana State University
NAFTA: New Directions	Mr. Howard O. Ness Director Mexico Affairs Office National Park Service

INTRODUCTION

Mr. Gary D. Goeke
Environmental Studies Section
U.S. Minerals Management Service
Gulf of Mexico OCS Region

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

ITM INTRODUCTION

The primary purposes of the ITM are (1) to provide a forum for interchange on topics of current interest relative to environmental assessments in support of offshore oil and gas activities in the Gulf of Mexico OCS Region; (2) to present the accomplishments of the MMS Environmental Studies Program for the Gulf of Mexico, and of other MMS research programs or study projects; and (3) to foster an exchange of information of regional interest among scientists, staff members, and decision makers from MMS, other federal or state governmental agencies, regionally important industries, and academia and to encourage opportunities for these attendees to meet and nurture professional acquaintances and peer contacts.

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

Meeting support funding is provided through the MMS Environmental Studies Program. All meeting logistical support is provided by a contractor (Office of Conference Services, University of New Orleans) and subcontractors selected through the usual federal procurement process. A proceedings volume is prepared for each ITM based on presentation summaries submitted by each speaker and on session introductions prepared by session chairpersons.

OPENING PLENARY SESSION
INTRODUCTION

The Opening Plenary Session is planned each year to address changing themes, which have included environmental topics, industry technology, offshore resources, marine research, and OCS program issues. This year's Opening Plenary Session was planned to revisit some of the basic considerations in OCS operations.

AGENCY WELCOME

Mr. Chris Oynes
Acting Regional Director
U.S. Minerals Management Service
Gulf of Mexico OCS Region

Welcome to our Information Transfer Meeting. This is a very important meeting for MMS in the Gulf of Mexico Region, one that focuses on significant developments in the oil and gas industry. We're glad to have you here, and we hope that you have a good time over the next couple of days.

A tremendous number of environmental studies have been brought to bear on the OCS-related issues in the Gulf of Mexico. Some of the efforts we would like to highlight are that MMS is just completing a five-year, $16 million study to examine the physical oceanography of the Gulf of Mexico, as well as a four-year, $5.7 million study on air quality, and a number of other broad-brush efforts to further our understanding of the environmental nature of the Gulf of Mexico. There are also a number of new trends affecting the oil and gas industry in the gulf. The industry is increasingly moving towards deep waters with the development of new technology.

LOCAL PERSPECTIVES

Dr. Don Davis, Administrator
Louisiana Applied Oil Spill Research and Development Program

In 1947 Kerr-McGee and the Scanlon Oil Company, now known as Amoco, put the first well out of sight of land off the Louisiana coast. Today the offshore industry has grown to include deepwater projects such as Auger, Neptune, and Cervesa. Although the industry's impact on the people of Louisiana has been enormous, this impact has at times been both promoted and ignored.

The largest non-tax source of income to the U.S. Treasury is off Louisiana's coast, and it is worth from $3.4 to more than $10 billion annually. MMS's directive is to meet the nation's present and future energy needs, to reduce our dependency on foreign energy sources, and to protect the environment, the people, in addition to the animals that inhabit our coasts and oceans.

Therefore, when we look at oil and gas exploration, we should recognize that in Louisiana its a two-fold development. First of all, when we consider onshore, beginning in 1906, moving into Catto Lake, which is the first over-water exploration in the world, we find dramatic input, not only in oil in Southeastern Louisiana but also in natural gas in Southwestern Louisiana. As a result, we recognize prior to spacing laws, throughout coastal Louisiana there was enormous oil production so successful that one out of three wells was productive.

But there is also the forgotten coastal resource: sulphur. The city of Sulphur was developed as a result of the Frasch sulphur process, so much so that now we turn to Main Pass Block 299, a $30 billion production. It overshadows other South Louisiana producing areas such as Garden Island Bay, Grand Isle, and Caminada. Therefore, when we look at Louisiana's perspective, we are tied directly to the petroleum industry. The Texas company now known as Texaco developed the first mobile drilling barge. We had to gain access. To do that we built an extensive network of oil and gas canals. Then the offshore industry simply transported this kind of technology to move product ashore.

Thus, Louisiana has been involved in the offshore oil and gas industry for almost 100 years. It is an enormous industry, one that moves by boat or helicopter. The largest privately-owned helicopter fleet in the world is based in Louisiana. And of course, there are also all the other logistics. The technology for the construction of offshore facilities was developed in coastal Louisiana. The development of onshore support bases at places like Intercoastal City, Empire, Morgan City, and Grand Isle has been significant as well. Do you realize that one large oil company annually buys $500 thousand worth of soft drinks and has over 55 18-wheelers parked at their facilities?

And yet, this is a conference that is going to look at the Caribbean initiative. One MMS employee in the audience that has spent almost a lifetime looking at recreation. Has anybody thought for a moment that with the development of oil in Trinidad/Tobago, we're also going to see a spinoff industry? We should be looking at that.

The Caribbean initiative is only one. You're going to hear about the North America Free Trade Agreement. If you develop offshore wells in the Gulf of Campeche and off of Yucatan, recognizing that the Mexican government controls the industry in Mexico, has it occurred to you that the logistic support may in fact come from Louisiana? It's been done before. A well off Yucatan was once supported out of Venice.

So the oil and gas industry is a non-renewable resource that indeed has enormous impact. Note for a moment, there are 30,900 plus oil and gas wells drilled in federal offshore waters; 7,900 producing wells; 3,700 oil and gas producing platforms; 21,000 miles of pipeline. Question: Do we know where they are? And are we ready for the oil spill if we don't?

If you get an oil spill out of a pipeline in San Jacinto and future prices increase, what happens when you have a pipeline that carries two billion cubic feet of natural gas that's also disrupted?

Let us keep in mind these human impacts from a Louisiana perspective. In 1992, there were 13,000 producing company jobs, and of those 10,000 were in Louisiana. The payroll resulted in an average income of $52,580 per employee. More than $4.1 billion was paid by producing companies to vendors annually. I suspect most people are unaware of that. And I remind you that there are 6,000 vendors, but if you'll note, 3,800 of them are in Louisiana. And those people get an annual income of $2.4 billion.

When you begin to look then at a Louisiana perspective, the numbers explain it clearly. There are 167 different communities in 47 parishes influenced by the oil industry. And numbers directly from the oil industry suggest there are 55,000 vendors. Forty-five percent derive most of their income from the OCS. So is OCS important to Louisiana? Unquestionably, the answer is yes. The impact of this oil and gas activity on the human, marine and coastal environments are significant. It is the reason for this plenary session.

We need to look at some of the social as well as the economic impacts. Currently (December 1994) there are 198 platforms or operations drilling in the Gulf of Mexico, higher than in 1990. The industry has been rediscovered. And quickly we see that the wells drilled and the percentage off coastal Louisiana is represented in the 90th percentile. But to move this product ashore we have to get it there by affecting our wetlands. Pipelines are critical.

I was involved in a study not too long ago in which we changed MMS numbers because MMS felt that there were 100 pipelines making landfall in coastal Louisiana when in point of fact, there were close to 200. Recognizing that that's nobody's fault, we are going to have to look carefully at this aging infrastructure because there's no doubt we're going to go into deeper water and there's no doubt that through the Oil Pollution Act of 1990 we're going to have to take critical steps in looking at the pollution problems. But in reality, the pollution from offshore is minimal. A number of studies suggest it is less than one percent of all oil found in the world's seas. With that in mind, Louisiana's production is somewhat staggering. It is hard to visualize a trillion cubic feet of natural gas. And it is hard to visualize that most of Illinois, Wisconsin, Michigan, Minnesota get their natural gas from one pipeline off Louisiana's coast.

I am involved in an oil spill research and development program. In terms of a partnership, I suggest to MMS that we need to move ahead with an MOU. And through your coastal studies program I suggest that we should not take five years to initiate studies. We should fast-track them. The environment simply cannot wait.

MMS scientists and engineers work to determine ways to protect our environment. We're in the business of meeting U.S. energy needs and co-funding is a reality. Co-funding needs to be looked at very carefully at the highest level.

And if we talk about new partnerships, what is Louisiana's position? I have talked to the new secretary of the Department of Natural Resources, from the Governor's office. Dr. Len Bahr is in the audience who represents coastal activities, Mr. Roland Guidry, who is the director of Louisiana's oil spill program, all agree it is time to move forward, it's time we speak with a common voice. And with that we feel barrier islands are absolutely critical. Remember for a moment, those barrier islands are your anchor points for pipelines. They protect the bay's infrastructure. The pipelines are aging. The pipelines' locations are not fully understood. And it is a difficult, multi-million dollar job.

Unitization needs to be looked at carefully by MMS and the state of Louisiana. I realize there are some legal questions, but there have been other legal issues we have overcome. The aging infrastructure, orphan wells, plug-and-abandon issues need to be clearly looked at. Logistic support will be the driving mechanism as we continue to go into deeper water.

Do you realize there are 500 operators in the Gulf of Mexico? Do you realize that 70% of U.S. production comes from independents, not the majors. Therefore, we have some important liability issues that also need to be addressed. Planning and cooperation are critical.

Let's take a look at the barrier islands for a moment. I can tell you that the Department of Natural Resources, the Office of the Governor wants this looked at very carefully. And we feel we can enter into a partnership. You already know that recent legislation allows you to go into ship shoal and mine the sand. You also realize that the Jones Act prohibits us from importing the dredge technology.

Pipelines represent a potential for ecodisaster, not a good word. But think of it for a moment. I can show you a pipeline incident in which it took ten hours to find the company to turn off the oil. Not their fault; they bought the pipeline from Company A that sold it to B. It was absorbed by D that was broken up into E, F, and G, and you see what happens. Pipelines are an issue we're going to have to look at very carefully. And that is an area of partnership.

So the bottom line is simply cooperation, communication, coordinated policy. These should be complementary. And we must look for decisive solutions. But let us not take forever. Let us move fast-track. Because if we are indeed talking here of partnerships and a new beginning, from Louisiana's point of view, I can tell you unequivocally that we are now speaking with a common voice.

FEDERAL/STATE PARTNERSHIPS

Dr. Robert S. Carney, Executive Director
Coastal Marine Institute
Louisiana State University

As a graduate student at Texas A&M twenty-five years ago, my first job was to sort marine animals. Since I had never seen most of the creatures before, I learned a great deal about the animal kingdom. At the same time I also began also began to formulate questions that eventually became part of my research in the gulf.

Returning to Texas A&M after military service, I found most of the people I had known had moved on to jobs with the Bureau of Land Management. These youthful new administrators were posing questions about pollution and then funding research at Texas A&M, the laboratories where they had been educated, to find answers the questions.

In contrast to the relationship between the Bureau of Land Management and Texas A&M, some years ago NOAA chose to not to contract with the University of Hawaii when it needed to have fifty box cores from 4,000 meters below the ocean sorted. Instead, the agency chose a more cost-effective independent firm in New Jersey for the job. So, university students were denied opportunities to study the diversity of life in the Pacific Ocean and to formulate ideas that would carry forth into their professional lives.

The current relationship between MMS and academia is the result of hard work by Scott Sewell. A Bush administration appointee and an LSU alum, he proposed an arrangement between MMS and universities that works somewhat differently from traditional situations. For example, according to guidelines of the 1993 agreement MMS and LSU, both groups first sit down and identify topic areas after which a solicitation is issued to LSU researchers. However, rather than maintain its normal hands-off treatment of solicited proposals, MMS can negotiate with the individual principal investigators whenever necessary. This prevents the academics from going off on tangents and producing results that are academically interesting but of questionable use to MMS.

As an example of the breadth of the agreement, as of November 1994 nearly twenty projects had been reviewed and had undergone negotiation with a commitment of over $4.2 million in federal funds to economics, physical oceanography, platform ecology, deepwater policy issues, geohazards, spills, bioremediation, and laboratory studies of toxicity.

The system is not perfect. There are some difficulties because it is a partnership with the provision that the state of Louisiana will provide a dollar-for-dollar match to the federal money coming in. Up to now matching funds have come from existing university resources, but with many departments competing for a limited amount, there is always the possibility that matching money may not be awarded.

Another complication of the partnership is that the program has to remain fairly restricted. Since LSU is not in a position to fund research done by other universities, only schools that can commit to the fifty-fifty match can be asked to participate in the research.

As part of the partnership, the Coastal Marine Institute at LSU and those being set up at the University of Alaska and the University of California at Santa Barbara have been encouraged by MMS to include students in research projects. MMS must continue to encourage student involvement since such training is vital to the generation of ideas in the field.

With MMS obligated to foster educational research, academia must meet its obligation to provide matching money. Additionally, educators must commit to treat the partnership projects not simply as adjunct undertakings but as central issues of genuine research that should be put into the arena of scientific debate.

Dr. Robert Carney, an associate professor in LSU's Department of Oceanography and Coastal Studies, has served as director of LSU's Coastal Ecology Institute since 1986 and has been director of the LSU-MMS

CMI program since its inception. He received his M.S. from Texas A&M University and his Ph.D. from Oregon State University. Prior to LSU, Dr. Carney was employed at Moss Landing Marine Labs, the National Science Foundation, and the Smithsonian Institution.

NAFTA: NEW DIRECTIONS

Mr. Howard O. Ness
Director, Mexico Affairs Office
National Park Service

Before we can understand where we are today with NAFTA, the North American Free Trade Agreement, we need briefly to review recent Mexican history.

The United States' relationship with the Republic of Mexico has not been entirely smooth. Established after the Mexican Revolution (1936-1938), the new republic was led by a strong president, Lázaro Cárdenas, who nationalized the oil and gas industry as well as other natural resources, including fisheries, agriculture, and hard minerals. He also forced the foreigners, the British and the Americans, out of Mexico. Cárdenas did this for political reasons, primarily to help Mexico recover from a revolution that killed over four million people, about 20% of the population. This allowed them to take control of their destiny. He unified Mexico and proved to be one of the greatest presidents that Mexico has ever had until the most recent president, Carlos Salinas.

Carlos Salinas completely changed the policies that Cárdenas had initiated. Salinas, a Harvard graduate in economics, understood that to correct Mexico's economic difficulties he had to open Mexico to trade. An important step in this process was opening trade with the United States. Mexico decided to lower tariff areas and get rid of restrictive trade policies for the United States before they ever negotiated with NAFTA. Thus, even if we had not passed an agreement in Congress, Mexico would still have opened its doors to the world. NAFTA is as much a Mexican initiative as a U.S. initiative.

Mexico pushed NAFTA so hard because in the GATT, General Agreement of Tariff and Trade, environmental issues were obstructing negotiations between the United States, Mexico, and other countries in the hemisphere. Disputes such as the tuna-dolphin matter and the subsequent embargo by the United States government stopped very important, very high dollar, trade negotiations. With NAFTA, Mexico decided a front-door solution would best promote direct negotiations with the United States.

Ethical questions regarding environmental protection arose in Mexico in the early 1980s irrespective of NAFTA. At that time Mexico initiated important environmental regulations, some of which were modeled after the United States' EPA protection laws and the Department of the Interior's land management policies. Although some of them have proven unenforceable, they are nevertheless excellent laws and policies.

NAFTA is a very high forum partnership among three nations, the United States, Mexico and Canada. It commits the three countries to "sustainable development consistent with environmental protection and conservation." Along with NAFTA there are numerous and complicated site agreements. Many are still forming and are still somewhat competitive with each other. One of them is the North America Development (NAD) Bank that was founded to finance environmental protection research, particularly that concerned with hazardous waste and water quality.

The Border Environmental Cooperation Commission is an advisory board to the NAD Bank. Their charge is environmental protection focused on the water. It is a bi-national commission between Mexico and the U.S. headquartered in Juárez, Mexico. Its job will be to certify the NAD Bank projects.

The EPA has already opened two more offices, one in El Paso and one in San Diego. Again, this is part of the environmental protection and conservation concerns, particularly on the U.S. side, that were required by Congress before NAFTA was approved.

Another site agreement is the Environmental Cooperation Committee. It is a committee of U.S. members only living on the Canadian and Mexican borders. The group is funded with several million dollars. The Good Neighbors Commission is a presidential commission created to enhance a good neighbor policy with Mexico. These commissions and committees are all offshoots of NAFTA.

Finally we come to the U.S. Department of the Interior. In the prior administration, EPA administrator Bill O'Rielly ran the negotiations on environmental policy for the U.S. side, and Interior was not well represented. This is incredible when you consider that Interior manages 30.7% of the U.S./Mexico border. The border is 2,000 miles long, and over 700 miles is under the auspices of the U.S. Department of the Interior with nine bureaus involved.

In this administration, Interior Secretary Bruce Babbitt was involved early in negotiations with Mexico. Secretary Babbitt's close relationship with Mexico's former Environmental Protection Social Development administrator greatly assisted us. Sadly, the administrator was assassinated. However, we are optimistic that the new Mexican administrator will continue environmental quality policies with the United States.

Our current administration has aggressively tried to patch the rift between Interior and the EPA. Interior has said, "We are the resource managers. We need to be involved in the NAFTA process." So Secretary Babbitt got involved in the Bi-National Commission, a high-level commission between the U.S. Secretary of State and Mexico's Secretary of Foreign Relations. Together, they got the dialog going between the two countries on land policies.

We have recently formed a partnership that many of us are very proud of, a field coordinating committee with nine members. One member is the Bureau of Indian Affairs. With 75 miles of land adjacent to Mexico, the Indian tribes insist that they are a part of NAFTA. The Bureau of Reclamation, the old dam builders, is another member. They are viewed not in their old role, but as an agency that is changing direction and one involved with the water issues on the border. The Rio Grande, a highly used and highly polluted river, takes up over half the U.S./Mexico border.

In our next fiscal year this new partnership has a three million dollar budget. The nine bureaus are going to concentrate on environmental education and the socio-economic issues of the lower Rio Grande as a region and as a natural contributor to the Gulf of Mexico. We will look at Padre Island as part of the ecosystem in the Gulf of Mexico. Water quality takes on a very high priority with the committee. This is a new, more efficient way of doing business with this administration in that we are pooling our expertise on resources.

Realistically, Mexico's next administration will probably de-emphasize environmental protection issues. Mexico has a rural countryside to feed that will likely take precedence over other concerns. However, we have no doubt that the partnerships with Mexico will continue.

The number one state-owned industry of the government of Mexico is oil and gas. The fact that it was not de-centralized demonstrates that the government has no intention of letting go of its most important source of revenue. But we have made some real progress between our two nations with their two languages and two distinct cultures. In fact, environmental issues in some ways have brought us closer together.

Mr. Howard O. Ness is the Head of the Mexican Affairs Office for the National Park Service, a cooperative program with Mexico in natural resource management and cultural affairs. He has over 20 years' experience in conservation and resource management working for various federal and state agencies. Prior to his current position, he worked in Mexico City for the U.S. State Department as Attache for Fisheries, Wildlife and Natural Resources for Mexico and Latin America. Mr. Ness received a B.A. in biology and a master's degree from New Mexico State University.

SESSION 1A

UNIVERSITY RESEARCH INITIATIVE STUDIES

Session: 1A - UNIVERSITY RESEARCH INITIATIVE STUDIES

Co-Chairs: Dr. Robert Rogers and Mr. Marion Fannaly

Date: November 15, 1994

Presentation	Author/Affiliation
The University Research Initiative: Overview and Current Status	Mr. Marion T. Fannaly Director of Special Programs Louisiana Universities Marine Consortium
The Recovery of a Deltaic Barrier Island to Hurricane and Oil Spill Impacts in Coastal Louisiana	Ms. Dianne Lindstedt Center for Coastal Energy Louisiana State University Ms. Karolien Debusschere Coastal Environments, Inc. Dr. Irving A. Mendelssohn Wetland Biogeochemistry Institute Louisiana State University Mr. Qiang Tao Coastal Studies Institute Louisiana State University
Satellite Based Assessment of the Mississippi River Discharge Plume's Spatial Structure and Temporal Variability	Dr. Nan D. Walker Coastal Studies Institute Louisiana State University
Biotransformation Pathways of Heterocycles in the Marine Environment. Benzo(f)quinoline and Benzothiazole: Potentiation of Mobility and Toxicity	Dr. W. James Catallo Laboratory for Ecological Chemistry & Toxicology (SVM) & Center for Coastal Energy and Environmental Research Louisiana State University
Oil and Gas Development and Coastal Income Inequality: A Comparative Analysis	Dr. Charles M. Tolbert Louisiana State University Agricultural Center

THE UNIVERSITY RESEARCH INITIATIVE: OVERVIEW AND CURRENT STATUS

Mr. Marion T. Fannaly
Director of Special Programs
Louisiana Universities Marine Consortium

BACKGROUND

In 1989, the Minerals Management Service (MMS) began two university-based research programs on the long-term environmental and socioeconomic effects of offshore oil and gas development, one based in the Gulf of Mexico region and the other in California. The purposes of these programs were to

- increase strategically the emphasis on long-term effects within the MMS Environmental Studies Program (ESP), and
- expand the involvement of universities in the ESP, stimulating innovative research and training students in relevant areas.

The Louisiana Universities Marine Consortium (LUMCON), acting on behalf of Louisiana's state universities, was competitively awarded a five-year cooperative agreement to conduct the Gulf of Mexico university-based research program. This report provides an overview of the objectives and organization of the MMS/LUMCON University Research Initiative (URI) in the Gulf of Mexico, reviews overall accomplishments, and presents a status report for the fifth and final year of the program.

Since the 1940s, the Gulf of Mexico region, and Louisiana in particular, has dominated offshore oil and gas production. From 1941 to 1991, Louisiana produced 84.5% of all the oil derived from U.S. federal offshore waters and 87.9% of the natural gas (Francois and Barbagallo 1992). These figures have not changed greatly. In 1991, Louisiana accounted for 83% of all the oil and condensate produced from the OCS and 75% of all natural gas production.

Clearly, the central Gulf of Mexico region is where most of the OCS oil and gas production lies within the United States. Because of the historical and future focus of offshore oil and gas development off Louisiana and Texas, the region serves as a living laboratory. The experience of over forty years intensive development can be used to guide prudent development elsewhere and minimize undesirable environmental and social impacts.

GOALS

The LUMCON-MMS University Research Initiative in the Gulf of Mexico has three long-term goals:

1. To identify and implement innovative ideas for studies of relevant environmental and socioeconomic effects, to foster interdisciplinary investigations of these issues in a peer-review environment, and to encourage and train students in research applicable to decision making,

2. To allow MMS to meet its established information needs by fostering multiple, interdisciplinary investigations as opposed to one or a few large efforts, and

3. To build intellectual and technical capacity within Louisiana's universities for research and problem-solving concerning offshore and coastal petroleum development.

This cooperative program seeks to approach these goals by supporting investigator-initiated research germane to one or more key framework issues. The university scientists are encouraged to propose novel approaches to their investigation. Proposals are subjected to internal and external review both in terms of scientific rigor and innovation and relevance to the identified issues. Research projects are supported at modest levels in comparison to typical MMS studies, but support may be provided over several years. Research projects under this program complement MMS' larger, multi-investigator studies by filling gaps in understanding, providing technological innovation, and testing concepts that may be addressed ultimately by larger MMS programs.

PARTICIPATING INSTITUTIONS

The Louisiana Universities Marine Consortium (LUMCON) is an organization of Louisiana's public universities, established by statute in 1979 to "conduct research and promote education in the marine sciences and marine technology, particularly where related to coastal resources and the impact of energy-related industries upon these resources." Thirteen public universities in the state are members of the Consortium. Affiliate members include five private institutions, one non-degree granting public institution, the Louisiana Association of Independent Colleges and Universities, and three state departments responsible for environmental and resource management.

CURRENT STATUS

The URI is currently in its final year and is operating under a no-cost extension to the contract that will expire 31 January 1995. The major tasks remaining are completion and publication of final project reports and publication of a compilation of the quarterly issues of the bibliography.
Fifteen of the final study reports have been published. The remaining seven are in draft form and at various stages of the editing process leading to publication. All are on schedule for publication before 31 January 1995.

SCIENTIFIC ACCOMPLISHMENTS

The University Research Initiative has produced valuable results for MMS, resulting in

- 22 research projects, providing significant new insights into the environmental and socioeconomic impacts of oil and gas development,
- 92 conference presentations,
- 68 journal articles,
- a new social sciences research agenda for MMS via a socioeconomic workshop,
- 58 new research proposals related to this program, with 35 funded to date,
- $11,970,000 in additional funding derived from related federal grants and private sources, and
- the involvement of 191 university students and junior researchers (60 graduate and 54 undergraduate students, 76 post-doctoral fellows and research assistants, and one award-winning minority high-school student).

CONCLUSIONS

The program has been successful in achieving the original goals set for it by MMS in 1988. The URI allowed researchers to address a variety of questions related to long-term, low-level impacts of oil and gas development and production on the OCS. It provided general conceptual guidance on subject areas of interest and then permitted considerable latitude in the formulation of proposals for specific studies to address the pre-defined framework issues. This approach stimulated and broadened the participation of the academic community, developed new concepts and directions within the MMS relating to the long-term impacts of oil and gas operations to be addressed.

Although much valuable research was conducted under the URI, much still remains to be learned about the long-term effects of oil and gas development on Louisiana's environmental and socioeconomic resources. Research in the living laboratory provided by over 40 years of offshore development in Louisiana is needed and should continue in order that we may fully understand its impacts and intelligently guide development in areas of future oil and gas exploration and production.

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THE RECOVERY OF A DELTAIC BARRIER ISLAND TO HURRICANE AND OIL SPILL IMPACTS IN COASTAL LOUISIANA

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ABSTRACT

The effects of two disturbances in the fall of 1992, Hurricane Andrew and the Greenhill Petroleum Corporation oil spill, on salt marsh recovery on East Timbalier Island were evaluated through a combination of landscape and community scale analyses. Landscape scale analysis indicated that the hurricane had a profound effect on the island's land cover and morphology. The analysis indicated that the oil spill had minimal effect on island vegetation. The landscape scale analysis detected changes in vegetative cover in areas where oiling occurred in 1992. The community-scale analysis detected fine-scale vegetative responses to the spill.

INTRODUCTION

Coastal Louisiana is a region of intense oil-and gas-related activities and is potentially subject to frequent oil spills that affect coastal marshes. Although many studies have focused on the immediate impact of oil spills on coastal marshes (Mendelssohn *et al.* 1990), longer-term impacts and the eventual recovery of these marshes from oil spills are not well documented. In addition, the confounding effects of natural disturbances on the recovery of coastal salt marshes from oil spills in unknown.

In 1992, Hurricane Andrew and the Greenhill Petroleum Corporation (GPC) oil spill impacted East Timbalier Island, Louisiana within one month of each other. East Timbalier Island, a deltaic barrier island in Southeast Louisiana is located in an area characterized by high rates of land loss and shoreline erosion. Initial reports indicated that both disturbances had negatively affected the salt marshes on the island. The impact of the natural and human-induced disturbance within such a short time period was evaluated regarding their potential impact on the island's vegetation and recovery from those impacts.

The overall goal of this study was to evaluate the effects of the GPC oil spill on East Timbalier Island with regard to salt marsh recovery and the extent to which this recovery was influenced by hurricane disturbance. Specific objectives were to (1) determine the impact and recovery of salt marshes on East Timbalier Island to the oil spill as a function of degree of initial oiling and residual surface and penetrated oil, and (2) document the impact of Hurricane Andrew on East Timbalier Island and its effect on salt marsh recovery to the oil spill. This paper is a summary of the research discussed in Debusschere *et al.* 1994.

METHODS

A combination of remote sensing/image analysis procedures, replicated field surveys, and quantitative field sampling was employed to assess the potential impact and subsequent recovery of East Timbalier Island to both disturbances. Large-scale changes in island geomorphology, marsh habitat, and oiling were documented with pre- and post-disturbance aerial imagery (1990, 1992, and 1993) in conjunction with field surveys (1992 and 1993). The data were mapped, analyzed, and processed for spatial and temporal variations in oiling and hurricane impacts.

The community scale assessment of recovery was based on a statistical evaluation of the degree to which the oil-affected areas had recovered (in terms of plant species composition, biomass, and percent cover), compared to adjacent reference marshes (hereafter referred to as unoiled marshes). This technique provided a quantitative and statistical assessment of residual oil effects on the vegetation and a measure of residual oil in the soil.

Table 1A.1. Summary of land cover area in square meters by land cover type for the study period.

Land Cover	1990	1992	1993
Vegetated Marsh	1,284,815	932,474	896,012
Vegetated Shrubs	121,007	96,946	101,159
No Vegetation	713,202	569,289	486,150
Submerged Washover	0	748,085	462,035
Water	334,018	61,217	54,233
Seawall	154,451	118,809	126,539
Marsh Platform	16,012	4,577	12,143
Intertidal	22,152	49,209	57,375
Inert Solid	6,335	4,053	4,212
Inert Liquid	5,065	4,246	4,001
Total Land Area	**2,300,888**	**1,730,394**	**1,630,216**

Table 1A.2. Land loss by land cover type in square meters between 1990 and 1993 for East Timbalier Island.

Land Cover	1990–1992	1992–1993	1990–1993
Vegetated Marsh	-352,341	-36,463	-388,804
Vegetated Shrubs	-24,061	-4,213	+198,848
No vegetation	-143,913	-83,138	-227,052
Submerged Washover	+748,085	-286,050	+462,035
Water	-272,801	+6,984	+279,785
Seawall	-35,642	+7,730	-27,912
Marsh platform	-11,435	+7,566	-3,869
Intertidal	+27,057	+8,165	+35,223
Inert solid	-2,282	+159	-2,123
Inert liquid	-820	-245	-1,064
Total Land Area	**-570,494**	**-100,178**	**-670,672**

Table 1A.3. Land cover change for East Timbalier Island between 1990–1992 and 1992–1993 in square meters.

LAND COVER CHANGE	1990-1992	1992-1993
Not Vegetated to Not Vegetated	291,348	342,088
Not Vegetated to Vegetated	126,062	92,424
Not Vegetated to Water	477,655	266,466
Change	**895,065**	**700,978**
Vegetated to Not Vegetated	232,155	83,967
Vegetated to Vegetated	842,230	813,242
Vegetated to Water	331,437	132,213
Change	1,405,822	1,029,422
Water to Not Vegetated	177,470	206,989
Water to Vegetated	62,087	91,508
Water to Water	117,573	560,007
Change	**357,130**	**858,504**

Table 1A.4. Summary of 1992 oil impacted areas on 1992–1993 land cover change map.

LAND COVER CHANGE	PERCENT
Percent Land Cover Change of Total Not Vegetated Oiled Area in 1992	
Not Vegetated to Not Vegetated	43
Not Vegetated to Vegetated	18
Not Vegetated to Water	39
Percent Land Cover Change of Total Vegetated Oiled Area in 1992	
Vegetated to Not Vegetated	5
Vegetated to Vegetated	80
Vegetated to Water	15
Percent Land Cover Change of Total Oiled Area in 1992	
Not Vegetated to Not Vegetated	14
Not Vegetated to Vegetated	6
Not Vegetated to Water	13
Vegetated to Not Vegetated	3
Vegetated to Vegetated	54
Vegetated to Water	10

RESULTS AND DISCUSSION

The landscape scale analysis indicated that between 1990 and 1992, East Timbalier Island land mass decreased by 25%; the island's shoreline changed from continuous to fragmented; and 56% of the island's land cover changed. Most of the land loss and land cover changes during the study period occurred in the mid section and on the east and west ends of the island. Between 1992 and 1993, changes in land area and land cover continued to be dramatic and were occurring in the same areas as between 1990 and 1992 where Hurricane Andrew's impact had reshaped the island's morphology.

The 1992 oiling data indicated that 26% of the island's land mass was impacted by oil. One year later, 0.19% of the island's land mass was impacted by oil. Only surface oil was observed during the 1992 surveys and in 1993 both surface and penetrated oil were present. The extent of area impacted varied significantly: a total of 379,307 m^2 of surface was oiled in 1992 from heavy to light categories. In 1993, 1,087 m^2 of the surface was lightly oiled and 11 m^2 was lightly penetrated.

The analysis indicates that the GPC oil spill had minimal large-scale effects on land cover. Much of the erosion that occurred between 1992 and 1993 is more likely due to natural erosion than oil impact. The analysis did identify some areas where oil seemed to have an effect on the land cover. These areas were located in the interior of a land mass or in sheltered areas. The analysis was not able to identify small areas where field surveys noted that oil did seem to have an effect on the land cover. Field surveys enhanced the remote sensing/image analysis of oiling and hurricane impacts.

From a community-scale perspective, dead aboveground biomass, live-to-dead biomass ratio, and dead vegetative cover were not sensitive evaluators for oil impact in this particular case. The community scale analysis was able to detect fine-scale vegetative responses. Live aboveground biomass was significantly lower in oiled compared to unoiled marshes at four of the nine marsh sites investigated; two marsh sites had significantly greater live aboveground biomass at the oiled locations compared to the unoiled, while the remaining marsh sites did not differ as a function of oiling. Vegetative cover generally showed similar trends as aboveground biomass. When plant biomass and cover were averaged over all marsh sites across the island, oiled marshes were not significantly different from unoiled marshes. Although site-specific impacts, apparently because of the oiling, were identified, marsh recovery was apparent as evidenced by similar vegetative responses between the oiled and unoiled marshes, when averaged over all marsh sites that were sampled.

CONCLUSIONS

The acute and longer term effects of Hurricane Andrew and the Greenhill Petroleum Corporation oil spill were evaluated from a landscape scale and community scale perspective. In general, the landscape scale analysis indicated that Hurricane Andrew had a dramatic effect on the morphology and land cover of the island. In addition, landscape scale and community scale analyses showed that the Greenhill Petroleum Corporation oil spill had minimal negative effect on the island vegetation.

More specifically this study demonstrated that:

On a landscape scale

- The East Timbalier Island land mass decreased by 25% between 1990 and 1992, most of which can be attributed to Hurricane Andrew.
- The East Timbalier Island shoreline changed from continuous to fragmented between 1990 and 1992, most of which can be attributed to Hurricane Andrew.
- Between 1990 and 1992, 56% of the island's land cover changed, most of which can be attributed to Andrew.
- Most of the land loss and land cover changes during the study period occurred in the mid section and on the east and west ends of the island.
- Changes in land area and land cover between 1992 and 1993 continued to be dramatic and were occurring in the same areas as between 1990 and 1992 where Hurricane Andrew's impact had reshaped the island's morphology.
- The analysis indicates that the Greenhill Petroleum Corporation oil spill had minimal large-scale effects on land cover.
- In 1992, 26% of East Timbalier Island's total land mass was impacted by oil.

- In 1993, 0.19% East Timbalier Island's total land mass remained oiled.
- Surface and oil penetration were present in 1993. Oil penetration occurred in areas where the oiling was classified as pooled in 1992.
- Much of the erosion that occurred between 1992 and 1993 is more likely because of natural erosion than oil impact.
- The analysis identified some areas where oil did seem to have an effect on the land cover. These areas were located in the interior of a land mass or in sheltered areas. The majority of those areas were located on the eastern end of the island.
- The analysis was not able to identify small areas where field surveys noted that oil did seem to have an effect on the land cover.
- Field surveys enhanced the remote sensing/image analysis of oiling and hurricane impacts.

On a community scale

- The analysis was able to detect fine-scale vegetative responses.
- Live aboveground biomass was significantly lower in oiled compared to unoiled marshes at 4 of the 9 marsh sites investigated.
- Two marsh sites had significantly greater live aboveground biomass at the oiled locations compared to the unoiled, while the remaining marsh sites did not differ as a function of oiling.
- Vegetative cover generally showed similar trends as aboveground biomass.
- When plant biomass and cover were averaged over all marsh sites across the island, oiled marshes were not significantly different from unoiled marshes.
- Dead aboveground biomass, live to dead biomass ratio, and dead vegetative cover were not sensitive evaluators for oil impact in this particular case.
- The analysis indicated that oiling appeared to have a more negative effect on the east end marshes while the west end marshes were more positively affected.
- Oil concentration in the soil was significantly greater in oiled versus unoiled marshes; however, no significant relationship between oil content in the soil and vegetative response could be identified 14 months after the spill event.
- Although site-specific impacts, apparently because of the oiling, were identified, marsh recovery was apparent as evidenced by similar vegetative responses between the oiled and unoiled marshes, when averaged over all marsh sites that were sampled.

These conclusions clearly indicate that the landscape scale and community scale analyses of East Timbalier Island's response to the Greenhill Petroleum Corporation support and complement each others findings. In addition, the landscape scale analysis was able to estimate the impact of the Hurricane Andrew on the island. Furthermore, this investigation indicated that the post-hurricane coastal processes controlling island morphology did not appear to have an effect on salt marsh recovery to the oil spill. This was probably due to the fact that the Greenhill Petroleum Corporation oil spill had minimal impact on the East Timbalier Island vegetation, while Hurricane Andrew had a dramatic effect on the island's morphology and land cover.

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SATELLITE BASED ASSESSMENT OF THE MISSISSIPPI RIVER DISCHARGE PLUME'S SPATIAL STRUCTURE AND TEMPORAL VARIABILITY

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INTRODUCTION

The Mississippi River is the major contributor of freshwater, sediments, pollutants, and nutrients to the northern Gulf of Mexico continental shelf and slope. These river inputs have important impacts on all aspects of continental shelf oceanography in the northern Gulf of Mexico. This study utilized five years of satellite information obtained by the NOAA Advanced Very High Resolution Radiometer (AVHRR) to quantify which areas of the continental shelf and slope of the Gulf of Mexico are subjected to discharges emanating from the Mississippi River on various time scales ranging from days to years. Correlation and multiple regression techniques were employed to identify the environmental forcing factors which most affect plume variability. Results of this study provide important information concerning suspended sediment distribution on the continental shelf, potential fate of riverborne contaminants, and circulation processes in the vicinity of the Mississippi River delta. The primary objectives of this research were

1. to determine which areas of the continental shelf and slope in the Gulf of Mexico are most influenced by riverborne sediments and pollutants of the Mississippi River through the Balize delta

2. to gain a better understanding of the environmental forcing factors controlling the distribution of river water and sediments in the northern Gulf of Mexico.

RESULTS AND DISCUSSION

Five years of digital data acquired by the Advanced Very High Resolution Radiometer (AVHRR) of the NOAA environmental satellites were used in this study. Reflectance information, derived from the visible channels, provided a quantitative means of defining the Mississippi River plume and was used as the primary database for this investigation.

The study area included much of the Gulf of Mexico, including but not limited to the area 25° to 31° N latitude, 86° to 92° W longitude. In year 1, a calibration algorithm relating satellite reflectances to suspended sediment concentrations was developed. The satellite image database was comprised of 113 NOAA-11 afternoon images, hand selected from over 3,000 images obtained at the Earth Scan Laboratory (ESL), Coastal Studies Institute, Louisiana State University between July 1988 and October 1993. The image database was used to investigate the spatial and temporal variabilities of plume morphology on various time scales. The environmental variables included in the study were river discharge, hourly wind data from the Burrwood C-man station, tidal phase and tidal range. The relationships between five plume measurements and these environmental variables were explored using correlation and multiple regression techniques.

Individual satellite images revealed that the Mississippi River sediment plume ranged in size from 822 km^2 under low river discharge conditions to 7,700 km^2 under high river discharge conditions. The sediment plume exhibited annual variability which was related to the annual river discharge cycle. The average plume for October 1989, a low discharge month, measured 2,058 km^2, less than one-half the area of the average plume for March/April 1989, during the spring flood. Although the time-averaged plume was found to be closely related to large variations in river discharge, tremendous day-to-day variability was observed which was unrelated to discharge.

Results of the correlation analyses revealed that the size and morphology of the Mississippi River sediment plume is influenced by several environmental forcing factors. The most important factors determining plume area were found to be river discharge, prevailing winds 12 hours prior to image acquisition, and wind speed. Tidal phase and range explained very little of the variability in plume area or morphology. Southeasterly winds confined the plume to the continental shelf and nearshore zone. The presence of westerly winds maximized the areal extent of the sediment plume west of the Balize delta throughout the year. During winter, northerly winds associated with eastward-moving winter storms increased the areal extent of the Mississippi plume and maximized the offshore dispersal of the suspended sediments. The presence of southerly and westerly winds increased the areal extent of the plume east of the delta as well as the extreme eastward extent of the plume.

Multiple regression techniques were employed in an attempt to use the relationships observed between the plume parameters and the environmental variables to help establish predictive models for plume variability. More success was obtained in predicting plume area than plume length. The best model was obtained for the eastern area from May through September when 70% of plume variability was explained by river discharge and local wind behavior. Plume area was found to increase in size under conditions of high river discharge and southerly or westerly winds. The largest sediment plumes east of the delta were observed after exposure to at least 12 hours of strong southwesterly wind forcing (8-10 m s^{-1}) when river discharge was high. In predicting the eastern extent of the sediment plume, local wind behavior was found to be more important than river discharge. The enormous sediment plume observed east of the delta in August 1993, subsequent to the Great Flood of 1993, provides an excellent example of how efficiently the surface sediment is dispersed towards the east under prolonged exposure to southerly and southwesterly winds. In this extreme case, so much Mississippi River water flowed onto the continental shelf east of the delta that a detectable amount reached the Florida Keys and the east coast of the United States, entrained by southward-flowing currents associated with the eastern edge of the Loop Current.

The second best predictive model was obtained for the western plume area during the summer months. In this case, 64% of plume variability was explained by river discharge, wind speed, and the east-west wind component. The western plume area was maximized during summer under conditions of high river discharge and weak to moderate westerly winds. During winter, a prevalence of northerly or westerly winds maximized sediment dispersal west of the delta. Strong northerly winds, associated with eastward moving winter storms, maximized the offshore transport and dispersal of plume water and sediments.

CONCLUSIONS

This study has demonstrated the all-important role of river discharge variations and wind forcing to the fate of river sediments from the Mississippi River delta in the northern Gulf of Mexico. In most cases, the plume's response to wind forcing was maximized after 12 hours. The multiple regression model results were encouraging and demonstrate that the plume's areal extent and surface morphology are somewhat predictable from readily accessible environmental variables. Further satellite-based research should incorporate information on the sub-surface characteristics of the plume.

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BIOTRANSFORMATION PATHWAYS OF HETEROCYCLES IN THE MARINE ENVIRONMENT. BENZO(F)QUINOLINE AND BENZOTHIAZOLE: POTENTIATION OF MOBILITY AND TOXICITY

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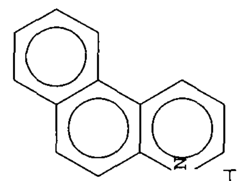
INTRODUCTION

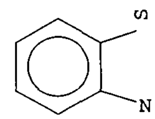
The purpose of continuing work in this laboratory for MMS is to examine degradation rates and pathways of N-, O-, and S- heterocycles (NOSHs) in marine sediments. NOSH compounds are found in petroleum, produced waters, coal chemicals, and pyrogenic mixtures (Catallo *et al.* 1992). Several NOSHs and their oxidation products are mutagenic, carcinogenic, and/or teratogenic (Catallo *et al.* 1992; Ho 1984).

Relative degradation rates have been determined for 19 prominent NOSH compounds under oxidized (aerobic) and reduced (anaerobic/methanogenic) electrochemical conditions in three marine sediments (Catallo 1994). In the course of work, degradation pathways for several NOSHs were inferred from analysis of transformation products using gas chromatography-mass spectrometry (GC-MS). Sediment microbes capable of degrading NOSHs were isolated during these experiments. To facilitate accurate identification of the NOSH degradation products and evaluate their potential toxicity and mobility *in situ*, methods were developed to synthesize several compounds in deuterated form for use as tracers. Access to both protiated and deuterated homologs allows for isotopic dilution mass spectrometry and tracer studies to be undertaken in microbial cultures and environmental matrices (*e.g.*, marine sediment/water).

CASE STUDIES

Sediments (fine-grained estuarine mud) were collected from coastal marine systems in Bay St. Louis Mississippi. The sediments were added to sealed teflon and glass reactors as slurries and maintained under oxidized (aerobic) or reduced (anaerobic methanogenic) electrochemical conditions in the laboratory. Benzo(f)quinoline (I) and benzothiazole (II) are present in petroleum and produced water,

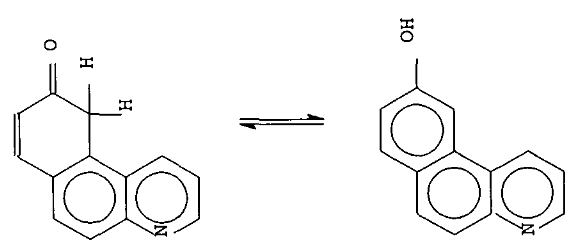

I


II

and are of interest because of their reactivity and toxicity. Both I. and II. were synthesized in deuterated form using the HTDA method (Werstiuk and Kadai 1974) or *de novo* syntheses starting with commercial deuterated precursors.

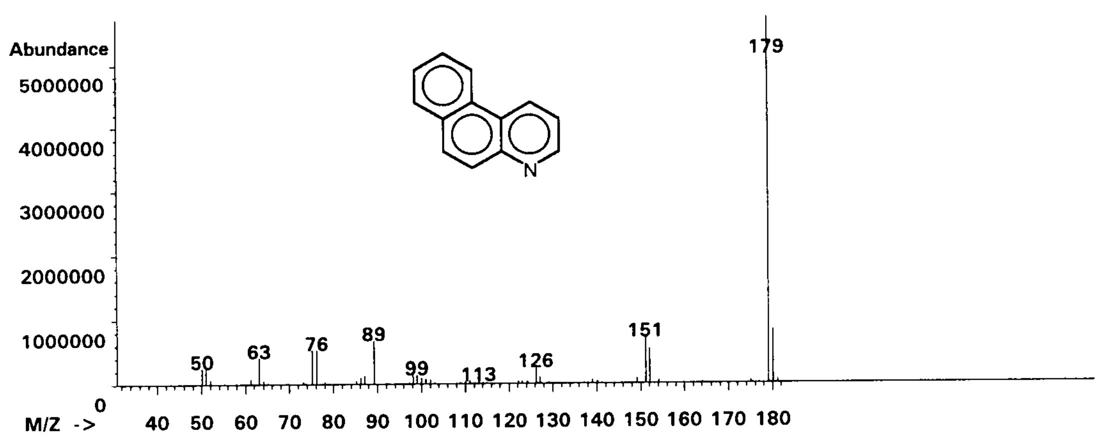
Mass spectra for the protiated and deuterated homologs of I. and II. are shown in Figures 1A.1 and 1A.2. The protiated and deuterated compounds were added to oxidized and reduced sediment/water followed by equilibration for several months. Samples were collected periodically over the incubation period, followed by solvent extraction and quantitative analysis using GC-MS.

With respect to I., a major stable metabolite observed was a polar compound with a molecular ion at m/z 195 (Figure 1A.3A). The mass spectrum suggested that the identity of this metabolite was 5(H)-6-benzo(f)quinoline-one, although the corresponding phenol also would be consistent:



Benzo(f)quinoline oxidation products consistent with the mass spectrum shown in Figure 1A.3A (m/z 195).

A



B

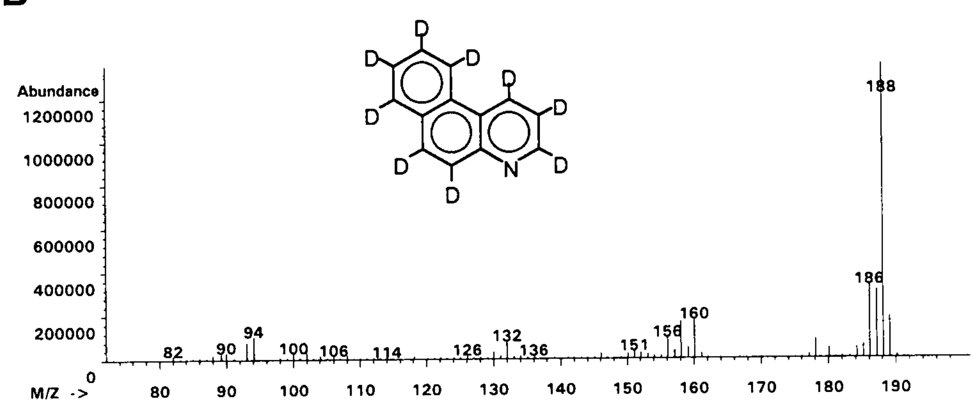


Figure 1A.1. Mass spectra of protiated (A) and deuterated (B) benzo(f)-quinoline homologs.

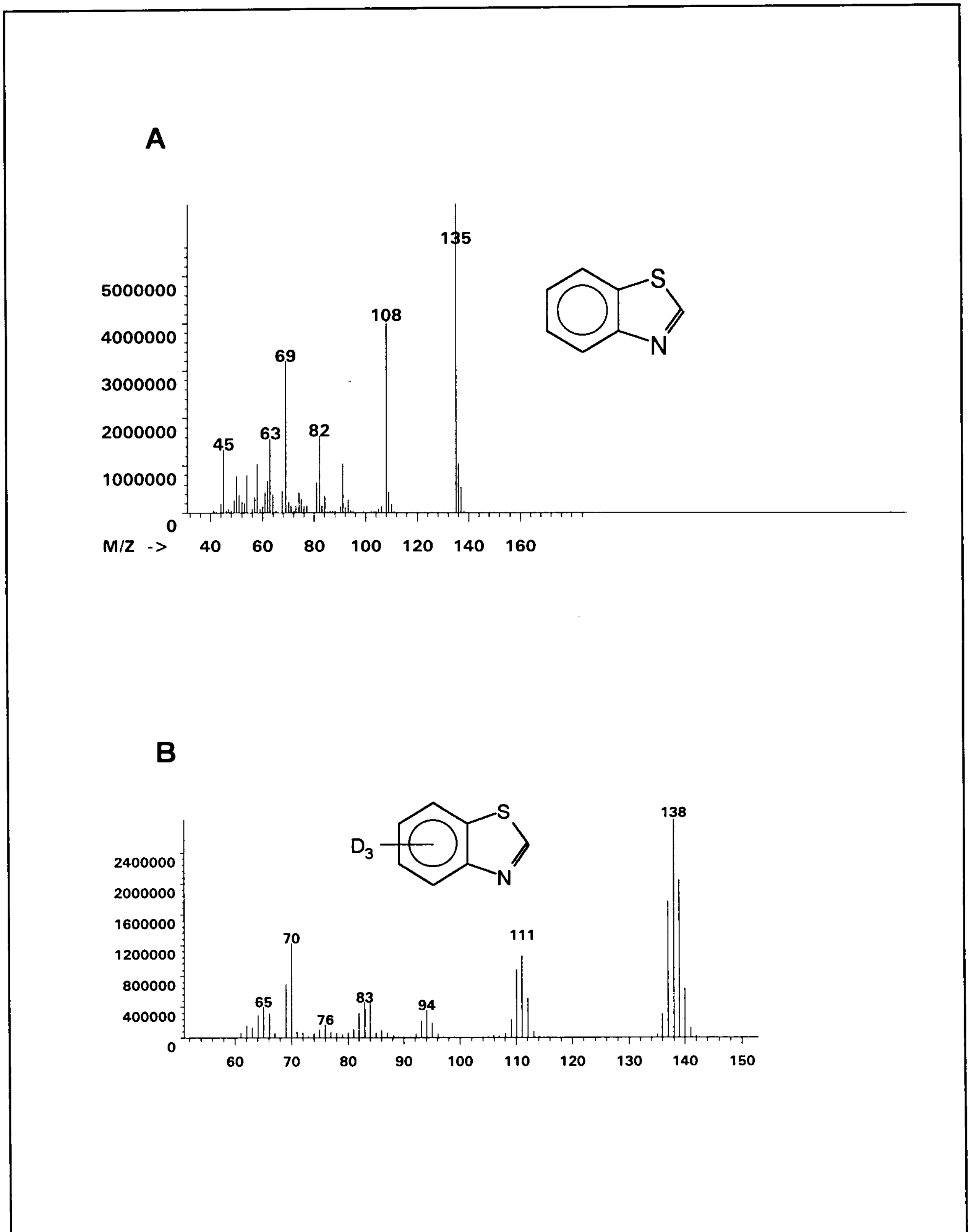


Figure 1A.2. Mass spectra of protiated (A) and deuterated (B) benzothiazole homologs.

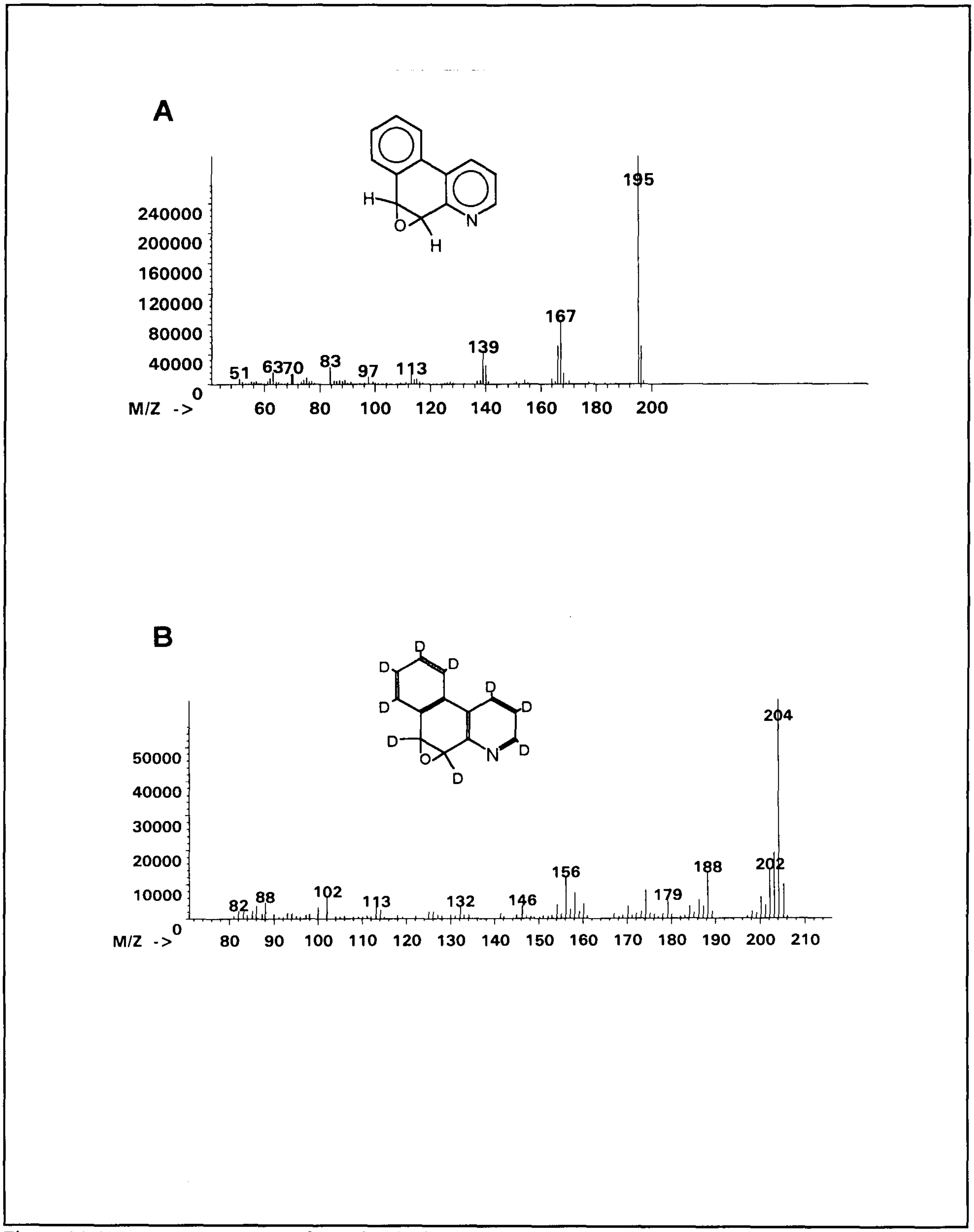


Figure 1A.3. Mass spectra of protiated (A) and deuterated (B) microbial oxidation products of benzo(f)quinoline.

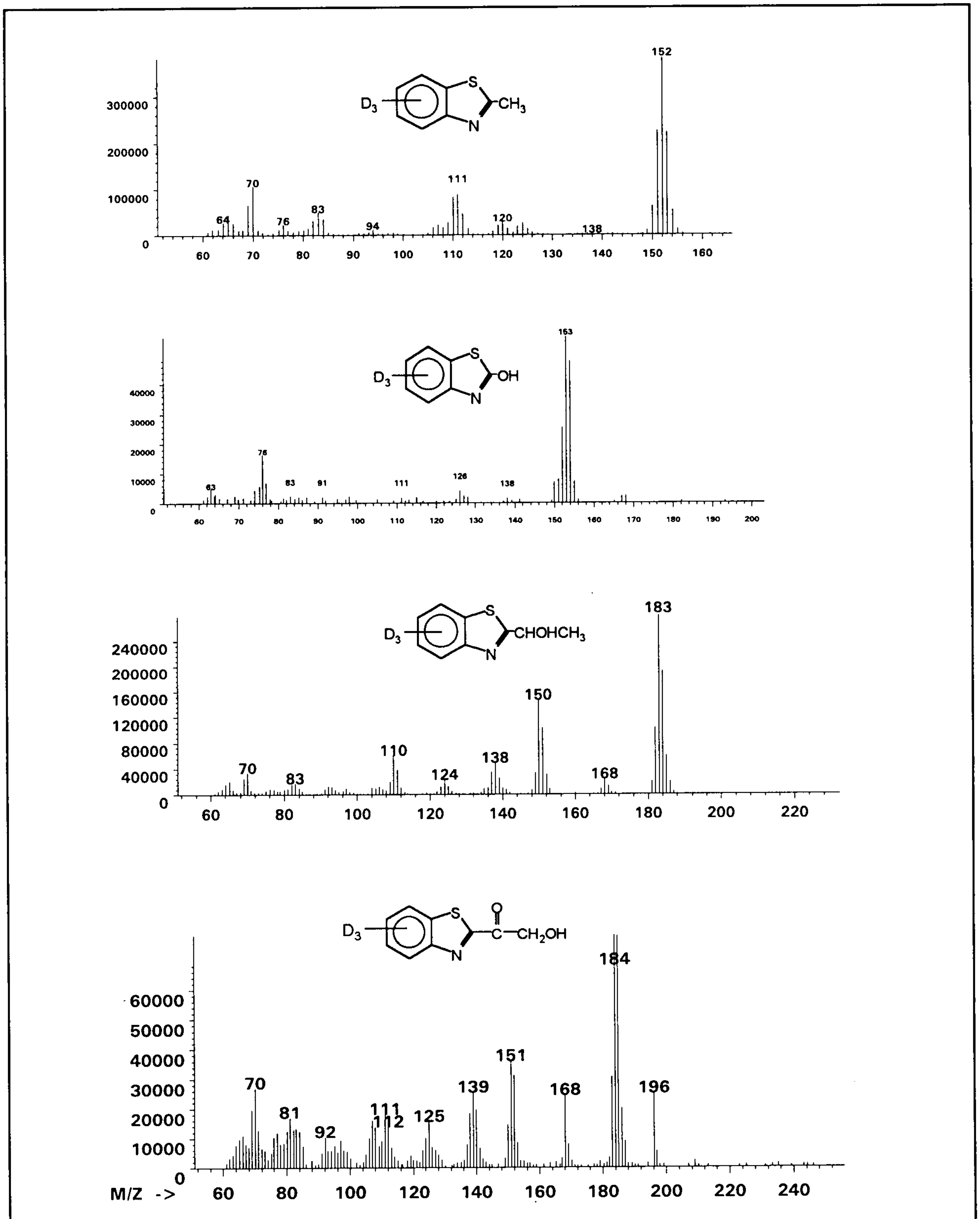


Figure 1A.4. Mass spectra of microbial transformation products of benzothiazole from deuterated tracer experiments.

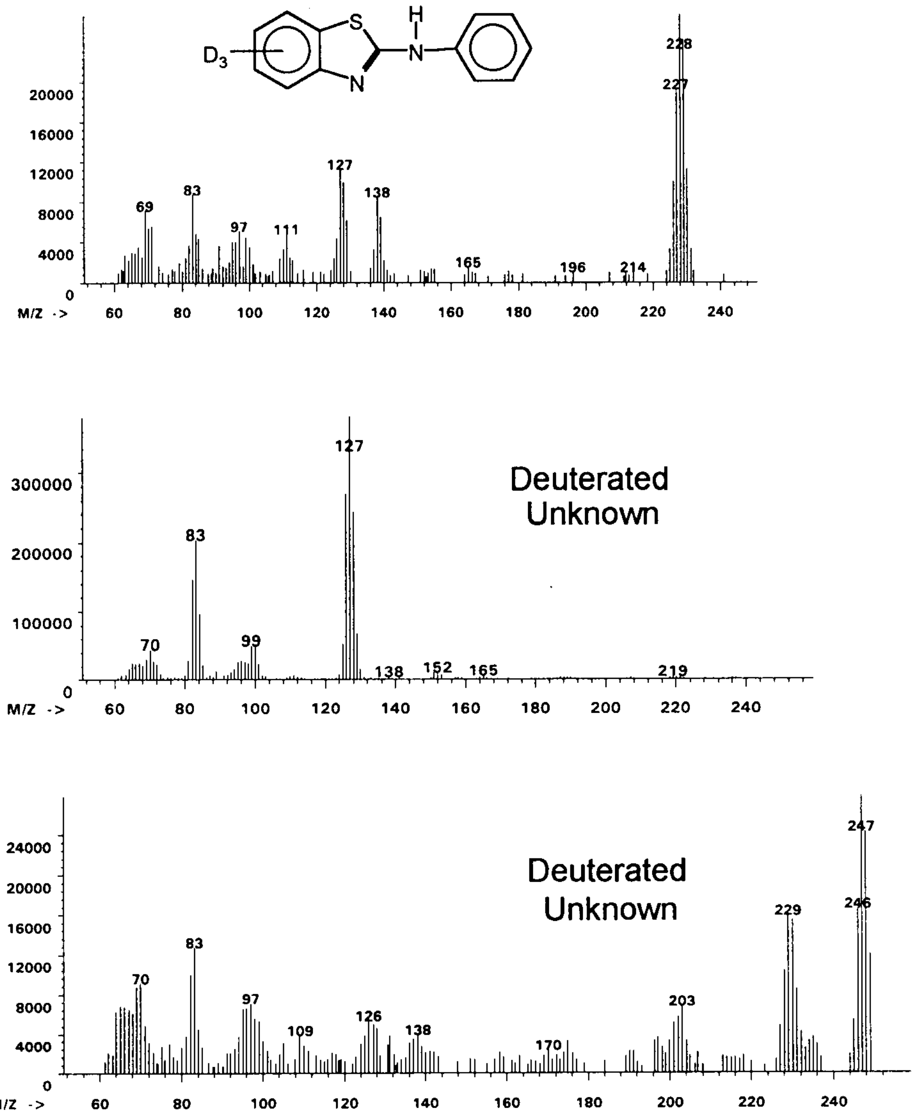
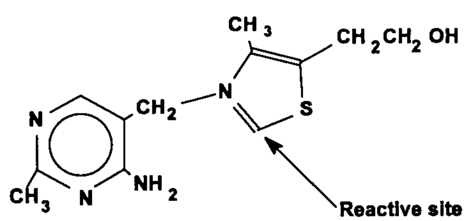


Figure 1A.5. Other deuterated compounds observed in the tracer runs of benzothiazole.

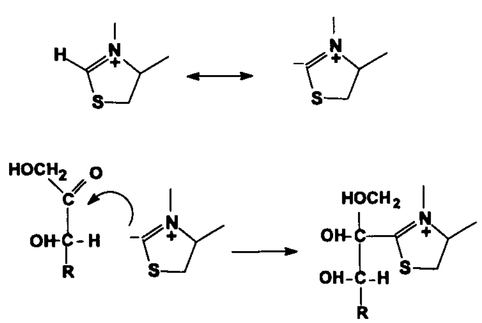
Parallel runs using the deuterated homolog of I. (Figure 1A.1B) also produced a major oxygenated product with the same retention time as the protiated compound. But mass calculations showed that a ketone or phenol derivative of the deuterated compound would have a molecular ion of m/z 203, which was not found. The only structurally consistent product with appropriate masses in both protiated and deuterated experiments is benzo(f)quinoline epoxide, probably the 9,10 epoxide (shown in Figure 1A.3B, the corresponding protiated system is shown in Figure 1A.3A). These epoxides are of interest because they are similar to precursors of known carcinogens and teratogens.

The mass spectra of protiated and deuterated II. are given in Figure 1A.2. In general, the main metabolic products of II. were alkylated and glycolated benzothiazoles, with smaller amounts of oxidized species also present (Figure 1A.4). These transformation products are very similar to those seen in biochemical reactions of thiamine, which has a thiazole ring active site:



Thiamine (Vitamin B1)

Intermediates these reactions *in vivo* can include reduced thiazole and its alkyl substituted homologs including glucoaldehydes and thiols:



The products of benzothiazole and its deuterated homolog in marine sediments were precisely of these types (Figure 1A.4), and this suggested that benzothiazole competed with thiamine for enzyme active sites (e.g., in transketolase). A range of other deuterated compounds were observed in the tracer runs of benzothiazole, but these have not submitted to identification (Figure 1A.5). There also was evidence of biochemical oxidation reactions which gave rise to heavy addition products including anilobenzothiazole and dimeric bis-2,2'-benzothiazole. These products and the results of subsidiary experiments indicated that $1H^+/1e^-$ oxidations of benzothiazole at the acidic 2-proton were followed by recombination to the dimer or reaction with other amines, including aniline.

RELEVANCE

A fundamental goal of biodegradation research is to understand the transformation pathways of toxic chemicals under conditions found in nature. Once understood mechanistically, the environmental effects from pollutants can be more adequately anticipated, and affected systems can be manipulated in ways that may promote the removal of inhibitory or toxic products.

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OIL AND GAS DEVELOPMENT AND COASTAL INCOME INEQUALITY: A COMPARATIVE ANALYSIS

Dr. Charles M. Tolbert
Louisiana State University Agricultural Center

INTRODUCTION

This research was conducted as part of the University Research Initiative (URI). The URI was sponsored by the Louisiana Universities Marine Consortium (LUMCON) through a contract with the Minerals Management Service.

OVERVIEW OF KEY FINDINGS

This research employed parish- and county-level data from the 1970, 1980, and 1990 censuses in a comparative analysis of family income inequality. We focused on the analysis of trends in family income inequality in coastal Louisiana parishes adjacent to the substantially developed Outer Continental Shelf (OCS). With a comparative analysis design, we examined inequality trends in Louisiana parishes and in coastal counties of the Florida panhandle where there has been no significant onshore or offshore development of oil and gas resources. Inequality trends in the parishes and counties along the Gulf of Mexico were also compared to statewide family income inequality in Louisiana and Florida.

The analysis framework enabled a temporal comparison across key decades in the recent history of the oil and gas industries. While the decade of the 1970s was one of rising oil prices and greatly expanded oil and gas development, the 1980s saw prices fall and industry activity generally decline. Income inequality was gauged with multiple measures of inequality computed with decennial census data.

An initial review of per capita income and median family income figures indicated lower 1970 income in Louisiana parishes than in Florida counties. By 1980, the income relationship in coastal areas was reversed, with Louisiana parishes generally exhibiting higher incomes—some precipitously higher—than Florida counties. Louisiana statewide and coastal 1990 incomes, however, were well below those of Florida. After taking inflation into account, coastal 1990 median family income levels in Louisiana were actually lower than they were in 1970 (see Figure 1A.6).

A comparative inequality analysis revealed very different patterns of income inequality for statewide and coastal areas of Florida and Louisiana. While Florida inequality primarily trended downward across time, inequality in Louisiana exhibited a great deal of volatility and, by 1990, was higher than in 1970 in several cases. The Louisiana patterns suggest a substantial impact of oil and gas development on coastal families in the middle to upper, middle portions of the income distribution. Sample results targeting the middle of the income distribution with the Atkinson (1970) inequality measure are presented in Figure 1A.7.

The inequality patterns suggest that the Kuznets (1955) hypothesis does hold for the decennial census years 1970-1980 that approximate the oil and gas industry expansion period. At the state level and in the coastal parishes, Louisiana income inequality declined. Though Kuznets did not focus on the case of a decline in development, the contraction of the oil and gas industry brought about a corresponding increase in inequality.

In the modeling phase of the analysis, we attempted to account for these inequality patterns by controlling for important factors known to influence inequality. At best, the models accounted for roughly half the variance in the observed inequality. Moreover, through these modeling procedures, we were unable to eliminate the sharp differences between coastal Louisiana parishes and panhandle counties of Florida or the volatility in the Louisiana patterns. Education, race, industry mix, and the national economy simply do not account for the volatility or trends in Louisiana inequality patterns. When we control for these factors, a boom and bust pattern that corresponds to the expansion and contraction of the oil and gas industry is still evident.

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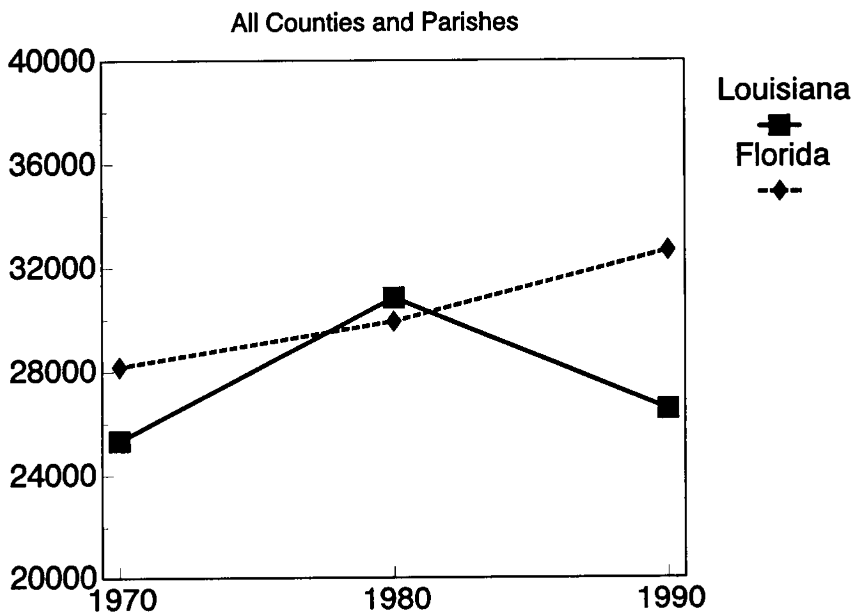

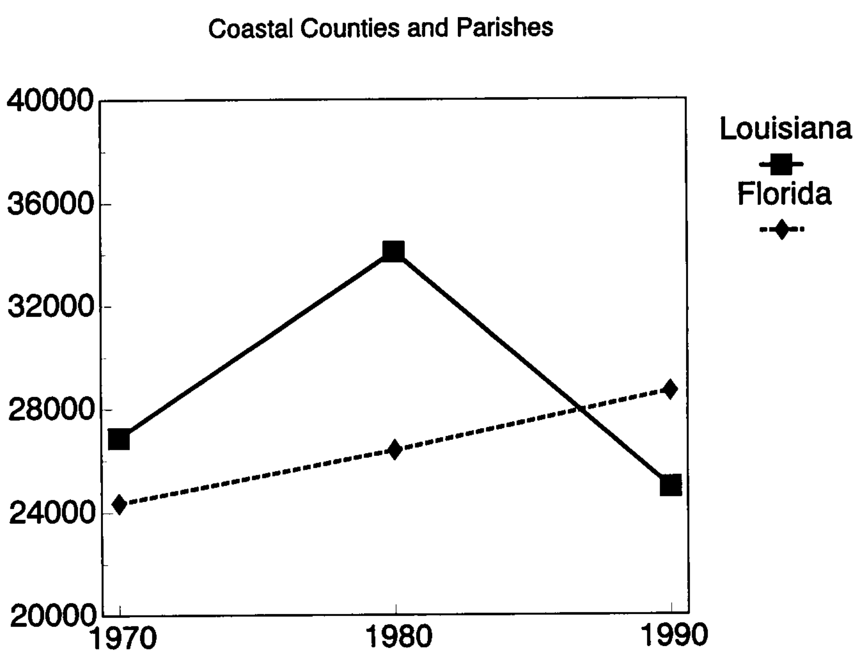

Figure 1A.6. Statewide and Coastal Median Family Income: 1970, 1980, 1990 (1990 Dollars).

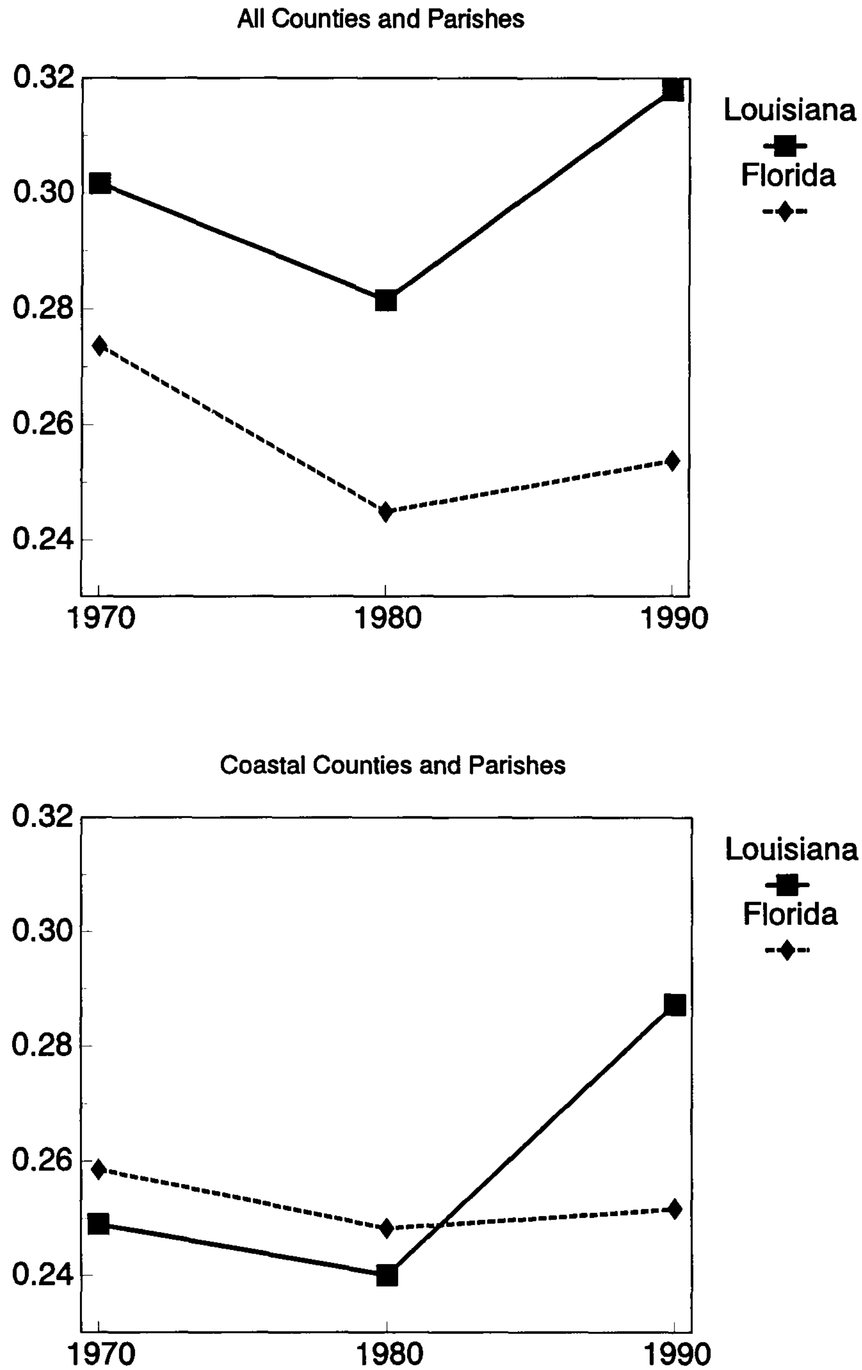

Figure 1A.7. Statewide and Coastal Income Inequality: 1970, 1980, 1990. Atkinson Measure (1.0).

Dr. Charles M. Tolbert is Professor of Sociology and Rural Sociology at LSU and is Senior Research Scientist at the Louisiana Population Data Center. He specializes in socioeconomic research, including employment, earnings, and industrial organization. He came to LSU in 1992 after 11 years in the Department of Sociology at Florida State University, where he served as chair from 1988 until 1992. He received his Ph.D. from the University of Georgia in 1980. His research has been supported by the Economic Research Service (U.S. Department of Agriculture), the Louisiana Agricultural Experiment Station, the Minerals Management Service, and the National Science Foundation.

SESSION 1B

CONSERVATION AND ENVIRONMENTAL AWARENESS

Session: 1B - CONSERVATION AND ENVIRONMENTAL AWARENESS

Co-Chairs: Ms. Carla M. Langley and Dr. Pasquale F. Roscigno

Date: November 15, 1994

Presentation	Author/Affiliation
Introduction	Ms. Carla M. Langley Dr. Pasquale F. Roscigno U.S. Minerals Management Service Gulf of Mexico OCS Region
MMS CARE Award Program: Overview and Highlights	Mr. Villere Reggio U.S. Minerals Management Service Gulf of Mexico OCS Region
Coastal America - A Partnership for Action	Mr. Jim Ratterree U.S. Environmental Protection Agency Region VI
Sea Turtle Strandings Along the Texas Coast During 1994	Ms. Donna J. Shaver National Biological Survey Southeastern Biological Science Center Padre Island National Seashore
Handshakes Curb Heartaches: Cooperation the Key to Conservation at the Flower Gardens	Dr. Stephen R. Gittings Mr. Christopher L. Ostrom National Oceanic & Atmospheric Administration Sanctuaries and Reserves Division
A Clockwork Orange: The Trans-Gulf Migration of the Monarch Butterfly	Dr. Gary Noel Ross President, Baton Rouge Audubon Society
No manuscript submitted	Mr. Harold Schoeffler Sierra Club State Conservation Chair
The Louisiana Program: Programmatic Overview	Mr. Rik Kasprzak Louisiana Wildlife and Fisheries Rigs to Reefs Program

INTRODUCTION

Ms. Carla M. Langley
Dr. Pasquale F. Roscigno
U.S. Minerals Management Service
Gulf of Mexico OCS Region

The primary focus for this session is to address conservation issues to enhance environmental awareness in the Gulf of Mexico region. The speakers for this session are affiliated with federal, state, and private sectors with backgrounds in the environmental field. Presentation topics discussed within the speakers' respective areas of expertise focus on the interrelationships of OCS oil and gas activities and environmental conservation.

Ms. Carla M. Langley is an environmental scientist in the MMS Environmental Studies Section in New Orleans where she oversees publications coordination and information transfer. She is a graduate of the University of New Orleans in Louisiana.

Dr. Pasquale F. Roscigno is a program manager in the MMS Environmental Studies Section in New Orleans. Previously he held several positions in the Department of the Interior's Fish and Wildlife Service.

MMS CARE AWARD PROGRAM: OVERVIEW AND HIGHLIGHTS

Mr. Villere Reggio
U.S. Minerals Management Service
Gulf of Mexico OCS Region

INTRODUCTION

The Minerals Management Service (MMS) has established a Conservation Award for Respecting the Environment, better known as the CARE Award. The CARE Award recognizes and champions exemplary actions and accomplishments by those private companies engaged in offshore energy development and that support the broader conservation and environmental goals of the nation, the Department of the Interior, and the coastal states. Although MMS currently has a Safety Award for Excellence (SAFE) program that has environmental protection as a stated purpose, the focus of that program is to protect the human and natural environment by avoiding accidents and pollution through adherence to safety and environmental protection regulations and guidelines. There are many opportunities, however, to go beyond these requirements and invest time, capital, and human resources specifically to enhance the environment or to cooperate voluntarily with others seeking solutions to onerous environmental problems resulting from multiple use of the marine environment. The CARE Award program has been established to acknowledge that such efforts and investments are worthy of recognition and appreciation.

PROGRAM OBJECTIVES

Establishment of the CARE Award seeks to achieve the following objectives:

A. Recognition of outstanding environmental accomplishments by companies involved in Outer Continental Shelf (OCS) activities.

B. Endorsement of the concept that conscientious environmental concern and initiative can be good business and good public relations.

C. Resolution of environmental problems without undue regulation.

D. Demonstration that energy development and environmental conservation can be mutually supportive.

E. Encouragement of cooperation between private industry, environmental groups, and government to achieve conservation and environmental goals.

SCOPE

The CARE Award is presented on the regional level for projects or actions occurring on the OCS or within the Gulf States. Presentation is judged on the guidelines outlined in Section IV. The CARE program is focused toward OCS lessees and operators but may be extended to any private company involved with offshore operations that warrants environmental distinction. The CARE Award is honorary and will be presented annually, if warranted, by the Gulf of Mexico Regional Supervisor, Leasing and Environment. Conservation achievements resulting from required mitigation actions are not eligible for the Minerals Management Service CARE Award.

SELECTION GUIDELINES

Guidelines considered in making recommendations for the CARE Award include the following:

A. Relevancy—The nominee's achievement(s) assist(s) the Department and coastal States in implementing a particular and timely conservation or environmental policy, program, goal, or philosophy.

B. Leadership—The nominee's achievement(s) establish(es) a precedent or an improved, new way of doing business likely to be copied by other companies with similar environmental problems or opportunities.

C. Scope of influence—The nominee's achievement(s) has (have) regional or national application or contribute(s) to enduring appreciation, understanding, enhancement, preservation, or use of our natural resources.

D. Innovation—The nominee's achievement(s) involve(s) the use of new technology, approaches, or methods environmentally superior to standard methods and practices.

E. Commitment—The nominee's environmental/conservation achievement(s) require(s) significant time, money, effort, or company resources.

SELECTION PROCEDURES

The CARE recipient is selected from a field of nominees by an MMS committee.

A. Nomination of Candidates—Nominations of appropriate candidates for a CARE Award will be solicited by MMS from environmental groups, state and federal agencies, private industry, OCS Advisory groups, the MMS regional staff, and others. Companies are encouraged to nominate themselves. Each nomination should meet one or more of the guidelines for selection discussed in Section IV.

Nomination should be solicited by MMS three months prior to the planned award presentation date. All nominations should be provided to the MMS Regional office within one month after the call for CARE Award nominations. The award presentation date may vary from year to year as this date will be determined on an annual basis by the MMS. Selection of the CARE award presentation date should be made well in advance, and nominators and nominees should be so notified. Although the award will, if warranted, be presented annually, candidates nominated for the award can be considered for environmental contributions preceding the current calendar year. However, once a candidate has received an award for a project(s), that candidate will be judged in future calendar years only on the merits of those activities conducted after the date the award was received. Nominees not selected as recipient of the CARE Award can be considered, based on environmental contributions for which they are previously nominated, if renominated for future awards. A file will be maintained on each company nominated, and the selection committee will consider the cumulative achievements of each nominee in recommending annual selections.

Recommendations should be submitted on an official Minerals Management Service CARE Award nomination form (Section VII), along with a letter or memorandum not to exceed three pages, providing justification for the nomination of the candidate on the basis of the company's environmental contribution(s). The transmittal letter and nomination form will constitute the essential elements of a CARE Award nomination. Supporting documentation can be included as an attachment when such documentation will provide more insight into the company's achievement or the selection rationale.

B. Selection of CARE Award Recipient—A selection will be made by the MMS Regional Director from recommendations provided by a selection committee chaired by the Regional Supervisor, MMS, Leasing and Environment (LE). The selection committee will be comprised of section chiefs, MMS (LE), and other discretionary members within the MMS or United States Department of the Interior. The use of discretionary members will be decided upon by the selection committee chairman. The selection committee is responsible for evaluating the recommendations submitted by the nominees. All information presented in the recommendations will be considered. In order to verify and supplement the recommendations, the selection committee may consult with representatives of other federal and state agencies, and other interested parties, as well as nominees and nominators.

The selection committee shall identify the selection for the CARE Award, via memorandum to the Regional Director, one month after receiving nominations. The selection memorandum shall provide appropriate details of the justification used for the selection. If a candidate is not chosen for that calendar year, a memorandum of explanation shall be submitted in accordance with the above procedures. Within five working days from receipt of the selection, the Regional Director should inform the selection committee chairman regarding his decision for concurrence.

After concurrence is received, the selection committee is responsible for procuring the appropriate memento for the CARE Award recipient and for preparing the final written documentation to be presented along with the award. The CARE Award selected for the recipient should relate to the nominee's environmental contribution(s) and should be suitable for display. The selection committee will prepare the final written documentation and the chosen award for presentation no less than three days prior to the designated presentation date. The successful candidate and nominator will be notified of the selection along with the date, time, and place of the award conveyance several weeks prior to the scheduled presentation.

AWARD PRESENTATION

The Regional Supervisor will formally present the award to the winner on an annual basis. Date and time of presentation will be determined by the selection committee with special consideration to the best interest of the recipient.

Mr. Villere Reggio, Jr., has been an Outdoor Recreation Planner with the U.S. Department of Interior's Leasing and Environment division of the OCS Program for almost 20 years. His responsibilities include investigation, assessment, and reporting on the interrelationship of the offshore oil and gas program with the recreational elements of the marine and coastal environment throughout the Gulf of Mexico region. Mr. Reggio was instrumental in developing and establishing the MMS CARE Award Program, and has served as the CARE Award Program Manager for the Gulf Region since the Program's inception since 1987.

CARE Award Nomination Form

Nomination Form

CONSERVATION AWARD FOR RESPECTING THE ENVIRONMENT

MMS CARE AWARD

Date ______________________________

PART I: GENERAL INFORMATION

Company Nominee's Name including Division or other subgroup:

____

Nominee's Address ____

____

City State Zip Code

Contact in Nominee's Organization ______________________________

TITLE ____

Daytime Phone Number ( ) ______________________

Type of Organization (Establish relationship to offshore oil and gas business)

[ ] Lessee [ ] Operator [ ] Service Company [ ] Other (Specify) ______________

Person Submitting Nomination:

Name ____

Address ____

____

City State Zip Code

Daytime Phone Number ( ) ______________________

Affiliation ____

PART II: JUSTIFICATION

Responses should be concise. If additional space is required please continue on a separate sheet of paper with reference to the appropriate location on the nomination form.

1. DESCRIPTION: Provide a general description of the nature of the nominee's achievement(s) warranting consideration for recognition under the MMS CARE Award. (This can be incorporated into a transmittal letter but should not exceed two or three pages.)

2. RELEVANCY: Explain how a conservation or environmental policy, program, goal, or philosophy was advanced by the nominee's action(s) or achievement(s).

3. LEADERSHIP: Did the nominee's achievement(s) establish a precedent likely to be adopted by others? Explain.

4. SCOPE OF INFLUENCE: Did the nominee's achievement(s) have Regional or National application or contribute to enduring appreciation, understanding, enhancement, preservation, or use of our natural resources?

5. INNOVATION: Did the nominee's achievement(s) involve the use of new technology, approaches, or methods environmentally superior to standard methods and practices? Explain.

6. COMMITMENT: Provide available quantitative information indicating the time, money, effort, or company resources invested in attaining the nominees's achievement.

PART III: OPTIONAL SUBMISSIONS (5 page limit)

You are encouraged to append new articles or published materials further describing the nominee's environmental/conservation achievement(s) that are the subject of this nomination. Photographs and an indication of other recognition received by the nominee for this accomplishment would also be appreciated if available or known.

Note: Environmental/conservation achievements resulting from legally required actions are not eligible for the MMS CARE Award.

Mail Completed Nominations to:

MMS Care Award
Regional Supervisor
Leasing and Environment
1201 Elmwood Park Boulevard
New Orleans, Louisiana 70123-2394

COASTAL AMERICA - A PARTNERSHIP FOR ACTION

Mr. Jim Ratterree
U.S. Environmental Protection Agency
Region VI

Coastal America began in fiscal year 1992 as a collaborative, multi-agency partnership to address environmental problems along the nation's coasts. The partners include the federal agencies with principal responsibility for the stewardship of coastal resources, those with responsibilities for infrastructure development, and those whose activities impact the coastal environment: the Departments of Agriculture, Air Force, Army, Commerce, Energy, Housing and Urban Development, Interior, Navy, and Transportation, the Environmental Protection Agency, and the Executive Office of the President. The concept originally envisioned pooling of fiscal resources from individual agency appropriations, to be used to implement projects on a competitive basis. However, due to government-wide streamlining and cutbacks, Coastal America has been compelled to evolve into an effective project endorsement process.

The partnership integrates federal capabilities with state, local, and non-governmental efforts to address habitat loss and degradation, non-point source pollution, and contaminated sediments, and essentially provides: 1) a mechanism for leveraging resources, expertise, and authorities; 2) a collaborative, problem-solving focus that expedites initiatives; 3) a consensus-building process that avoids conflicts; 4) a philosophy that encourages cost-efficient, creative solutions; and, 5) an action-oriented approach that achieves results. A Memorandum of Understanding signed by the 11 federal agencies outlines the operational framework, goals, and objectives of the partnership. The partnership is guided by a Principals Group, comprised of sub-cabinet level representatives of the signatory agencies, and by a National Implementation Team and nine Regional Implementation Teams (RITs), comprised of senior-level representatives from the partnership agencies.

Over the past three years, Coastal America has established an innovative, collaborative process that has encouraged national policy formulation, regional planning, and local project implementation. At the national level, the partners have resolved policy conflicts and corrected program directives that inhibited collaborative action. For example, a policy preventing the beneficial use of dredged material for wetland restoration was modified and a broader legislative solution was implemented which encouraged the use of dredged material for habitat creation.

At the regional level, the RITs are empowered to work through existing authorities to set regional agendas for the Coastal America priorities. Individual regional strategies have been developed to focus and prioritize multi-agency efforts. The strategies range from restoring habitat while developing transportation routes along the coast to targeting critical coastal watersheds for coordinated restoration projects.

At the local level, the partnership teams have pooled financial resources, technical expertise, and legislative authorities to implement projects no agency could accomplish alone. Project concepts endorsed by the regional teams are placed on a working list for priority funding, and partner contributions are solicited. To be eligible for endorsement consideration a project must 1) be action-oriented, with a focus on habitat loss and degradation, non-point source pollution, or contaminated sediments; 2) include at least three federal partners and one non-federal participant; and, 3) include education/outreach and monitoring components.

Although the partnership is relatively new, it has already proven to be cost effective: resources have been leveraged, implementation efforts have been expedited, and environmental improvements have resulted. More than 20 federal agencies and 150 non-federal organizations are now participating in Coastal America projects. In its first year, 1992, the partnership initiated 24 projects, valued at over $12 million, in 15 states, with over one-half of the funds contributed by non-federal partners. In 1993, the partnership initiated an additional 43 projects, valued at approximately $18 million, in 17 states. These efforts have resulted and will continue to result in the restoration of thousands of acres of wetlands; the reestablishment of hundreds of miles of spawning streams; and, the protection of coastal birds, anadromous fish, and marine mammals.

The Gulf of Mexico Regional Implementation Team (GMRIT) is composed of federal and state agency representatives from the five Gulf Coast states of Alabama, Florida, Louisiana, Mississippi, and Texas. It has had a distinct organizational advantage over the other eight Regional Implementation Teams, since its formation in May 1991, due to the existence of the Gulf of Mexico Program (GMP), which features a highly structured and well-supported committee system. Because the Coastal America partners have been active participants in the GMP, a spirit of cooperation and a sense of organization was established almost from the very beginning of the GMRIT. Consequently, attention was turned immediately to the task of identifying projects eligible for Coastal America endorsement consideration, rather than expending energy on establishing rules of order or defusing conflict arising from individual parochial concerns. Also, members were anxious to lay the foundation for devising a mechanism to implement projects aimed at correcting problems identified by the GMP committees.

The GMRIT is at the forefront of the RITs in its makeup and philosophy. The five Gulf states' representatives sit on the RIT as equal voting members. Recently, non-governmental organizations have been invited to participate in the project identification and implementing process. Two Gulf Region projects have been cited by the NIT as excellent examples of the Administration's emphasis on sustainable development and ecosystem management.

The GMRIT Regional Strategy is among the more flexible and innovative of the nine regional strategies. The geographic focus is the entire Gulf of Mexico. Projects are endorsed, but not prioritized, so as not to detract from a project's opportunity to be funded through an existing mechanism. In addition, to receive GMRIT endorsement a project must:

1. Include the national Coastal America eligibility requirements;
2. Have at least one federal sponsor, strongly committed to securing project funding or to developing an implementation strategy;
3. Have a project success assessment and reporting mechanism; and,
4. Be formally submitted to the GMRIT by the primary federal sponsor for endorsement (subject to existing federal and state laws and regulations), which must be unanimous.

Three projects lists are maintained by the GMRIT chair: a Completed Projects List, a Endorsed/Funded Projects List, and an Endorsed/Unfunded Projects List. To date, eight projects have been completed, 12 are on the funded list, and 19 are on the endorsed list. Since 1991, over 200 projects have been considered.

To improve the project endorsement and implementation processes, the GMRIT recently devised a project success assessment mechanism (for those projects that are similar in scope to previously completed or funded projects) and a non-governmental organization participation strategy.

Mr. Jim Ratterree has worked at EPA, Region 6, as an Environmental Scientist for the past eight years, the last four in the Marine and Estuarine Section. Prior to that he was employed with the Department of the Interior and Federal Energy Regulatory Commission in Washington, D.C.; the Bureau of Reclamation in Amarillo, TX, and Albuquerque, NM; and, the U.S. Fish and Wildlife Service in Galveston, TX, in various aquatic biologist-related positions. His areas of interest and responsibility lie in coastal wetlands and estuarine ecology. Mr. Ratterree received his B.S in biology from Lamar University and pursued an M.S. in geology from the University of Houston at Clear Lake.

SEA TURTLE STRANDINGS ALONG THE TEXAS COAST DURING 1994

Ms. Donna J. Shaver
National Biological Survey
Southeastern Biological Science Center
Padre Island National Seashore

INTRODUCTION

The Sea Turtle Stranding and Salvage Network (STSSN) was established in 1980 to document strandings of marine turtles on United States beaches located along the Gulf of Mexico, Atlantic Ocean, and Caribbean Sea (Schroeder 1988). Stranded sea turtles are defined as those non-headstarted turtles that wash ashore or are found floating either dead or alive (Schroeder 1988; Teas 1993).

Individuals of all five threatened and endangered sea turtle species occurring within the northwestern Gulf of Mexico, including the loggerhead (*Caretta*), Kemp's ridley (*Lepidochelys kempi*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), and leatherback (*Dermochelys coriacea*), have been found stranded in Texas (Rabalais and Rabalais 1980; Whistler 1989). Despite on-going research and conservation efforts, strandings of sea turtles along the Texas coast reached unprecedented levels during 1994. This study was undertaken to examine stranding patterns for sea turtles found along the Texas coast during 1994 and to determine possible causative factors for the strandings.

METHODS AND RESULTS

STSSN Procedures and Number of Stranded Turtles
Stranded sea turtles were located by network participants in response to information provided by beach visitors and during systematic patrols conducted in various areas of the state. For each stranded turtle, information was collected on species, size, stranding date and location, tag numbers (if applicable), visible injuries, condition, and final disposition of the animal. Information was recorded on standardized forms that were forwarded to the state and subsequently the national STSSN coordinators.

The Texas STSSN database was queried for records of turtles found stranded in Texas from January through October 1994. Four hundred and seventy-nine (479) turtles were located stranded, more than during any previous entire year on record for the Texas STSSN. Previous yearly totals ranged from 77 in 1980 to 355 in 1990. Of the 479 turtles found stranded during 1994, 446 were located dead and 33 alive. Live individuals were taken to rehabilitation facilities. Species composition of the 479 stranded turtles included 173 *C. caretta*, 241 *L. kempi*, 37 *C. mydas*, three *D. coriacea*, 13 *E. imbricata*, and 12 unknown species turtles.

NECROPSIES AND GUT CONTENT ANALYSES

All of the turtles that died during rehabilitation efforts and many of the dead, stranded turtles that were not highly decomposed were salvaged for necropsy and study. General necropsies, similar to those described by Wolke and George (1981), were performed by a limited number of STSSN participants and veterinarians. Due to the large number of turtles found stranded and salvaged during 1994, necropsies have not been completed for all individuals. Of those for which necropsies have been completed, tissue deterioration often prohibited conclusive determination of cause of death.

I necropsied and removed the entire digestive tract from approximately 120 turtles found stranded along the lower Texas coast during 1994. For the 37 Kemp's ridley digestive tracts analyzed to date, ingested items were identified, categorized into seven general food groups, baked in a drying oven, and weighed according to procedures outlined by (1991). Gut contents were present in all 37 analyzed, indicating recent foraging, and none appeared to have been ill prior to death. Overall, crabs comprised 95% of the dry mass. Although marine debris was ingested by 19% of the 37 *L. kempi*, only minute amounts were found and in no instances did it appear that marine debris ingestion led directly to the demise of the animal.

POSSIBLE SOURCES OF MORTALITY

Comments listed on STSSN forms revealed possible causes for strandings of 41 turtles, including boat propeller injuries (19), entanglement (13), hook and line ingestion (4), illegal gillnetting (2), and being lodged in rocks (3). Eleven turtles had been bitten by sharks and 18 had straight-edged cuts at the bases of missing appendages, typical of human-inflicted mutilation (Heinly *et al.* 1988). In most cases it was impossible for the STSSN participant to determine whether the bites and mutilation occurred before or after death. Although 11 turtles were found with water coming out of their mouth and/or froth in their trachea, this condition has been disputed as conclusive evidence of drowning. Based upon necropsies performed to date, illness and marine debris ingestion probably caused relatively few of the 479 turtles to strand. Several other possible causes

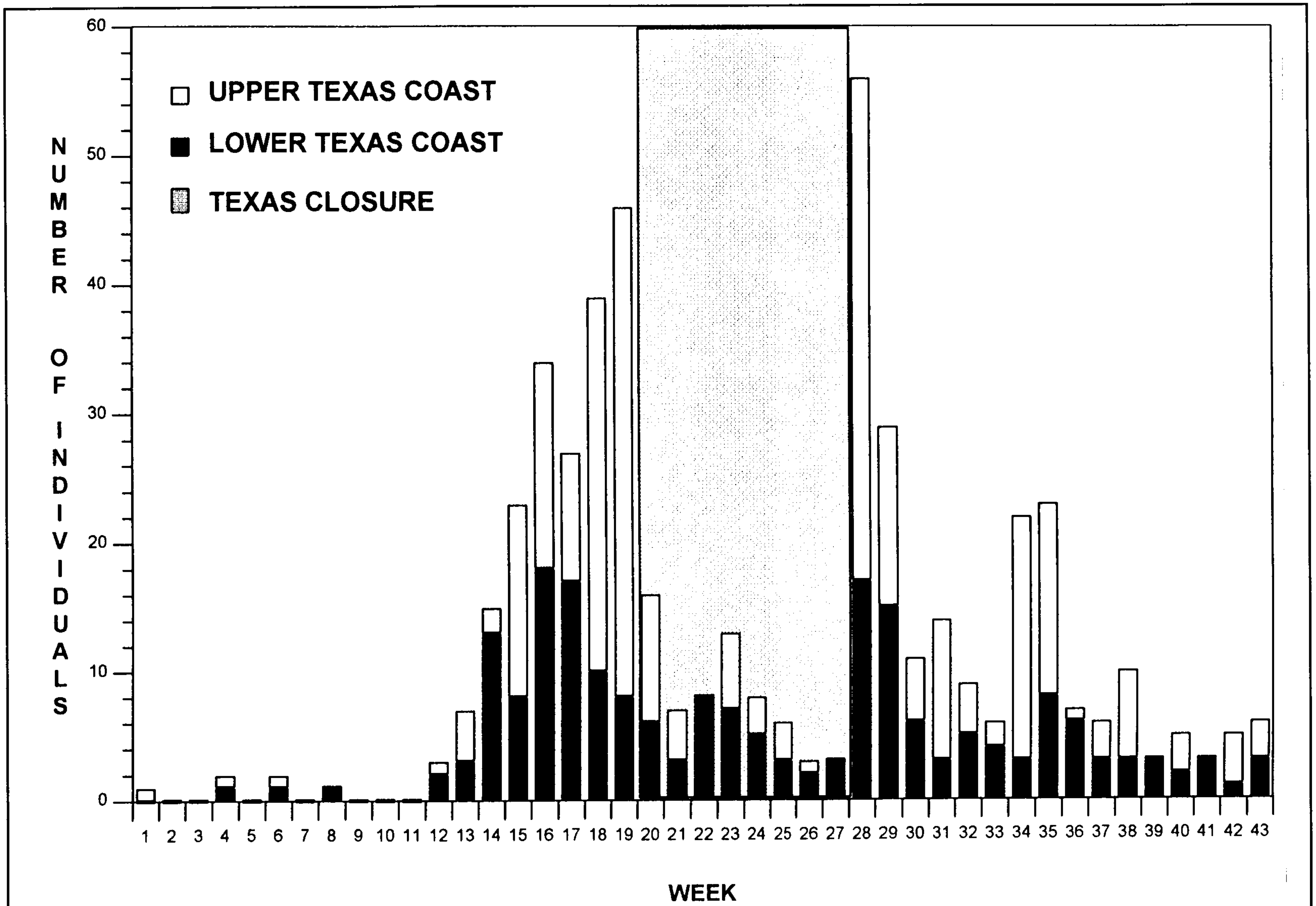

Figure 1B.1. Weekly number of non-headstarted sea turtles found stranded on the Texas coast from January through October 1994. Upper Texas coast is defined as the region from Matagorda Island and nearby inshore waters northward and lower Texas coast is defined as the region from San Jose Island and nearby inshore waters southward.

for the strandings have been suggested, but were subsequently dismissed because of a lack of supportive evidence. Among the unlikely contributing factors proposed were seismic exploration, oil platform removal, menhaden fishing, low water oxygen, pollutants, toxic wastes, dinoflagellate blooms, and ingestion of fish killed by any of the preceding factors (Zimmerman personal communication). There is circumstantial evidence that a large percentage of the strandings during 1994 resulted from incidental capture in shrimp trawls. Stranding patterns closely followed nearshore shrimping patterns. Strandings increased dramatically during early April and continued at high levels through mid-May (Figure 1B.1: Weekly number of non-headstarted sea turtles found stranded on the Texas coast from January through October 1994. Upper Texas coast is defined as the region from Matagorda Island and nearby inshore waters northward and lower Texas coast is defined as the region from San Jose Island and nearby inshore waters southward). From April through mid-May, strandings were concentrated on Galveston,Mustang, and North Padre Islands. When shrimping activity increased along the Texas coast during April, and boats were most numerous in nearshore waters off Galveston, Mustang, and North Padre Islands, strandings were most numerous in those areas. Strandings abruptly decreased and remained at relatively low levels from 13 May to 7 July, when Gulf waters were closed to shrimping activities out to 322 km (termed Texas closure). When shrimping resumed in Gulf waters, large numbers of turtles were again found stranded. Strandings at that time were concentrated in the Galveston, Matagorda, and Mustang Island areas, where nearshore shrimping effort was high. In the latter portion of July, when intensive turtle excluder device (TED) enforcement and education activities occurred, strandings decreased. However, strandings again increased during late August, when TED enforcement activities decreased, and subsequently decreased when TED enforcement activities resumed. Correlations have previously been found between shrimping effort and strandings of sea turtles in Texas (Whistler 1989; Magnuson *et al.* 1990; Caillouet *et al.* 1991; Sis *et al.* 1993). In an attempt to reduce trawl-related mortality, TEDs have been phased into mandatory usage since 1990. Most of the shrimp vessels inspected by the National Marine Fisheries Service and the U.S. Coast Guard in Texas during 1994 had TEDs present in their nets. However, TED installation and operational problems that might have caused turtles to be retained in the nets were noted in numerous instances (Zimmerman personal communication). Continued strandings of sea turtles at levels similar to those recorded in Texas during 1994 could diminish the effectiveness of conservation programs undertaken on behalf of these threatened and endangered species. The STSSN should continue to document stranded turtles and investigate possible sources of mortality so that sources related to human activities can be identified and reduced. TED education, enforcement, and research/development activities must be continued.

SUMMARY

1) Four hundred seventy-nine (479) non-headstarted sea turtles were found stranded along the Texas coast from January through October 1994, exceeding the number found during any entire year from 1980-1993.

2) Approximately one-half of the turtles found stranded were Kemp's ridley, the most critically endangered sea turtle species in the world.

3) Strandings were most numerous from April through mid-May and during mid-July. Temporal and spatial distributions of the strandings closely coincided with nearshore shrimping effort. A large percentage of the strandings documented during 1994 probably resulted from incidental capture in shrimp trawls.

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HANDSHAKES CURB HEARTACHES: COOPERATION THE KEY TO CONSERVATION AT THE FLOWER GARDENS

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INTRODUCTION

Doing things at the Flower Gardens has always been difficult. The banks contain the northernmost coral reefs in the United States and are over 100 miles offshore. While this has insulated them from most human impacts and left them in nearly pristine condition (Gittings *et al.* 1992), it has historically made them difficult to visit, to monitor, and to study, at least when compared to most other Atlantic reef systems. And with the designation of the banks as a National Marine Sanctuary by the National Oceanic & Atmospheric Administration (NOAA), and approval by Congress and the President in 1992, their isolation has made resource protection, education, surveillance and enforcement all challenges for resource managers.

Formal environmental protection can be a double-edged sword. Though protective regulations are promulgated, designation is typically followed by increases in recreational use (Tilmant 1987), elevating the task of enforcement. Recent years have seen substantial increases in the number of visitors to the Flower Gardens. Nearly 3,000 recreational divers annually arrive on charter boats or private vessels.

Industry has also expanded offshore. Currently seven oil or gas production platforms and over 60 miles of pipeline are within the Four-Mile Zone around the banks. The immediate future is likely to see even more recreational divers, more private boat arrivals, more fishing, increased industrial activity, and more scientific use of the Flower Gardens resources. But all these uses, which many view as threats, are accompanied by a high level of interest in and awareness of issues related to resource protection and environmental stewardship on the part of the public, industry and other federal agencies. This has lead to a number of unique and productive partnerships. The cooperative nature of the users of the resources above, on and below the Flower Gardens has resulted in a more effective and comprehensive protective regime for the banks and the unusual biological assemblages they contain.

HISTORICAL PERSPECTIVE OF CONSERVATION AT THE FLOWER GARDENS

The Flower Garden Banks are fortunate to have had a long history of efforts directed at resource protection. These efforts have come from several fronts, including government, industry, and the public.

Bright *et al.* (1985) summarized the history of protection for the Flower Gardens for the period up to 1985, and Gittings *et al.* (1993) updated the history. The most significant perceived threats to the resources of the Flower Gardens have generally been considered to arise from oil and gas development, from anchoring by large vessels, and from increasing levels of use by recreational divers and boaters. Oil and gas concerns included diminished water quality due to drilling and production discharges near the banks, and the threat of spills and clean-up operations. Large vessel anchoring has been documented on a number of occasions. The damage resulting from even single incidents can be extensive, and anchor scars can be seen on large-scale side scan sonograms. High levels of recreational use increase the amount of damage caused by anchoring as well the impacts of souvenir collection, trash disposal, and overfishing.

The majority of threats posed by oil and gas operations were addressed first by the Minerals Management Service (MMS). In 1974, regulatory zones were imposed prohibiting activity on the Flower Garden Banks themselves, and in adjacent areas required reef monitoring and/or shunting of discharges to within 10 m of the seafloor.

By all accounts, the MMS regulations have been very effective, and monitoring programs have revealed no industry-related deterioration at the Flower Gardens (*e.g.* Gittings *et al.* 1992). In fact, the Flower Garden Banks National Marine Sanctuary (FGBNMS) regulations (15 CFR Part 943) affecting the oil and gas industry are nearly the same as those adopted by MMS in 1974.

It was evident in the early 1970s that the Flower Gardens would be a strong candidate for sanctuary designation. The Banks were formally nominated in 1977 in part because of continuing threats posed by anchoring by non-oil industry vessels. Anchoring and the potential problem of coral collecting were nearly taken care of in the early 1980s. The Draft Gulf of Mexico Fisheries Management Plan (FMP) for Corals and Coral Reefs included a provision that would prohibit anchoring on and collecting corals. Because the Plan's promise of removing the final significant perceived threats, the Flower Gardens was removed from NOAA's List of Active Candidates for Marine Sanctuary status in 1982. But the final FMP did not contain the anchoring provision. It had been determined during the review of the Draft FMP that anchoring was not a fisheries issue.

In 1984, researchers on the East Flower Garden Bank witnessed an anchoring incident and documented the damage. Videotapes of the damage were shown at an MMS Information Transfer Meeting and raised the awareness of the problem to the staff of Representative Solomon Ortiz, a member of the House Merchant Marine and Fisheries Committee. He and another Committee member, then-Rep. John Breaux, recommended the Flower Gardens be again placed on NOAA's Site Evaluation List (SEL).

In 1990, the Gulf Reef Environmental Action Team (GREAT), a group of 24 volunteers with funding and support from federal agencies and private sources, installed 12 mooring buoys on the banks to reduce anchoring by small vessels. In January of 1992, the Flower Garden Banks were designated the nation's tenth National Marine Sanctuary (13 currently exist).

SANCTUARY MANAGEMENT

Marine Sanctuaries throughout the nation utilize management tools tailored to the sites. For each, the primary goal is resource protection. Each has unique regulations that address site-specific resource threats. Regulations may address discharges that alter water quality, activities that mechanically damage living and non-living resources (*e.g.* anchoring), molestation of marine mammals, allowable fishing techniques, salvaging of artifacts, or other activities. Sites use varying levels of education, research, and enforcement, which are determined by site needs. They also protect resources using proactive measures (such as mooring buoy installation and contingency planning).

Even more variable are the types of cooperation each Sanctuary uses to accomplish its goals. A treatment of nationwide cooperative efforts is beyond the scope of this paper. Here we discuss the role of cooperation in management of the FGBNMS, and discuss in some detail the teamwork between industry, the MMS, and NOAA in protecting the Flower Gardens.

COOPERATION AT THE FLOWER GARDENS

The Flower Gardens Sanctuary depends heavily on partnerships. The Sanctuary has taken advantage of regional expertise among industry, federal agencies, academic institutions, and environmental groups. One illustration of this is the composition of the Sanctuary's advisory group, a 14-member committee that consists of people from each of these user groups (Table 1B.1).

Table 1B.1. Cooperation between the Flower Gardens Banks National Marine Sanctuary and other organizations.

Sanctuary Functions	Cooperating Organizations	Activities
Management	Texas A&M Sea Grant Prog.	Provides reduced-cost office space and staff support
	Gulf of Mexico Foundation	Established Flower Gardens Fund to raise funds to support all aspects of Sanctuary
	Mobil, Texaco, Shell, MMS, Texas A&M, Louisiana Univ. Marine Consort., Gulf of Mexico Fdn., Dive Clubs, Env'l Groups, Rinn Boats, volunteers	Each have member(s) on the Sanctuary's advisory group
Resource Protection &	MMS	Contingency Planning, industry operations policy development, review of development plans, oil spill drills
Enforcement	Gulf Reef Env'l Action Team	Installed mooring buoys and donated system to NOAA
	U.S. Coast Guard	Surveillance, enforcement, contingency planning, spill response
	National Marine Fisheries Service	Enforcement, conduct investigations
	Mobil E&P U.S., Inc.	Report violations

Sanctuary Functions	Cooperating Organizations	Activities
	Texaco, Anadarko, Oryx	Oil spill drills
	Rinn Boats, Inc.	Charter boat operators report violations and buoy problems, and support damage assessment
Education	Sea Grant	Assist with production of brochures, posters, and videos
	Seaspace	Provides booth at annual dive show
	Houston Museum of Natural Science	Host annual Night on the Flower Gardens, an educational anniversary celebration
	Dive Clubs & Env'l Groups	Co-sponsor Night on the Flower Gardens
	Gulf of Mexico Fdn.	Publishes a Technical Series through the Flower Gardens Fund to keep public aware of Sanctuary activities & research
	Shell	Contributions to Flower Gardens Fund
	Volunteers, Experts	Present slide shows and talks (*e.g.* Elderhostel), provide materials for and review educational products
Research	MMS	Co-fund monitoring and 1992 mass spawning cruise
	Mobil E&P U.S., Inc.	Provides platform access, lodging and logistical support
	National Fish & Wildlife Fdn.	Co-fund fish censuses and Flower Gardens Fellowships
	Gulf of Mexico Fdn.	Co-fund fish censuses and scholarships, and provide cruise support and project funding
	Mobil, Texaco, and Natural Gas Pipeline	Contributions to the Flower Gardens Fund for research and monitoring
	Seaspace	Research scholarships
	National Biological Survey	Provided staff and funds for toxicology studies
	Rinn Boats, Inc.	Offers ship time to conduct graduate student research
	Sea Grant, Entrix, Oceanographic Expedition	Co-sponsored research cruises
	National Undersea Research Center/ Univ. North Carolina	Sponsored research workshop to summarize research interest and stimulate proposals

Table 1B.1 summarizes some of these cooperative efforts and indicates how the Sanctuary uses partnerships to

- reduce the costs of office management
- raise funds for Sanctuary programs
- obtain advisory support
- enhance resource protection efforts
- conduct surveillance and enforcement
- produce and distribute educational materials
- conduct educational programs
- facilitate, enhance, and fund research and monitoring

Two of the most important cooperating groups for the Sanctuary are the MMS and oil companies themselves. The FGBNMS works with MMS more than it does any other federal agency. MMS worked with the Sanctuary in 1992 to develop a policy on seismic exploration that was designed to control the activities of seismic vessels in certain parts of the Sanctuary. MMS requests NOAA review of plans for drilling, production, and pipeline operations in the Four-Mile Zone around the Sanctuary. MMS staff provides technical advice, when requested, during these reviews. They invite the Sanctuary manager to participate on spill drills. They assisted the FGBNMS in notifying companies operating in the Four-Mile Zone of the requirement to have permits and other authorizations certified. They jointly fund with NOAA the long-term monitoring program, and sponsored a 1992 research cruise. And currently, NOAA and MMS are collaborating on an oil spill risk assessment for the Flower Garden Banks. At the headquarters level, the two groups have periodic meetings to share information on current activities and to coordinate planning.

Several oil companies have been valuable partners for the FGBNMS. Mobil, Texaco, Shell, and Natural Gas Pipeline have all made donations to the Flower Gardens Fund for Sanctuary research and education programs (the Flower Gardens Fund was established in cooperation with the Gulf of Mexico Foundation, a non-profit 501(c)(3) organization, to enhance conservation efforts at the Flower Gardens through increased public and private sector involvement in research, monitoring, education, and communication). Mobil, Texaco, and Shell have also have representatives on the Sanctuary advisory group. And Mobil provides transportation, lodging, and logistical support to scientists conducting research from HI-A389A, a gas production platform in the Sanctuary. An inflatable is stationed on the platform for use in Sanctuary operations.

CONCLUSION

The FGBNMS has depended on partnerships since its designation and will continue to do so. Staff and resources will simply never be adequate to accomplish all the tasks required for resource protection without help from groups with similar or complementary goals. Furthermore, product quality is enhanced through partnerships, reducing wasteful, unnecessary, and even counterproductive duplication of effort. And because of vested interest on the part of cooperating partners, the final products are more effectively and widely used.

Comprehensive marine resource management, a goal of the National Marine Sanctuary Program, can only be attempted if regulatory agencies are willing to act in cooperation with other publics with vested interest in the resource. National Marine Sanctuary managers have become well aware of this fact and have made cooperative programs a high priority in their operational plans. This has had numerous positive effects. Resource protection has become more comprehensive and more effective. Education and outreach efforts have expanded. Research scientists are conducting more of their work in sanctuaries. And the National Marine Sanctuary Program's visibility has increased. In contrast to the past, agencies and groups have begun to approach the Sanctuary Program to develop cooperative programs, and support has grown substantially in the last several years. And while the outlook for future federal support is unclear, partnerships make the prospects for effective resource management much more promising.

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A CLOCKWORK ORANGE: THE TRANS-GULF MIGRATION OF THE MONARCH BUTTERFLY

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The monarch butterfly in eastern North America is world famous for its seemingly miraculous treks between Canada, the United States, and Mexico. Likewise, the overwintering roosts in the highlands of central Mexico have been well documented. Although the insect's land routes are fairly well known, there have been occasional reports that the gossamer-winged insects could not possibly navigate over large bodies of water, entomologists have concluded that the sightings were of insects blown out to sea by heavy offshore winds.

Now, with data spanning nearly three decades, scientists have had to revamp their theories, and the distinguished international traveler has acquired a new reputation: oceanic voyager.

My interest in monarchs began in 1965. As a graduate student at Louisiana State University, I assisted with research on migrating song birds along the coast of southwestern Louisiana. The work involved focusing high-powered field telescopes at the moon each moonlit night during fall and spring. This pioneering strategy allowed us to count the silhouettes of song birds as they crossed the bright disk. Then, using simple mathematical calculations, we extrapolated the total number of birds crossing the sky for a given period of time. The data were conclusive: a trans-Gulf flyway did indeed exist for avian migrants.

During our night vigils, we occasionally noted other winged creatures in the night sky. Now commonly termed "angels," many of these could be identified as monarch butterflies (monarchs have a distinctive soaring flight pattern). Not realizing the uniqueness of these observations we simply dismissed them as tangential to our research. After all, we reasoned, why shouldn't migrating butterflies use the same flyways as birds?

The data were forgotten until the late 1970s. Then, while researching the natural history of southwestern

Louisiana, I noted that during each spring and fall masses of monarchs were taking advantage of the oak and hackberry trees growing on the old beach ridges known by the local Cajun residents as *cheniers* (French for "oak ridge"). Furthermore, my casual observations indicated that in the spring, many of the monarchs were flocking onto the cheniers directly from over the Gulf waters to the south; and each fall, many monarchs were departing the cheniers to the south, again directly over the Gulf. I noted with interest the observations, but merely filed away the data.

Then, in the summer of 1990, a brief item appeared in a scientific newsletter claiming that "on the 17th and 18th of October, each year for the past 18-10 years, monarch butterflies in immense numbers alight on and rest on an offshore oil and production platform in the Gulf of Mexico."

How could I continue to disregard the long-term clues? With no more than a week of scientific sleuthing I was able to learn that the paradigm for monarch migration did not include night flying or navigation over large expanses of water. Monarchs supposedly skirted pilots and offshore workers in the petroleum industry stationed in an area of the northwestern Gulf known as West Cameron Block had on several occasions personally witnessed numbers of monarchs descending in mass upon production platforms and drilling rigs.

Now, following four years of research in the northwestern Gulf I have compiled substantial data that allows me to advance new theories on monarch migration.

To summarize, nearly 30 different man-made structures ranging from just a few miles to nearly 150 miles offshore, repeatedly host monarchs in mid-October and to a lesser degree again in mid March. Although Louisiana has more than 3,000 manmade structures fanning out into the Gulf, the monarch sightings are not distributed in a random pattern. When plotted on an aeronautical chart, the data reveal a specific arrangement: a 90-100 mile swath extending from southwest Louisiana to (by extrapolation since no structures reach beyond 150 miles, and no monarch tagged on a rig or platform has ever been recovered), northeastern Tamaulipas, Mexico. The flight path for the butterflies is consistently south to southwest in October and north to northeast in March. Although the insects seem to prefer moving when winds are favorable for gliding, the tenacious migrants are able to hold to their apparently prescribed course even when buffeted by strong head winds. The butterflies usually fly 30-130 feet above the warm Gulf water, presumably taking advantage of thermal uplift. At peak migration, on an average of one to two butterflies per minute can be observed, often circling the iron structures. During each year, at least one platform was inundated by hundreds if not thousands of butterflies, usually at dusk. The majority remained throughout the night. Some, however, departed into the darkened sky after but a brief respite.

I am often asked just how do the migrating monarchs home-in on the offshore structures? Again, the past four years of research offer compelling evidence. Over 90 percent of all butterfly records involve offshore structures that are yellow in color. Since monarchs are known to be highly sensitive to that color, I theorize that the fall migrants mistake the colorful protuberances in the Gulf for patches of golden-rod, a favorite source of nourishing nectar, or perhaps even for trees sporting autumnal foliage. In essence, the monarchs are exploiting the offshore structures as "pit stops."

But magnetism probably plays a significant role, too. The body of each monarch contains small quantities of magnetite, a kind of biosynthetic compass that presumably empowers the insects with the ability to orient to Earth's natural geomagnetism, and therefore, to navigate over great distances (the record for one monarch tagged in Ontario and later retrieved in Mexico stands at 2,133 miles). Since the offshore facilities continually generate substantial electro-magnetic fields because of their electrical generators, telecommunication equipment, and massive iron construction, I theorize that the insects' genetic programs are fooled. The butterflies are probably literally "pulled" farther offshore by false readings from fine-tuning, for yellow (and possibly bright lights, too) dictates a descent. If darkness is imminent, most butterflies simply remain for the night. Then, with renewed vigor and in the absence of suitable nourishment, the instinct to migrate drives them onward to complete their remaining hours (probably 10-12) of over-water journey (approximately 350 miles, a saving of over 200 miles).

In the spring, conditions are a bit different. Primed for reproduction, monarchs leave their forested retreats in central Mexico to begin searching out milkweeds, their only host plants. Instinctively, the butterflies move in a northwesterly direction. Of those that reach the Mexican Gulf coast, many probably continue to skirt the water line northward since offshore waters contain very few production platforms or drilling rigs. Also, only terra firma offers the possibility for immediate reproduction. However, my data indicate that some monarchs must launch-out over the water. Furthermore, I believe that those that do have a decided advantage. But let me explain.

Monarchs are genetically tied to breed on only milkweed plants mainly in the genus *Asclepias*. Relatively common along roadsides and within pastures, these showy plants survive because of a milky sap that contains chemical substances that render the plants more or less immune to predators. Monarch caterpillars throughout their evolutionary history have learned to not only tolerate these toxins but to actually sequestor and incorporate them into their own body chemistry. Monarch caterpillars, therefore are also immune to many predators. During metamorphosis, these same toxic alkaloids are passed on to the adults so that the butterflies are also unpalatable. (The striking colors of both the caterpillars and butterflies supposedly advertise this immunity to potential predators: "I taste bad. Leave me alone!")

But not all milkweeds are equally potent. That is, some species contain higher concentrations of alkaloids than do others. As a corollary, not all monarchs are equally potent. In fact, experiments have proven that some monarchs contain practically no measurable quantities of alkaloids. These butterflies are readily eaten by avian and mammalian predators.

According to evolutionary theory, these monarchs that breed on species of milkweed that are well endowed with alkaloids will have a greater potential for survival than those that do not. Since genes are passed on only by survivors, it is these chemically primed individuals that over time come to dominate a particular population. Therefore, natural selection favors those butterflies that breed on especially toxic varieties of milkweed.

My analysis of the vegetation of coastal Louisiana indicates that only one species of milkweed is common there. Known as green or antelope-horn (*Asclepias viridis*), the species is an early spring bloomer and distributed in dry woods, fields and prairies along the Gulf coast and then northward into the midwestern states. Chemical analysis of the plant indicates that it contains copious amounts of alkaloids so that it ranked as one of the most toxic of its kind. I reason, therefore that those monarchs that migrate in the spring across the waters of the Gulf are able to oviposit on a species of milkweed that virtually assures the survival of most of their offspring. As such, the oceanic route increases the survival potential for the butterfly species through time.

Although I am not yet in a position to propose that the oil industry's development in the Gulf of Mexico over the past 50 years has inadvertently sparked the evolution of a new, more direct flyway for the monarch, I do believe that this "Trans-Gulf Express" does offer migrants a definite advantage: a shorter route complete with open-sea oases and access to breeding grounds with host plants rich in alkaloids. And so what may have begun as only a chance wandering by few wayward individuals is now being continually reinforced and expanded.

22 April 1993. Baton Rouge, Louisiana. On that day the monarch was accorded an unusually festive tribute. The Earth Day ceremony—reputed to be the largest in the South—initiated its new" All Species Parade" in which 300 school children along with at least another 50 supportive older folks masqueraded as the state's native plants and animals. The participants were grouped according to major habitats: Gulf waters first, followed by marshlands, swamplands, and finally pine and hardwood forests. Since the monarch is a migrant throughout all parts of the state—and now proven to fly over the Gulf as well—the butterfly was the lead off for the parade.

Although all costumes sported a professional eye-catching pizzazz, the uncontested crowd pleaser was the colorful orange and black celebrity monarch that towered above the crowd. Since 1991 the parade has increased in size and has been applauded by both the populace and media as a grand success.

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THE LOUISIANA PROGRAM: PROGRAMMATIC OVERVIEW

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In 1986, Louisiana, concerned over the removal of offshore oil and gas structures (Reggio *et al.* 1986), proposed legislation to develop a comprehensive artificial reef program for the state. The Artificial Reef Program is responsible for siting, maintaining, and enhancing artificial reefs in both state and federal waters off the Louisiana coast, using, but not limited to, retired oil and gas structures.

The Louisiana Artificial Reef Initiative (LARI) drafted legislation modeled after the National Fishing Enhancement Act (NFEA). The NFEA provided encouragement and guidelines to states for creating well-developed, well-organized artificial reef programs. The LARI was created in 1985 and was composed of university, state and federal officials, members of recreational and commercial fishing interests, and representatives of Louisiana's oil and gas industry. The Louisiana Fishing Enhancement Act (Act 100), was signed into law in June 1986 and provided the authority to develop a comprehensive artificial reef program in Louisiana.

Act 100 established Louisiana's Artificial Reef Development Program and named and outlined the duties of the three participating agencies. The act created the Louisiana Artificial Reef Development Council composed of the Secretary of the Department of Wildlife and Fisheries, the Executive Director of the Center for Coastal Energy and Environmental Resources and the Director of the Louisiana Sea Grant College Program. The Council is responsible for overseeing development and implementation of the program. The program is administered by the Louisiana Department of Wildlife and Fisheries and conducted jointly with scientists from the Center for Coastal Energy and Environmental Resources at Louisiana State University.

The Act established the State of Louisiana as the permittee for artificial reefs developed under the program's jurisdiction and appointed the Department of Wildlife and Fisheries as agent for the state. The state assumes responsibility for the reefs upon placement within the established reef permitted area. The State, donors, and other participants constructing a reef under NFEA and Act 100 are absolved from liability, provided the terms and conditions of the authorizing federal artificial reef permits are met.

Act 100 mandated that a plan be drafted to establish the rationale and operational guidelines for the program, including the siting criteria for Louisiana's artificial reefs. The plan (Wilson *et al.* 1987) was accepted and endorsed by the 1987 Louisiana Legislature. With the plan in place for guidance, Louisiana began the lengthy process of identifying areas inappropriate for reef development. This process, known as exclusion mapping, excluded areas such as shipping lanes, traditional commercial fishing areas, pipeline corridors, restricted military zones, existing live bottoms, and other areas deemed unsuitable due to depth, bottom type, hydrological conditions, and preference by other user groups (Christian 1984; D'Itri 1985; Myatt 1985).

Following exclusion of areas where reefs should not be developed, a series of public hearings were held across south Louisiana to outline the program and, with public input, to select areas where reefs should be located. As a result of those hearings, eight artificial reef planning areas were chosen where specific artificial reef projects could be sited in Phase I of the program. These planning areas facilitate platform abandonment planning by oil and gas companies and provide flexibility in specific site selection within the planning areas, thereby encouraging industry cooperation. At the suggestion of local fishermen, a ninth planning area (Ship Shoal) was added seaward of the cities of Houma and Morgan City. Phase Two of the Program takes advantage of low profile materials such as shell and concrete rubble to allow reef development in Louisiana's shallow inshore and nearshore waters.

Louisiana Act 100 did not authorize the use of State general funds for the program but established the Louisiana Artificial Reef Trust Fund. Oil and gas companies that contribute structures to the program donate half the disposal savings realized through program participation for deposit into the Louisiana Artificial Reef Trust Fund. Based on average removal cost (NRCMB 1985) and the location of the state's artificial reef planning areas, Louisiana estimated that, depending on water depth, the oil and gas industry can save up to $1 million per structure (compared to the cost of traditional onshore abandonment) by converting it into an artificial reef. The interest generated by the Artificial Reef Trust Fund is designated for program operation, including buoy deployment and maintenance, monitoring, research, and development.

Since the program's inception in 1987, the program has created 19 offshore reefs utilizing 48 obsolete oil and gas platforms donated by 17 participating companies. Other offshore oil and gas operators have also expressed an interest in the program, and negotiations are in progress. Negotiations to obtain platforms and to determine the amount of donation are done on a case-by-case basis between the oil and gas operator and the State. The size, location, distance from shore, water depth, resale value, and proximity of the platform to the permitted reef site all affect the cost of converting a rig into a reef; thus, it is not always cost-effective for operators to participate (Pope 1988).

In addition to the offshore reefs, three inshore reefs have been constructed of oyster and clam shell provided to the Department as mitigation for shell dredging activities. This low-profile material is ideal for inshore reef development in that it can be shaped in such a manner to minimize the reef's impacts on navigation and the inshore shrimp trawl fishery.

Federal and state governments, the oil and gas industry, as well as commercial and recreational fishermen, have been beneficiaries of Louisiana's artificial reef program. However, it will take the continued cooperation of the various state and federal agencies involved and the support of the Gulf user groups to ensure that Louisiana's program will enjoy continued success.

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SESSION 1C

CHEMOSYNTHETIC COMMUNITIES IN THE GULF OF MEXICO

Session: 1C - CHEMOSYNTHETIC COMMUNITIES IN THE GULF OF MEXICO

Co-Chairs: Dr. Robert M. Avent and Dr. James M. Brooks

Date: November 15, 1994

Presentation	Author/Affiliation
The Chemosynthetic Ecosystems Study: An Overview	Dr. Ian MacDonald Geochemical and Environmental Research Group Texas A&M University
Chemosynthetic Ecosystems Study: Geological and Geophysical Characterization	Dr. W. Sager Dr. C. S. Lee Texas A&M University Dr. William W. Schroeder Marine Science Program University of Alabama
Paleontology of Seep Bivalve Communities	Mr. K. A. Warren Dr. E. N. Powell Department of Oceanography Texas A&M University

THE CHEMOSYNTHETIC ECOSYSTEMS STUDY: AN OVERVIEW

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INTRODUCTION

Planning for this study was initiated by MMS shortly after the 1984 discovery of chemosynthetic fauna at natural hydrocarbons seeps on the continental slope in the Gulf of Mexico. From a management point of view, the study was called for because of the agency's concern that energy exploration and production could harm an important component of the slope ecosystem. The Geochemical and Environmental Research Group (GERG) of Texas A&M University, was awarded the contract in July, 1991. GERG brought to the study a mature program of research that included investigators from several research universities in the Gulf region and elsewhere. As a result, the team was able to proceed immediately to the fieldwork stage of the program and to build upon a existing data base acquired through several previous years of field sampling and analysis.

The study is tasked with determining the abiotic factors that determine whether communities of chemosynthetic fauna become established and persist at hydrocarbon seeps and with estimating the relative importance of the communities to the slope ecosystem. To address the question of possible harm due to human activity, the study has examined the growth rates of the major faunal groups, the record of the community accessible to analysis by paleolotologists, and the incidence and causes of short-term change. Because the communities occur at depths of 500 m or greater, and because they tend to be small in area, the investigations have relied heavily upon research submarines for sample collection and exploration. Initially, five sites located in water depths of 500 to 720 m were selected for study on the basis of their faunal composition and geographic location. MMS contracted for 18 dive days with the submarine *Johnson Sea-Link* and her surface support ship.

In general, the study results show that the seep communities are a unique and important component of the slope ecosystem of both the regional and national EEZ. Although susceptible to damage through carelessness, this ecosystem can be protected through application of good scientific knowledge and appropriate management oversight. This presentation will discuss the regional and local patterns of occurrence evident in oil seeps and the biological communities associated with seeps.

REGIONAL OCCURRENCE

Regionally, a map of the known seep communities indicates a broad belt of occurrence across the upper to mid-continental slope. The landward limits of seep communities appear to be real and increasingly to restrict occurrence of seep fauna in water depths less than about 500 m—although physiological and ecological causes of this restriction are very poorly understood. The seaward and east-west extents of this distribution are artificially constrained by the limits of exploration. Collection of oil-laden surface sediments by piston coring also indicates the general prevalence of seepage on the slope. One deep water (2200 m) seep has been explored in Alaminos Canyon and the thriving chemosynthetic community found in that site (Brooks *et al.* 1990) support the idea that lower slope seeps are colonized. To the east, the Mississippi Fan and Canyon region does appear to limit seepage—this is confirmed by general lack of surface slicks and reduction in sediment hydrocarbon levels. There are seep communities off Mobile Bay in Viosca Knoll region. The steep Florida Escarpment (and coincident lack of hydrocarbon reservoirs) also limits the eastward occurrence of seep communities at slope depths; however, the first documented finding of tube worms and mytilids was at the base of the Florida Escarpment, at a depth of 3600 m (Paull *et al.* 1984). The Escarpment communities have been linked not to thermogenic hydrocarbons, but to connate fluid seepage from the highly porous Florida Platform. Noting the oil reserves of the Mexican slope, and the similarities between the Yucatan and Florida Escarpments, it is clear that seep communities have a known distribution that indicates their presence across the full extent of the continental slope in the U.S. Gulf of Mexico and a potential distribution that is circumambient of the entire Gulf.

To test this theory, locations of probable oil slicks were compiled from a number of sources: a photograph taken from the Space Shuttle, a Landsat Thematic Maper (TM) scene, and in three European Radar Satellite (ERS-1) scenes, as well as collections of floating oil and observation of sea-floor seeps from submarines. These locations were ranked according to recurrence of evidence for natural oil seepage among the various data sets. As a result, it was possible to verify 43 biological communities that depend on hydrocarbon seeps and 63 locations where remote sensing data indicate there are sea-floor sources capable of producing perennial oil slicks. Remote detection of natural seepage confirms that the range of chemosynthetic communities dependent on hydrocarbon seepage in the northern Gulf of Mexico extends over the full depth range of the continental slope.

This broad regional distribution, however, belies the local occurrence of chemosynthetic communities. Because the fauna depend upon geological processes, they are freed from the restrictions that increasing water depth imposes upon the photosynthetic food chain; thus they often form very dense aggregations in the otherwise food-poor deep sea. However, because their food supply is so specific, seep communities are sharply limited by the spatial and temporal conditions of seepage; thus seep communities tend to be dense, but small in area.

FINE-SCALE PATTERNS

Clear distribution patterns emerge at spatial scales of < 10 m. Spatially, seep mussels are the most restricted and typically occur as 1- to 5-m wide ovoid or linear patches, often on slope terraces or mound crests. Tube worms form in bush-like clusters that colonize surface sediments along fault zones. The widths of these colonies are typically 10 to 100 m, while the lengths often extend the entire active length of the faults. Vesicomyids and lucinids are spatially the least restricted. There is much difficulty in distinguishing living vesicomyids from accumulations of dead shells, and the infaunal lucinids are collected by coring. Generally, however, the bivalve beds occupy large flat regions up to 1,000 m in width. These distribution patterns are the result of the adaptations that each faunal group has made to colonize and exploit seepage and will be briefly outlined in the following.

Seep Mytilids

Methane availability limits the habitat suitable to seep mussels. Gaseous hydrocarbon, migrating from depth, is relatively less restricted by sediment pore structure than is liquid oil (Verweij 1993). Bubbling gas vents are therefore relatively more localized than the oily sediment in seep zones. Secondary processes such as hydrate formation and dissociation, carbonate precipitation, and indeed the tightly bound mat of mussels, will channelize and retard gas seepage; overall though, the cross-section is relatively small. A somewhat less restrictive case occurs where mussels are able to exploit methane dissolved in seeping brine. Here, the greater density of brine tends to maintain it as a distinct fluid in pools of flow channels on the seafloor. The major restriction here is substrate stability, because the anoxic brine becomes toxic to mussels unable to extend their siphons into the overlying sea water. In both cases, gas vents and brine seeps, the habitable gradient is steep and the actual habitat areas is restricted. At brine seeps, mussels dominate, with occasional solitary tube worms able to exploit sediment anoxia. At gas vents in oil seeps, the mussels usually occur surrounded by more extensive tube worm bushes.

Tube Worms

Tube worms have two requirements that, in combination, limit their habitat. Their symbionts utilize H_2S, which is probably derived from sulfate reduction in a sediment column made anoxic by the bacterial degradation of the massive carbon input provided by oil seepage. No measurable concentrations of H_2S have been detected at the off-bottom heights where the tube worms' gas exchange plumes are commonly found (MacDonald *et al.* 1989). The implication is that H_2S is supplied by diffusion across the tube wall in that portion of the tube that is usually buried in the anoxic sediments. The tube worms themselves require a hard attachment substrate for larval sediment—although this requirement may be relaxed somewhat where larvae can settle on adults. The combination of these two requirements is met along the active portions of faults where carbonates are exposed and sufficient sedimentation or mud expulsion has occurred to provide a sediment drape. Tube worms do occur in lithified crevices, but the extent of such colonies is sharply limited and the development of the individual worms is generally stunted.

Bivalves (Vesicomyidae and Lucinacea)

Seep clams also exploit sediment anoxia: the vesicomyids by extending their vascularized foot below the surface oxidized layer while their siphon takes in oxygenated sea water; the lucinids by constructing a Y-shaped burrow within which they can control oxygen levels through siphon pumping or shifting their position (Reid and Brand 1986; Cary *et al.* 1989). Lucinids have a very wide distribution in the Gulf of Mexico, including shallow estaurine areas where sediment anoxia is clearly not related to oil seepage. Of the two groups therefore, the spatial extent of lucinids around seeps should be the greater. There is difficulty in confirming this, however, because the animal's infaunal habits tend to hide them from view. Vesicomyids require the shallow anoxia typical of a mud flow flats and have been confirmed to colonize areas >1 km wide. All three groups, mussels, tube worms, and vesicomyids, have been sighted together under the exceptional circumstances where all of the conditions of brine seepage, sediment anoxia, and attachment substrate co-occur.

TEMPORAL STABILITY

Life-spans of the Gulf chemosynthetic fauna, where they can be determined by growth experiments, are long—on the order of tens to possibly hundreds of years. Short-term change in their communities should therefore result from variation in fluid flow or other seep-related processes. Successful settlement events should be relatively rare and the effects of predation relatively limited. Comparison of seep communities photographed at intervals of up to three years reveals little direct evidence for change in either community composition or density. This is in marked contrast with the chemosynthetic communities at the Galapagos hydrothermal vent, where entire aggregations of tube worms were replaced with mussels over a period of less than five years (Hessler *et al.* 1988). Indirect evidence, on the other hand, points to change and various rates. Most rapid change will undoubtedly result from catastrophic events such as blow-outs. Upended carbonate slabs and sharp sided pockmarks are clear indicators that such blowouts do occur. Over a circa-annual time scale, variation in water temperature can destabilize near-surface hydrates and greatly increase local seepage. (MacDonald *et al.* 1993). Finally, rechannelization of fluid-flow may choke off fluid flow in a highly localized area; evidence for this can be seen in the defunct mussel beds that are commonly found in the vicinity of living beds. In general, however, the incidence of short-term change seems to be low enough that likelihood of detecting it in the short term is reduced.

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Dr. Ian R. MacDonald has been working with questions concerning marine ecology in the Gulf of Mexico for the past 10 years. He has been involved in the study of chemosynthetic communities at oil seeps since the first discoveries in 1985 and has published numerous peer-reviewed papers on related topics.

CHEMOSYNTHETIC ECOSYSTEMS STUDY: GEOLOGICAL AND GEOPHYSICAL CHARACTERIZATION

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INTRODUCTION

Hydrocarbon seeps are caused by geologic factors; in the Gulf of Mexico, deeply buried mobile salt causes fracturing of the sediment pile (Worrall and Snelson 1989) and the consequent release of mature hydrocarbons along fault planes. What is more, the seeps themselves modify the local geology of the seafloor (Roberts *et al.* 1990) and provide substrate and sustenance to chemosynthetic organisms (Kennicutt *et al.* 1988; MacDonald *et al.* 1990).

Seeps have been studied in two main fashions: by submersible observations close to the seafloor and by geophysical remote sensing from the sea surface. Thus, one of the main gaps in such studies is the missing link from the broad scale of geophysical sounding to the ultra small scale of the submersible viewport. In this report we describe the use of a hybrid technique, geophysical data collected from a submarine, as the basis of a study of the geological and geophysical characteristics of hydrocarbon seeps in the Gulf of Mexico. These geophysical data provide a synoptic view on the scale of hundreds of meters, but with a resolution of less than a meter and this allows us to compare viewport-scale observations with broad scale seismic data. Furthermore, we have used ground truth data, collected by submersible, to better understand the geophysical picture.

OBJECTIVES

The objective of this study was to use maps of geophysical (mainly acoustic) characteristics of the seafloor and shallow subbottom at hydrocarbon seep sites to provide a framework for assessing the effects of the seeps on the seafloor and the relationship to chemosynthetic communities. Using the principles of seismic stratigraphy, we wished to classify and map the extent of sediments affected by seepage. Our goal was to ground truth these classifications with geologic data (cores and submersible observations) and to correlate these characteristics with other geophysical and geologic data. A major objective of this task was to compare the geophysical framework with locations of chemosynthetic communities, surface features, and subsurface structures, such as faults. In addition, we wished to use the observational framework developed in this study for implications about the geologic formation and evolution of hydrocarbon seeps.

METHODS

We studied four well-known seep sites located on the Louisiana continental slope in the Green Canyon and Garden Banks lease blocks areas (Figure 1C.1). These sites are located in or near lease blocks GC 184, GC 234, GB 386, GB 425 at depths from 535 to 600 m. GC 234 is located along a portion of a tensional fault between salt diapir ridges (Behrens 1988). The other sites are all mounds located either on the flank of a salt diapir (GC 386, GB 425) or on a fault radiating from a salt diapir (GC 184).

The primary data for this study were 25 kHz echo sounder profiles, 77 kHz side-scan sonar images, and bathymetry data acquired with the U.S. Navy research submarine *NR-1*. The bathymetry yielded

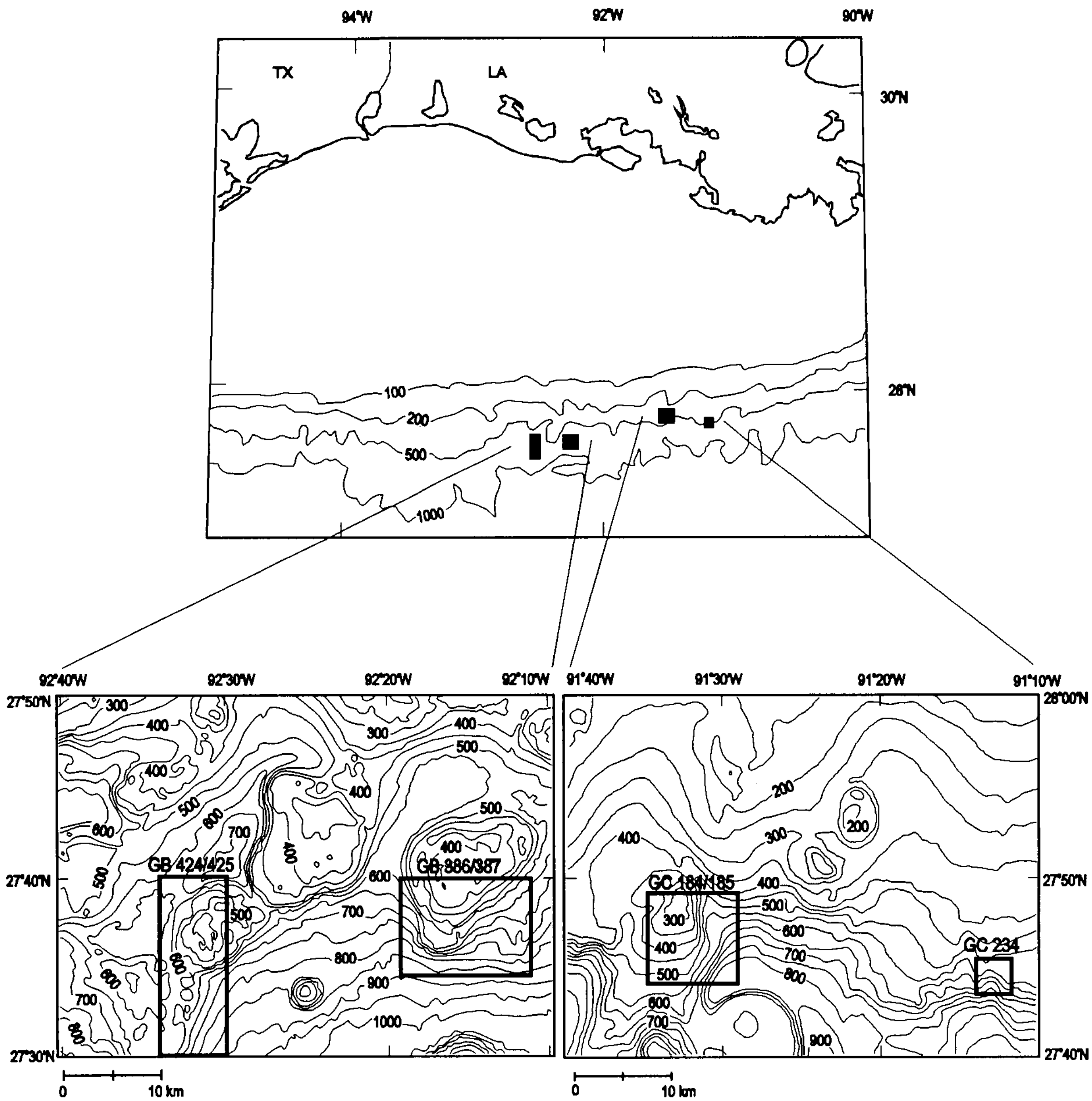

Figure 1C.1 Location of study areas. Simplified bathymetry of the Louisiana slope shown at top; bottom panels show multibeam echosounder bathymetry in vicinity of study areas. Boxes show areas of detailed study. Contours labeled in meters.

the morphology of the seep sites, and the side-scan sonar gave a high-resolution acoustic images of surface features, whereas the echo-sounder probed the shallow subbottom sediments. The geophysical instruments were mounted on the lower hull of the submarine, which was sailed at an a more-or-less constant altitude of several meters above the seafloor, typically at a velocity of one to two knots. Most surveys consisted of lines spaced approximately 30 to 100 m apart, giving more than 100% overlap of the side scan images from adjacent tracks. With the geophysical data, we constructed and compared bathymetric charts, sonar backscatter images, and maps of acoustic reflection character.

Geologic ground truth data were provided by analysis of 0.5-m push cores, visual observations, and video photography obtained with the submersible *Johnson Sea-Link* as well as 3-m piston cores acquired aboard the R/V *Gyre*. Sea surface geophysical data were available for all four sites, but these data were diverse in type and parameters because most were borrowed from industry sources.

RESULTS

Acoustic Echo Types

Echo sounder records were divided into six characteristic types (Figure 1C.2), based on the amount and type of apparent alteration of the sediment layers. These types are as follows:

Type 1: Characterized by a strong reflector at the seafloor and no apparent acoustic penetration into the subbottom. The strong reflector is probably carbonate or gas hydrate at or near the seafloor and has a high reflection coefficient, so that most of the acoustic energy is reflected or attenuated near surface. Cores within these zones were typically short and contained carbonate rocks, usually within the upper 20 cm, as seen for example in core GB386-A from the seep mound in GB 386 (Figure 1C.3). Side-scan mosaics often showed rough topography in these regions and when viewed by submersible, carbonate outcrops were often observed.

Type 2: Shallow penetration with an abrupt termination of acoustic penetration. This signature probably represents a thin layer of mud overlying a hardbottom, such as carbonate or hydrate. It may show areas in which recent mud flows have covered a pre-existing hard substrate. Such zones usually appeared no different from surrounding sediments when seen in side-scan images or from a submersible, because of the covering of sediment. Cores taken in these areas, however, showed similar features to Type 1 area cores, but the hard layers were buried below the surface. Push cores from a Type 2 area on the seep mound in GC 184 typically contained mud with disseminated carbonate, but one had nodular carbonate at its bottom. About half of these push cores showed traces of oil. Core GB425-A, from a similar zone on the flat-topped mud mound in GB 425, retrieved muds of two different colors, separated by an expansion void above which were small vesicles and a band of dark mud (Figure 1C.4). This core seems to show the boundary between two layers, presumably that seen in the echo sounder records. Moreover, the gas expansion feature suggests the buried strong reflector may have been a gas hydrate layer.

Type 3. Scattered subbottom echoes without continuous horizontal internal reflectors. Such a pattern probably shows non-layered sediments altered by oil, gas, disseminated carbonate precipitates, or hydrates.

Type 4. Scattered subbottom echoes with indistinct, horizontally continuous reflectors. This signature probably represents layered sediments disturbed by gas, oil, or carbonate precipitates. Types 3 and 4 are similar, except for the existence of internal reflectors, which are likely related to the original deposition of the sediments. Core GB425-D was recovered from a Type 2 zone and it yielded mud permeated with carbonate nodules, oil stains, and shell fragments. All three components are potential scatterers of acoustic waves (particularly if the oil is accompanied by gas) and may therefore be the source of the apparent alteration of the sediments noted in reflection profiles.

Type 5. Zones in which acoustic energy is abruptly attenuated; typically laterally continuous features disappear within these zones. Although we had no core samples of Type 5 acoustic wipeout zones, because they occurred rarely in our study areas, this type of acoustic behavior is widely recognized as the signature of gassy sediments (Behrens 1988; Hovland and Judd 1988; Anderson and Bryant 1990).

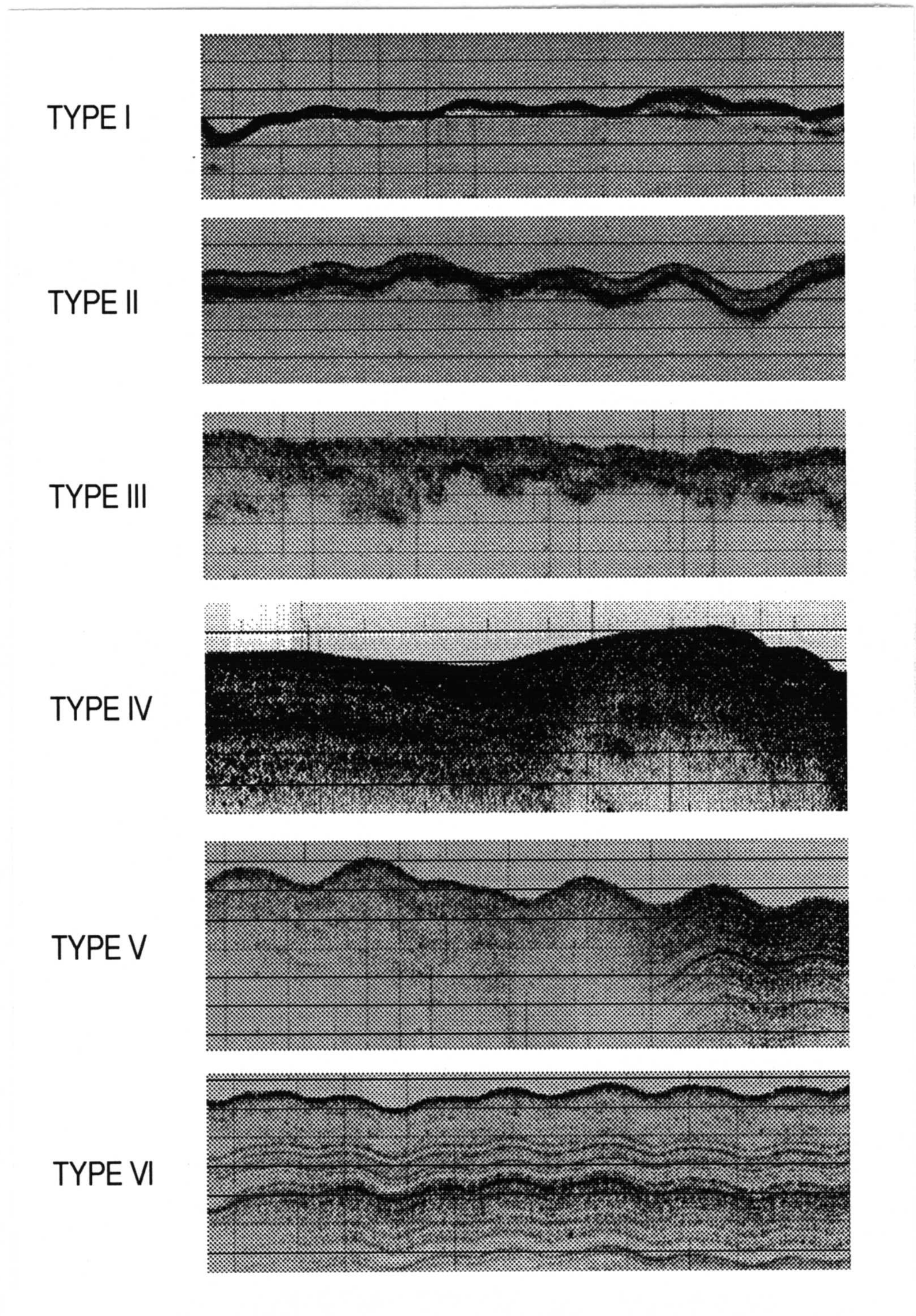

Figure 1C.2. Examples of echo types observed in 25 kHz subbottom-reflection profiles from the study sites. Distance between horizontal lines is 5 feet in seawater.

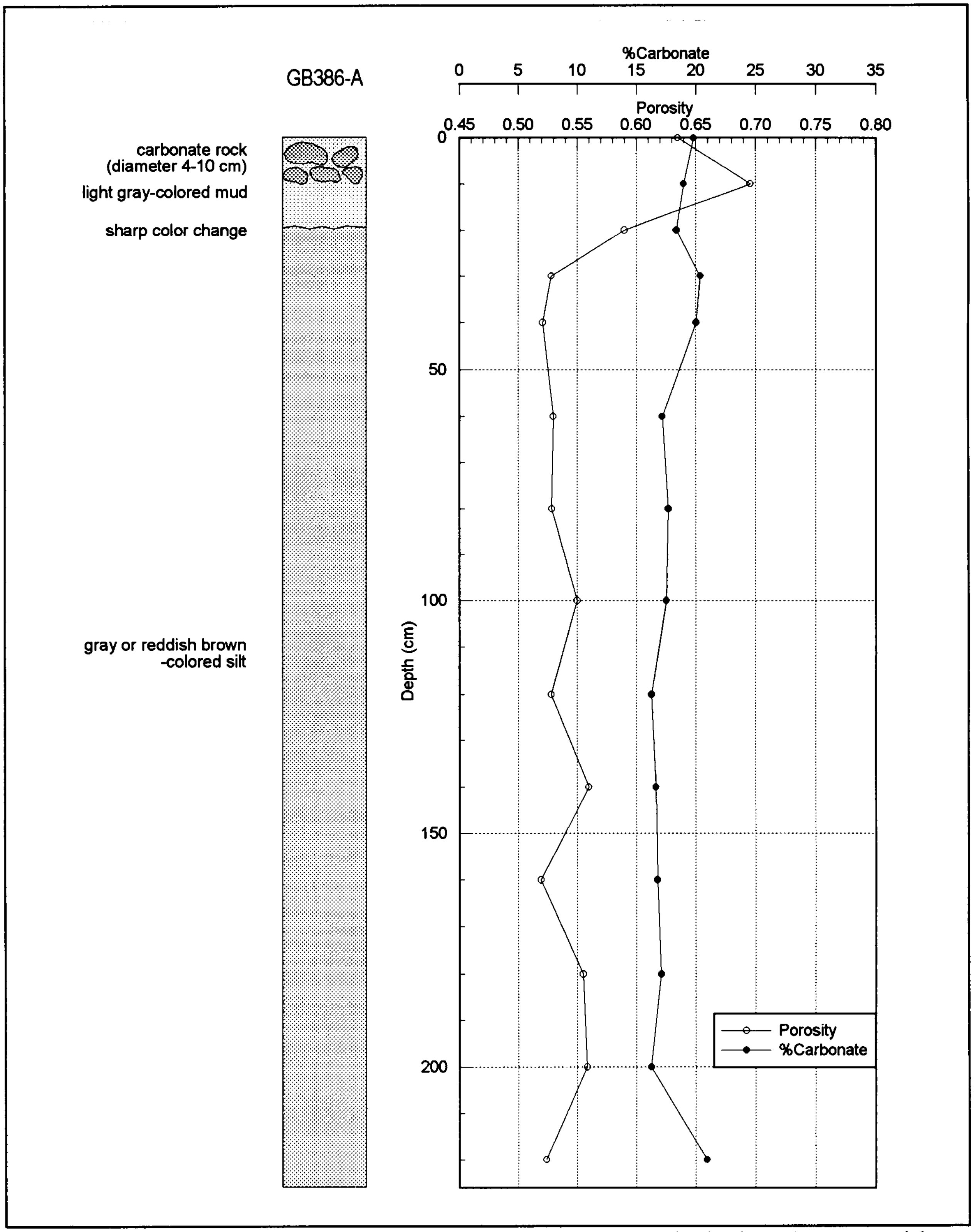

Figure 1C.3. Description of Core GB386-A: from a Type 1 echo type (hard substrate) zone. At right are trends in carbonate percentage and porosity.

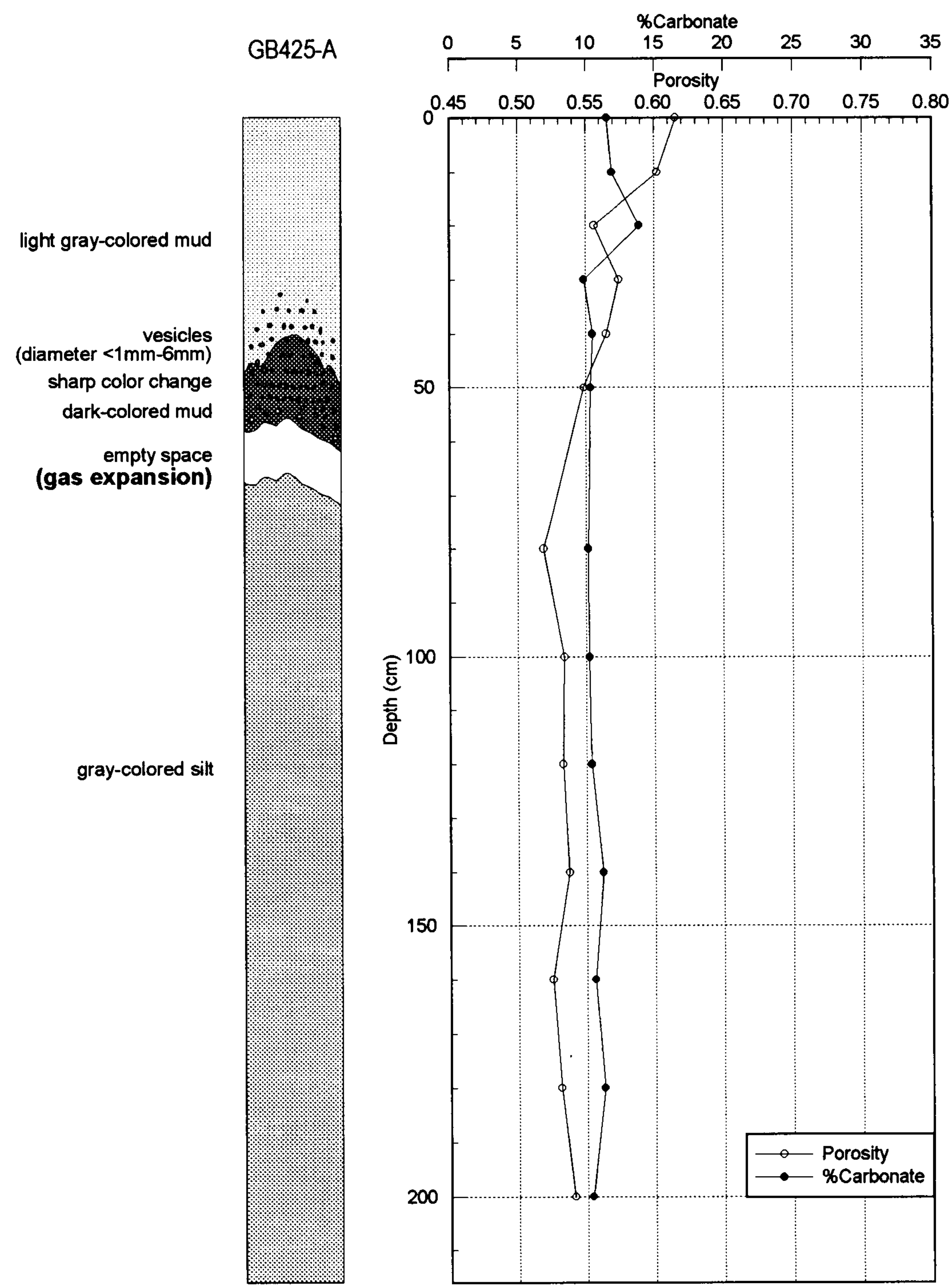

Figure 1C.4. Description of Core GB425-A: from a Type 2 echo type (buried hard substrate) zone, showing evidence of buried hard substrate. At right are trends in carbonate percentage and porosity.

Type 6. Parallel, continuous subbottom reflectors. These characteristics denote normal, undisturbed hemipelagic sediments. Several cores obtained from Type 6 zones in the GB 386 and GC 234 study areas contained hemipelagic muds with little evidence of alteration by hydrocarbon seeps and were similarly lacking in shell fragments and authigenic carbonates.

Distribution of Echo Types

Within the seep areas we studied, the echo types appear in two different patterns. The seeps that are characterized by mounds, such as GC 184, GB 386, and GB 425, and GC 184, are characterized by either Type 1 (hard substrate) or Type 2 (buried hard substrate) over the mound itself (Figures 1C.5, 1C.6, 1C.7). These two reflection types show hard substrates at or near the surface, owing to active or recently active precipitation of carbonate or hydrate. The Type 2 signatures may indicate recent mud flows that have buried a previous hard substrate, as interpreted from submersible observations at GB 425. That hard substrate is often at or near the present-day seafloor, suggests that with time, the covering of sediments is probably incorporated into the hard substrate, so that the hard reflector moves upward through the sediment column or that erosion may uncover the substrate. Given the uniformity of the burial or exposure of most hard substrate reflections, it seems that the upward movement is probably the most likely occurrence. On the other hand, the pattern of Type 1 and Type 2 occurrence is slightly different at each site. GB 386 has Type 1 over the mound summit and Type 2 around its edges (Figure 1C.6), whereas the distribution on the GB 425 mound is almost opposite (Figure 1C.7). GC 184 appears different from the other two because the areas of Type 1 echoes are patchy and scattered (Figure 1C.5). These differences probably reflect a variability in the occurrence of carbonate or hydrate, which in turn may signify variability in the structure of the mounds and hence the geometry of hydrocarbon seepage.

Around the mounds, the echo types are variable, apparently dependent on the areal extent of the seepage zone. GB 386 seems to be an isolated seep mound, as it is surrounded by undisturbed Type 6 sediments (Figure 1C.6). Both GB 425 and GC 184 are evidently part of extensive zones of seep alteration that are larger than the survey areas. In GB 425, Type 1 and Type 4 sediments surround the mound (Figure 1C.7), whereas in GC 184, Type 3 sediments surround the mound (Figure 1C.5). In both cases, sea surface geophysical survey data indicate that the study areas are only small parts of larger zones of seepage.

GC 234, which has no large mound structure, has echo type patterns that are clearly different from the other sites (Figure 1C.8). Here, the distribution is complex, but mainly consists of small patches of Type 1 (hard substrate), Type 3 (disturbed sediments), and Type 5 (acoustic wipeout) within an area of Type 6 (undisturbed) sediments. The occurrence of Type 1 and Type 5 reflections, scattered in patches throughout the survey area, seems to indicate that carbonate or hydrate formation and gas seepage are widespread along the fault scarp and not as localized as at the mound sites.

Backscatter Mosaics

Acoustic backscatter patterns in the side-scan sonar records seem to show mainly the effects of small scale topography; this topography is extremely variable in its appearance at the sites we studied. In some instances, the topography is apparently related to mound structure or formation because the topographic features follow the bathymetric contours, such as curved ridges at the edges of the mounds in GB 386 and GB 425.

In some locations, the topography appears to be rock outcrop. In the images, such features appear as small scale roughness or clusters of mounds (Figure 1C.9). The roughness, blockiness, and clear acoustic shadows cast by these features suggests they are outcrops. Probably these outcrops consist mainly of authigenic carbonate; however, in some such areas, rock outcrops are not apparent and the small scale roughness may be in part caused by clusters of tube worms (e.g., at GC 234) or even by hydrate mounds (MacDonald *et al.* 1990). Our study indicates that these outcrop zones are often correlated with Type 1 hard substrate reflection patterns. Furthermore, at GC 234, at least, many of the "outcrops" are more or less linear and seem to be correlated with faults mapped in multichannel seismic data (Figure 1C.10). Thus, the "outcrops" may represent the effects of seepage along the fault traces at the seafloor.

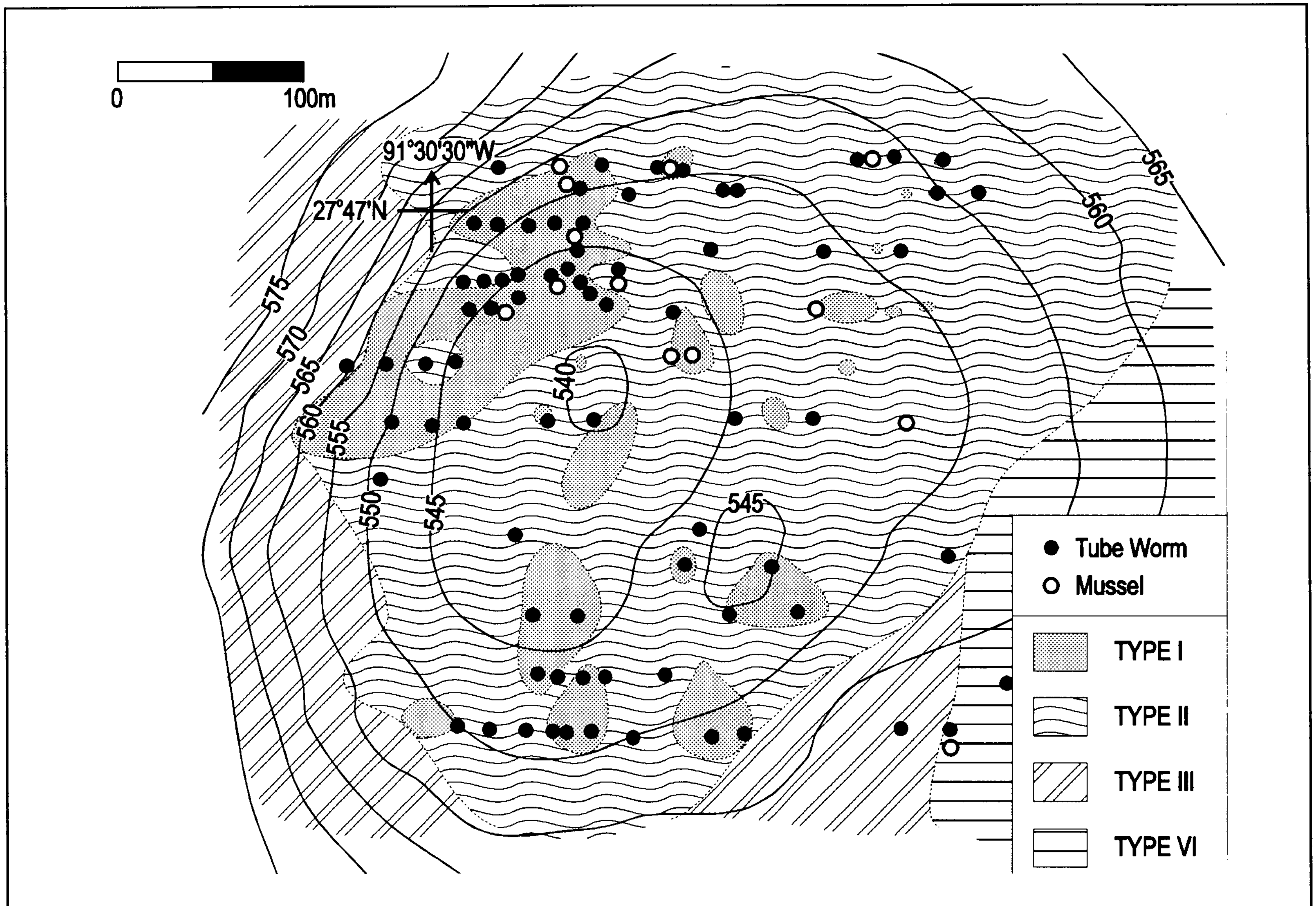

Figure 1C.5. Distribution of echo types, defined from 25 kHz subbottom-reflection profiles, in the vicinity of the seep-related mound in the GC 184 study area. Echo types are shown in Figure 1C.2. Observed chemosynthetic organism locations are shown by open and filled circles. Bathymetry contours shown at 5-m intervals.

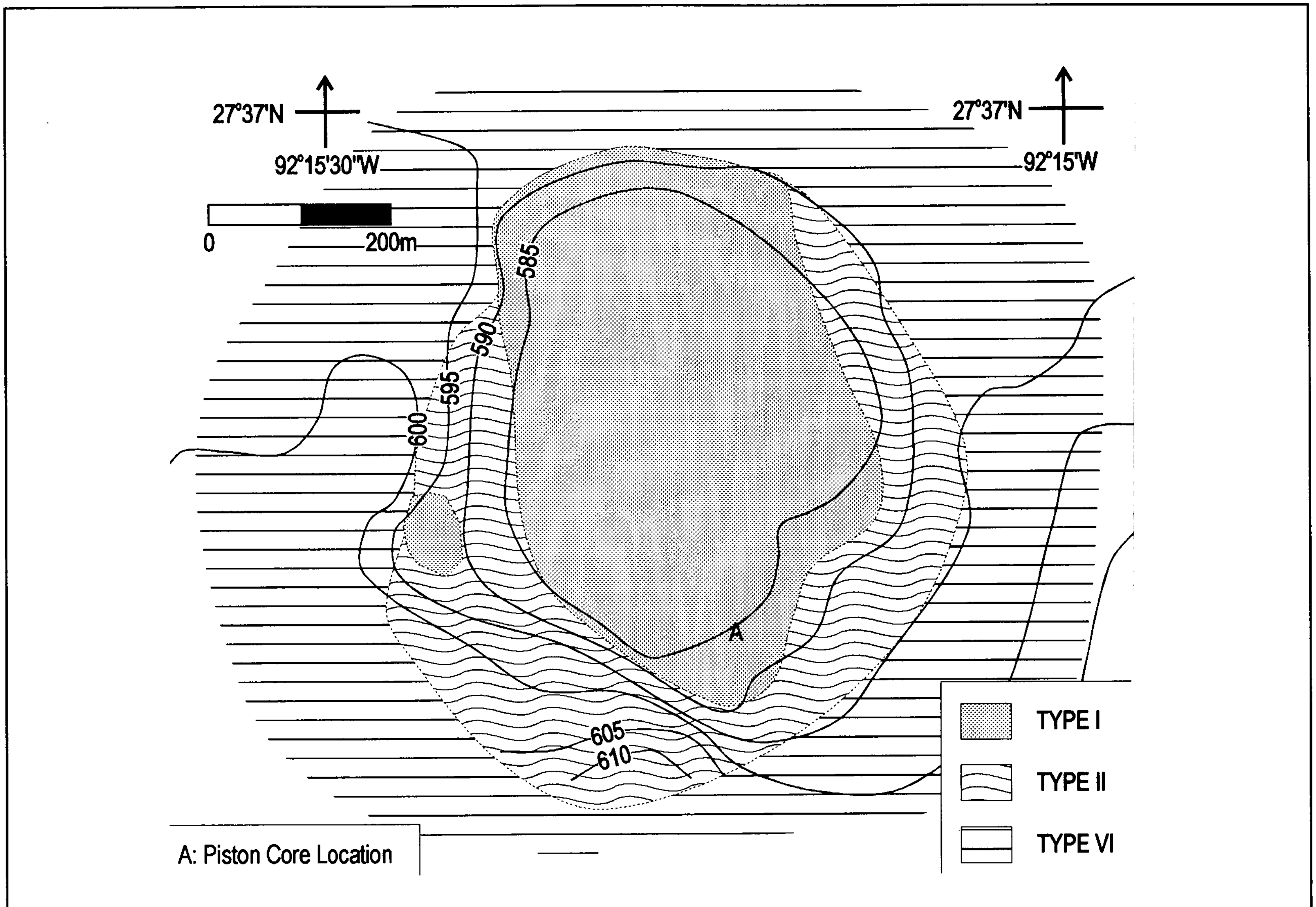

Figure 1C.6. Distribution of echo types, defined from 25 kHz subbottom-reflection profiles, in the vicinity of the seep-related mound in the GB 386 study area. Echo types are shown in Figure 1C.2. Bathymetry contours shown at 5-m intervals. Core locations denoted by letters; capitals signify piston cores, whereas lower case represent push cores.

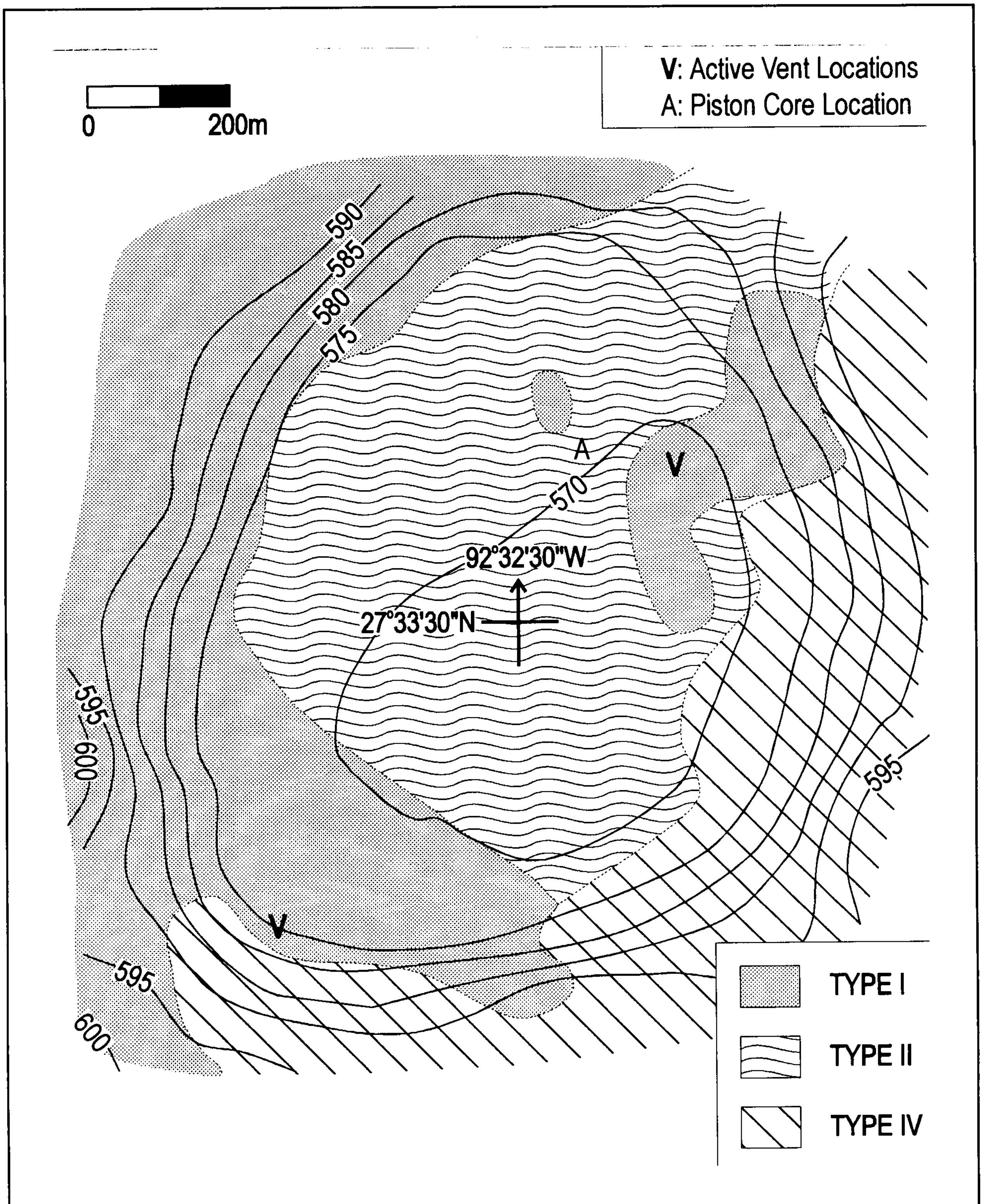

Figure 1C.7. Distribution of echo types, defined from 25 kHz subbottom-reflection profiles, in the vicinity of the seep-related mound in the GB 425 study area. Echo types are shown in Figure 1C.2. Bathymetry contours shown at 5-m intervals. Core locations denoted by letters.

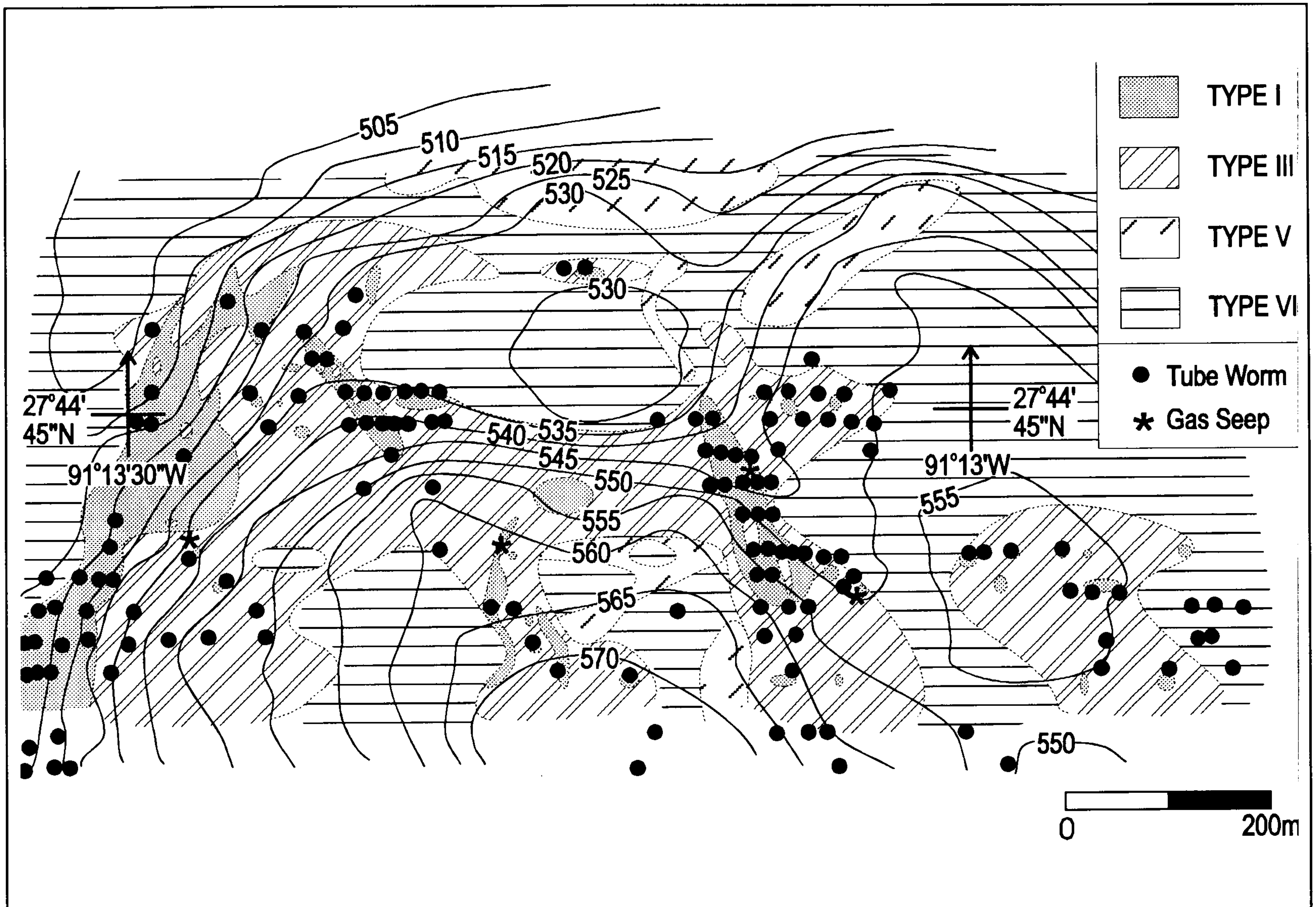

Figure 1C.8. Distribution of echo types, defined from 25 kHz subbottom-reflection profiles, in the vicinity of the seep-related mound in the GC 234 study area. Echo types are shown in Figure 1C.2. Observed chemosynthetic organism locations are shown by filled circles; gas seep locations shown by stars. Bathymetry contours shown at 5-m intervals.

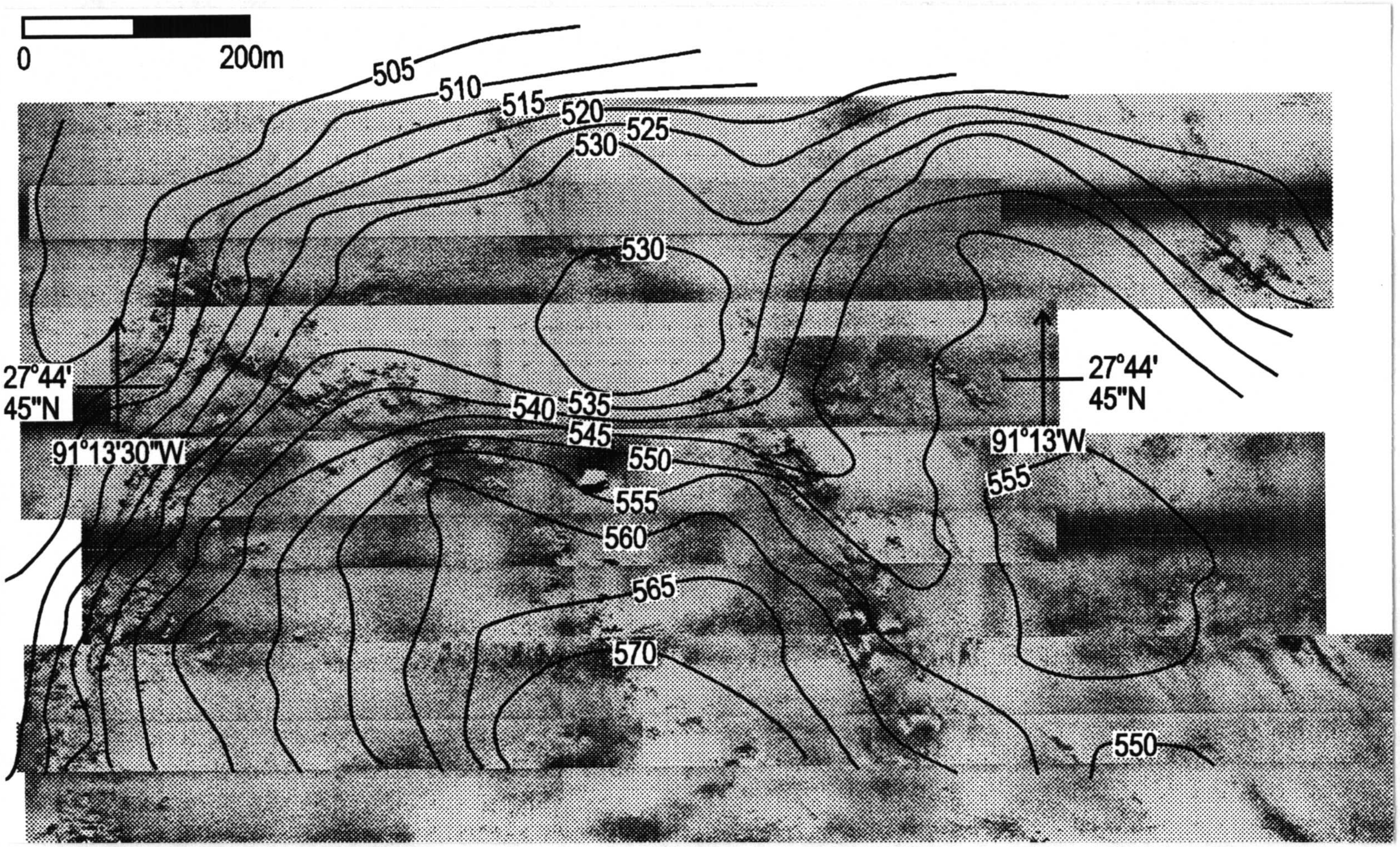

Figure 1C.9. Side-scan sonar mosaic of the GC 234 detailed study area. Dark areas show strong acoustic backscatter, whereas light areas show weak backscatter or acoustic shadow. Bathymetry contours, at 5-m intervals, are overlaid.

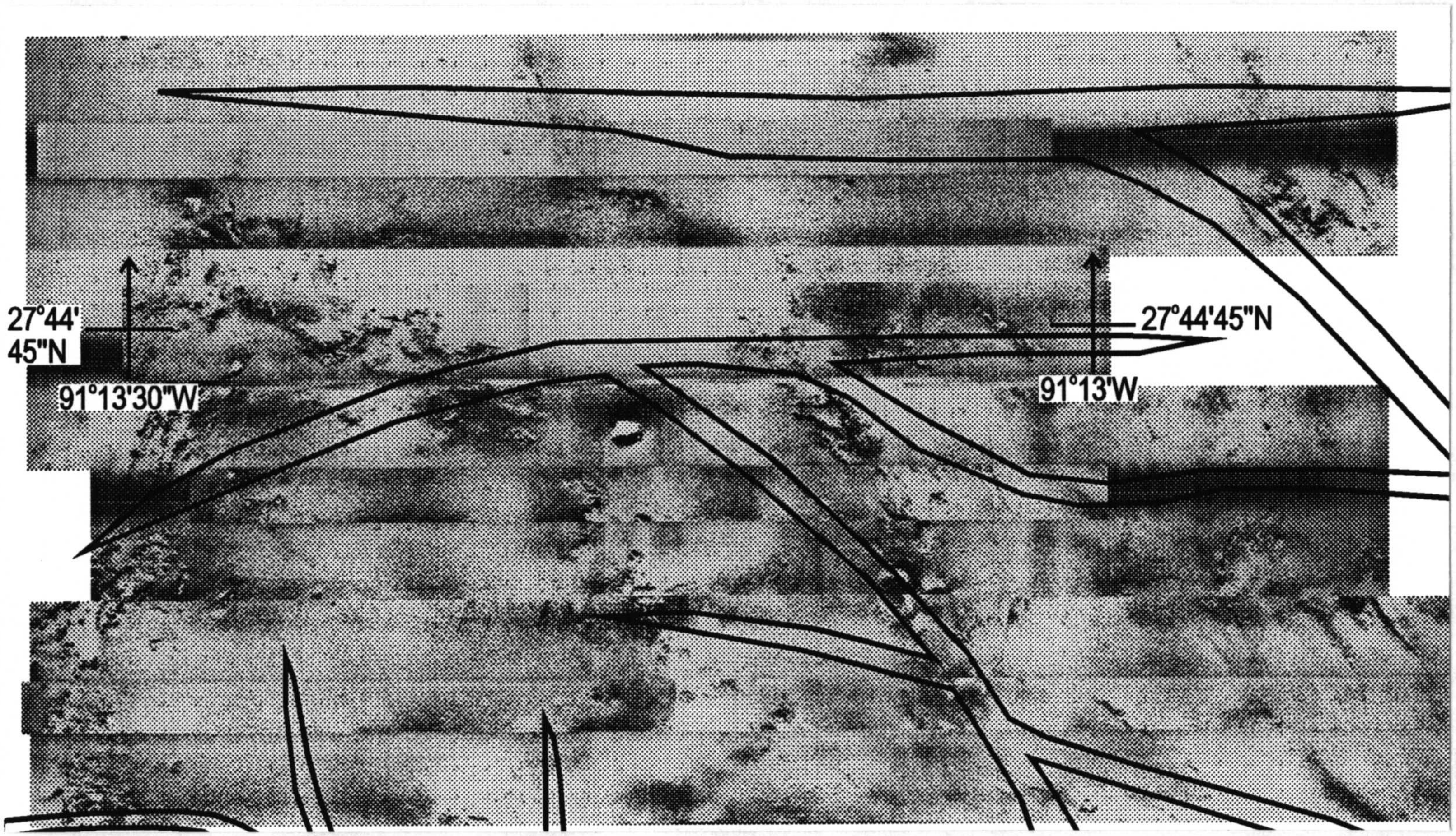

Figure 1C.10. Comparison of the GC 234 side-scan sonar mosaic and fault traces (heavy lines) mapped with multi-channel seismic data (J. R. Reilly, personal communication, 1994).

Relationship of Geophysical Signatures and Seep Organisms

Within the limitations of our data set, we note a good correlation among hard substrate reflections, "wipeout" zones, "outcrops" on side-scan sonar images, and the locations of chemosynthetic organism clusters. Comparison of echo types and chemosynthetic organism sitings shows that at GC 184, 97% of tube worm bush locations and 92% of bivalve sitings are within areas classified as having Type 1 or Type 2 reflection characteristics (Figure 1C.5). At this site, almost all of the seep mound shows these two reflection types, so we could also say that 96% of all chemosynthetic organisms are on the mound. The lack of organisms off the mound, even within the small survey area is striking. At the site in GC 234, the situation is slightly different. No Type 2 reflections were noted, but much of the seep zone is characterized by Type 1 or Type 3. Here there is a clear clustering of organisms near zones characterized by these two reflection types (Figure 1C.8). Although 86% of the organisms are located on Type 1 or Type 3 reflection zones, only 46% are located on Type 1 hard substrate reflectors, implying that Type 1 areas are not required as community sites.

These observations indicate a clear preference of chemosynthetic organisms for sediments showing Type 1, Type 2 (both hard substrates), and Type 3 (shallow disseminated seep products) characteristics. This is probably the result of two factors. First, these are areas where there has been a significant precipitation of authigenic carbonate, which may form a solid substrate to which organisms, such as tube worms, can attach themselves. Second, such areas also have high concentrations of seeping hydrocarbons, hence the massive carbonate precipitation, so the organisms find at such locations the hydrocarbons needed to produce food.

DISCUSSION

Hydrocarbon Seep Sediment Alterations

Tensional faults are one of the primary effects of deep salt movement on the sediment column of the Gulf of Mexico continental shelf and slope. These faults may dissect hydrocarbon reservoirs within the sediment column, allowing gas and oil to escape by providing both a break in the reservoir seal and an upward pathway. In order that the hydrocarbons reach the sea floor, it is probably necessary that the faults are large, or genetically related to one that is large, and also active. Only large faults will usually penetrate sufficiently deep to tap a mature reservoir and also provide sufficient offset to break through impermeable formations. Likewise, only active or recently active faults will break through to the sea floor, and this is necessary to let the hydrocarbons escape. In our study areas, which are limited in geographic extent, all of the seeps occur either on the flanks of salt diapirs or along a fault system formed between two diapirs. This implies that the diapirs are the locus of most intense deformation and hence the most likely locations for seeps to occur.

When hydrocarbons reach the seafloor, they have several geologic effects. The hydrocarbons change the characteristics of the sediments, causing alterations that can be imaged by acoustical methods. They may also entrain sediments, causing the formation of seep mounds.

The effects that perturb acoustic signals can be divided into two classes: the results of gas within the sediments and the results of materials precipitated within the sediments. The gas causes attenuation of the acoustic waves and the result is a zone of "acoustic wipeout" (signal loss) or "turbidity" (reverberation) where subsurface reflections are not seen (Hovland and Judd 1988; Anderson and Bryant 1990). This is the Type 5 reflection character noted in our study. The precipitates either cause acoustic "turbidity," the scattered, amorphous reflections within the sediment column, or a hard substrate that reflects most of the acoustic energy. Hard substrates may be caused by the precipitation of massive carbonate layers and blocks (Roberts *et al.* 1990) or by the formation of gas hydrate layers. We see these as the Type 1 and Type 2 reflections within our surveys. Carbonates can also be disseminated as macro- or micronodules (Behrens 1988; Roberts *et al.* 1990) and thus cause acoustic turbidity by the diffraction of acoustic energy throughout the affected sediment column. These effects cause Type 3 and Type 4 reflection characters in our study areas.

The formation of a seep mound implies the localization of the seep to nearly a point source. Interestingly, the three mounds we studied are all located on the flanks of salt diapirs, whereas the one site without a significant mound is along a fault system between diapirs. This may indicate that seeps next to diapirs are more likely to be localized, perhaps within a narrow fault, whereas those between along wider fault zones are less likely to be constrained and localized.

Our observations suggest that the mounds are formed by flows of low viscosity mud, like a "mud volcano," rather than by the diapiric rise of a mud body. Evidence in favor of this hypothesis is as follows. Low viscosity and fluidized sediments are inferred from observations of fresh mud flows and the active eruption of gas and oil-charged mud from vents on the summit of the mound in GB 425. In addition, a layer of fresh, buried mussel shells in a core from near GC 234 indicate that the shells were quickly buried by a mud flow, before the shells could be degraded by post-mortem contact with sea water. That these mounds are not diapiric is inferred from industry multichannel seismic reflection profiles that appear to show continuous layers beneath the GB 386 and GC 184 mounds. This observation implies that the sediments were not deformed by diapiric action.

Our observations also suggest that there are at least two types of mounds: those with rounded summits and those with flat-topped summits. The one rounded-summit mound we studied, in GC 184, is asymmetric and has Type 1 reflections and chemosynthetic organisms occurring mainly on one side of the mound (Figure 1C.5). These asymmetries suggest that the source of the hydrocarbons, probably the fault beneath the mound, lies under the west side of the mound. The flat-topped mounds appear more symmetric in cross-section. In addition, observed hydrocarbon venting on the GB 425 mound occurs only at locations along the edge of the summit platform. We suggest that the middle of the summit, which shows mostly Type 2 hard substrate reflections, is impermeable to hydrocarbon migration, perhaps because it is capped by hydrate or carbonate, and this causes the hydrocarbons to vent around the edges of the summit (Figure 1C.11).

Interestingly, the flat-topped mound in GB 386, which has hard substrate at the surface (Figure 1C.6), is not a site of abundant and varied chemosynthetic communities, whereas GB 425, which has a thin sediment covering a top hard substrate (Figure 1C.7), is inhabited by many different species of chemosynthetic organisms. This difference may indicate that the GB 425 mound is more active, expelling more mud, gas, and oil, and hence this is the reason for the greater numbers and variety of chemosynthetic organisms.

Chemosynthetic Organisms and Geophysical Signatures: Finding Seep Communities by Remote Sensing

Our study suggests that geophysical techniques can be used to narrow the areas of detailed study needed to locate and classify chemosynthetic communities. Ultimately, there is no geophysical method that will allow the reliable identification of such communities while profiling from the sea surface. However, by using known geophysical signatures and affinities, likely locations can be localized for more detailed study.

Seeps are located along faults and faults are usually identified in regional seismic exploration profiling surveys. Thus, the first step in locating chemosynthetic communities is to map the faults along which seeps could occur. The likeliest faults to harbor seeps are those which are active and thus extend to the surface and those which show a significant displacement.

Having found the faults, the next step would be to look for seep related topography and sediment alteration. Topographic features would be mud mounds, carbonate mounds, and pock-marks. The mud mounds are typically more than 10 m in height and more than several 100 m in diameter and would be evident on high-resolution bathymetry maps and side-scan sonar images. Carbonate mounds can be somewhat smaller, one to a few meters high and 10 m wide, or less. In addition, pock-marks are variable in size, from small shallow craters a few meters across to large craters many meters deep and hundreds of meters wide.

Sediment alterations can usually be found using acoustic profiling and imaging techniques. On side-scan sonar records, the alteration can appear as an increase in backscatter, particularly in conjunction with small mounds. In 3.5 Khz and other echo sounder profiles, the alteration may show up as an attenuation of signal reflections ("wipe out"), as an enhancement (hard substrate), or as reverberation ("turbidity"). These are caused mostly by gas,

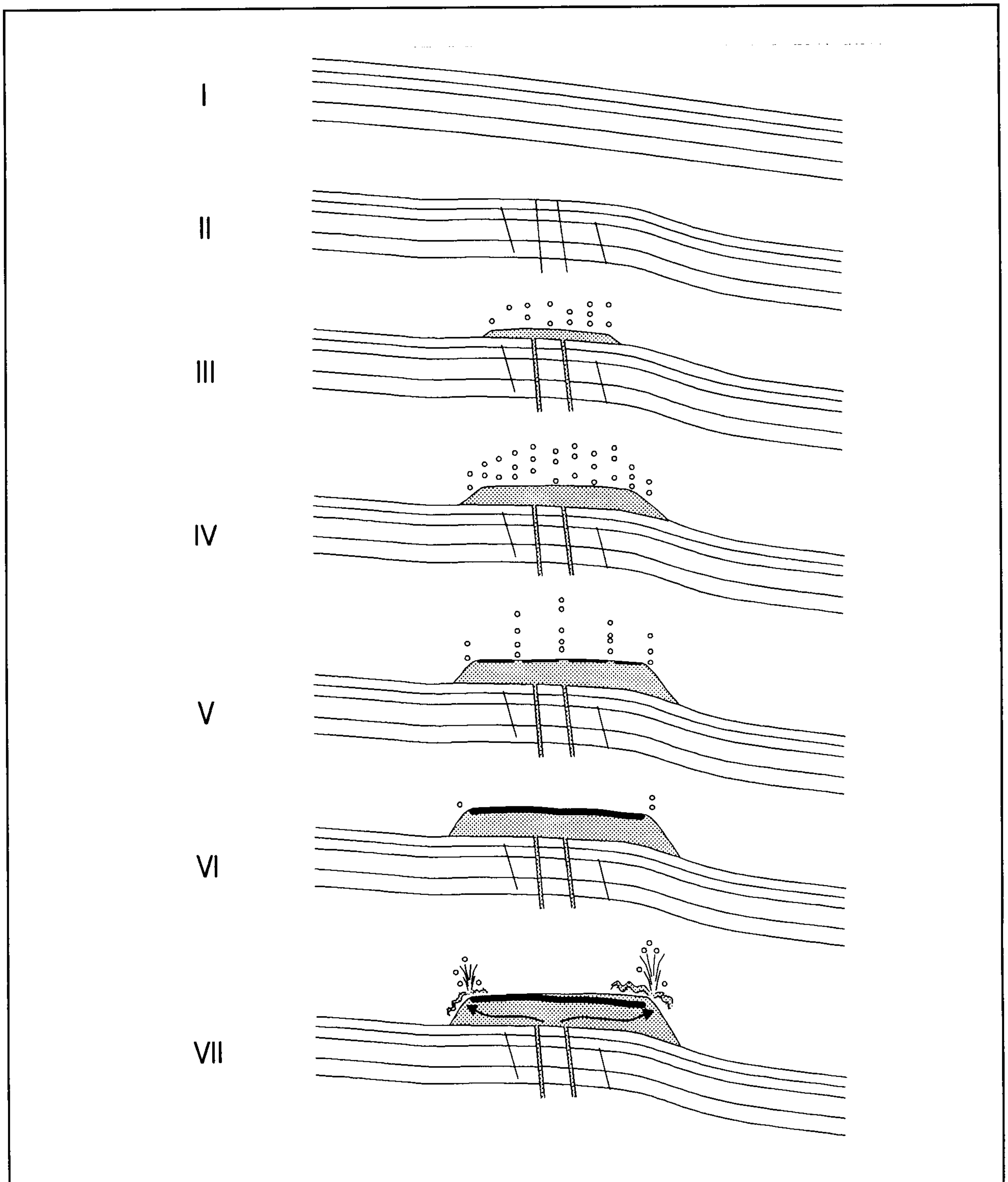

Figure 1C.11. Model for the formation of flat-topped seep-related mud mounds. Faulting associated with salt movement (II) creates fluid conduits (III). Fluid sediment slurry, propelled by rising gas and oil, vents along the fault zone and spreads radially from vent to build mound (IV). Authigenic carbonate precipitation and gas hydrate emplacement form a relatively impermeable cap at the mound top, so that vents are localized to the edges of the summit (VI and VII).

carbonate layers or disseminated nodules, or hydrate layers. In addition, if the seepage is particularly strong and contains much gas, the gas bubbles may be detected within the water column by these acoustic methods (Anderson and Bryant 1990).

Having located areas of larger scale topographic features or sediment alterations caused by seepage, a more detailed examination is necessary. To locate chemosynthetic communities, various ultra-high resolution imaging methods are needed. Side-scan sonar images will show carbonate outcrops, and may even show tube worm bushes or bivalve clusters if the resolution is high enough and the organisms are dense enough. Typically, this will require a deep-towed sonar or sonar affixed to a submersible, so that the acoustic source and target are not greatly separated. However, many chemosynthetic organisms, such as bivalves, may be invisible. Underwater photography, such as with a camera sled or a laser line-scan device can provide visual sitings, as can submersible dives. Although these last are slow and painstaking techniques, presumably they can be directed, using a nested search technique employing increasingly higher resolution methods, so that the time consuming visual searches can be minimized.

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PALEONTOLOGY OF SEEP BIVALVE COMMUNITIES

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Chemoautotrophic benthic assemblages have been discovered on the continental slope of Louisiana in the Gulf of Mexico. These communities are associated with petroleum seepage, and resemble those assemblages found at hydrothermal vents (Kennicutt *et al.* 1985 and Brooks *et al.* 1987). Callender and Powell (1992) describe the prominent features of petroleum seep assemblages as high density, high abundance of large organisms, dominance by a single taxon, and low diversity. Six distinct biofacies have been recognized from petroleum seep assemblages; dominated respectively by mytilid mussels, vesicomyid clams, Lucinoma clams, thyasirid clams, vestimentiferan tubeworms, and the normal slope fauna. The long-term history of these seep assemblages is not well known. This study was designed to examine the long-term record of seep assemblages by comparing guild and tier structure, paleoenergetics, and changes in community composition of the six biofacies at a number of petroleum seep sites.

Seep assemblages from five sites, GC-184, GC-234, GC-272, GB-386, and GB-425, were sampled by submersible grabs and surface vessel box cores and piston cores. The grab and boxcore samples were used for guild and tier structure and paleoenergetics analysis. The piston core samples were sectioned at five centimeter intervals and are being used to investigate changes in community composition over thousands of years of accumulation, in addition to paleoenergetics and guild and tier structure analyses.

Autochthonous seep assemblages are characterized by a unique tier and guild structure, size-frequency composition, and animal density that together identify the paleoenergetics structure of these communities and distinguish them from other autochthonous assemblages of the shelf and slope. All seep assemblages were dominated by primary consumers, whereas the non-seep assemblage was dominated by carnivores. Carnivore dominance seems to be typical of shelf (or euhaline) death assemblages. Seep assemblages, in contrast, retain the theoretically-expected rarity of predaceous forms in fossil assemblages. The infaunal tier was well represented in most petroleum seep assemblages because a large fraction of the shelled biota were infauna or semi-infauna. Dominance by shelled infauna is unusual. Local enrichment of food resources and the dominance of shelled primary consumers explain the guild and tier structure of seep assemblages. Nearby autochthonous and parautochthonous assemblages relying on planktonic production are substantially different in each of these criteria. The non-seep autochthonous assemblages were dominated by epifauna and semi-infauna as is typical for continental shelf and slope assemblages.

A hindcasting paleoenergetics model was used to estimate the energy demand of both seep and non-seep assemblages. The basic paleoenergetics equation is as follows:

$$A_{Lt} = P_{gLt} + P_{rLt} + R_{Lt}$$

where A_{Lt} is the energy assimilated over the individual's life span, P_{gLt} is the portion of net production devoted to somatic growth, P_{rLt} is the portion of net production devoted to reproduction, and R_{Lt} is the amount of energy respired over the organism's life span. The two important products of the hindcasting model are paleoproduction and paleoingestion. Paleoproduction is equal to the individual's biomass-at-death, while paleoingestion is the assimilated energy divided by the assimilation efficiency,

$$I_{Lt} = A_{Lt} (A/I)^{-1}.$$

Hindcasting of energy demand based on the observed biomass as preserved and an estimate of sedimentation rate shows that energy demand by the community exceeds the supply from planktonic rain in seep communities, a crucial verification of the adequacy of the hindcasting model.

Bathymodiolus sp., *Lucinoma atlantis*, and *Thyasira oleophila* shells were radiocarbon dated from the seep sites at GC-234, GC-184, and GB-425, respectively. A calibration curve of amino acid dating was used to increase the number of lucinids and thyasirids that could be aged. Piston cores from the "Mussel Beach" area of GC-234 recovered two buried mussel beds. The first bed, centered at about 95 cm depth, contained shells estimated to be between 2,000 and 3,000 years old. Mussels from the deeper bed, at about 195 cm were estimated to be between 3,000 and 4,000 years old. Thus, the two mussel beds were approximately 1,000 years apart in age. Both of these beds contained individuals in life position, and some of the mussels still had byssal thread attachments, indicating the importance of catastrophic burial in the preservation of mussel beds. The lucinids from GC-184, at 68 centimeters depth, were calculated to be over 3,500 years old, while the GB-425 thyasirids at 40 cm depth were 500 to 1,000 years old. The lucinids from a depth of 10 centimeters at GC-272 were found to be modern in age, and no deeper individuals were encountered.

We also developed a computer program designed to reconstruct the original abundance and size-frequency distribution from a collection of bivalve fragments. The need for this shell reconstruction program comes from the fact that many seep bivalves are obtained in fragmented condition due to taphonomic processes.

A primary attribute of the program design was the use of simple readily measured characters (shell length, width, thickness, weight) allowing rapid analysis of shell fragments. The program was tested using a mussel, two lucinids, and an arc shell. In each case, the whole shells were measured, broken into a minimum of three to four pieces, and then remeasured. Numerical abundance was slightly overestimated and size-frequency skewed slightly towards smaller size classes. In terms of paleoproduction and paleoingestion, these errors proved of little consequence. This computer program was then applied to the seep mussel, lucinid, and thyasirid fragments from the piston cores. The size-frequency distributions of the reconstructed thyasirid populations were similar to those of the whole shells present in the cores, with most individuals being over 50% of the species maximum size. The reconstructed seep mussel size-frequency distributions, on the other hand, revealed that there were both very small and very large individuals, but most were in the middle-size classes.

Combining detailed sampling of cores, reconstruction of fragmented individuals and paleoenergetics analysis permits the study of the persistence and resilience of seep communities. Some sites retained optimal habitat for some species continuously over geologically-long time periods of time. More commonly, however, habitat optimality varied substantially over time scales of 300 to 500 years. Local extinctions and recolonizations occurred, and these seemed to occur fairly rapidly in the context of the time span represented by the entire core or a portion of the core recording times conducive to a selected fauna. Thresholds of optimality seem to be present. Triggering mechanisms producing the rapid faunal changes are unknown, but could include small changes in sediment chemistry.

In the case of mussel beds, catastrophic burial was implicated in preservation, but the importance of catastrophic burial in fostering local extinctions seems to be minor. Most extinctions occurred quickly, but without hiatuses of faunally depauperate sediments that might be typical of catastrophic sedimentary events. Thus, one important characteristic of these sites was the degree of persistence of the chemosynthetic biota. A fauna was typically persistent over a time span of a few hundred years, but was typically not persistent over a time span of 300 to 500 years.

Faunal succession was not observed. When local extinctions occurred in the chemosynthetic biota, the biota was replaced by the normal slope biota or a mixture of a normal slope biota and the juveniles of chemosynthetic species that failed to survive to adulthood. Thus the only faunal transitions were between chemosynthetic and non-chemosynthetic faunas. Not one distinctive faunal transition between two chemosynthetic species was observed. Sites were always recolonized by the chemosynthetic species that had previously become locally extinct. Accordingly, the chemosynthetic faunas were resilient over long time scales, time scales of geological importance. The inescapable conclusion is that sites are more or less permanently conducive to only one, or at most two, chemosynthetic species. Site specificity is retained over geologically-long time frames. This suggests that site chemistry remains within a narrow range for geologically-long times and that the local variations in site chemistry are sufficient to control the presence or absence of the locally preferred chemosynthetic fauna at the expense of the background heterotrophic fauna.

The relatively low persistence but high resilience of the seep faunas indicates that sites retain a degree of uniqueness in their capacity to support seep faunas over geologically-significant time periods. In this study, only the Lucinoma sp. biofacies was found at more than one site. Significantly, this species was rarely persistent over long time spans and rarely did a significant number of individuals attain near-maximum size, so that this species was simply more capable of surviving in a variety of suboptimal habitats than were the other species. At least as important was the failure to sample habitats optimal for several important chemosynthetic species, namely the solemyids (a few were taken at GB-386), *Lucinoma atlantis* (occasionally collected at GB-425) and *Vesicomya cordata*. We suggest that at least three additional unique habitats remain unsampled and unsurveyed. Given the uniqueness of sites, we would expect these biofacies to dominate sites that are as yet unexplored rather than to be present but unsampled within already explored sites.

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SESSION 1D

GIS APPLICATIONS TO OIL SPILL CONTINGENCY PLANNING IN THE GULF OF MEXICO

Session: 1D - GIS Applications to Oil Spill Contingency Planning in the Gulf of Mexico

Co-Chairs: Dr. Norman Froomer and Dr. Shea Penland

Date: November 15, 1994

Presentation	Author/Affiliation
Introduction	Dr. Norman Froomer U.S. Minerals Management Service Gulf of Mexico OCS Region
MMS Gulfwide Information System (GWIS): A Consistent Regional GIS Database for Oil Spill Contingency Planning Based on Interagency and Industry Consensus	Dr. Shea Penland Ms. Karen Ramsey Mr. Ed Vigil Ms. Lynda Wayne Ms. Karen Westphal Mr. Chris Zganjar Louisiana State University Dr. Norman Froomer U.S. Minerals Management Service Gulf of Mexico OCS Region
Mississippi Oil Spill Planning GIS: Current Status and Future Plans	Mr. Stephen M. Oivanki Mississippi Office of Geology
Development and Application of the Florida Marine Spill Analysis System	Mr. Christopher A. Friel Florida Marine Research Institute

INTRODUCTION

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U.S. Minerals Management Service
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The Geographic Information System session at this year's ITM was associated with a cooperative effort between the MMS and Louisiana State University, Center for Energy and Environmental Research. The purpose of this project, which has been developed as part of the MMS Coastal and Marine Initiative (CMI), is to develop a GIS database for use in oil spill contingency planning in the Gulf of Mexico region. An important step in the project is to develop consensus among users on what data categories to include in the database and on sources of data. The MMS and LSU have established a Steering Committee for the project to help guide these, and other, decisions. The Steering Committee includes representatives of the major user groups of the database, including state and federal regulatory and resource protection agencies, and industry.

The ITM session was divided into two parts. During the first part, Dr. Shea Penland, LSU project director, presented an overview of project accomplishments to date and future objectives. He was followed by Steve Oivanki, Mississippi Office of Geology, and Mr. Chris Friel, Florida Marine Research Institute, who presented overviews of GIS database development and applications underway in their respective states.

The second part of the session was used for a Steering Committee meeting. The objective of the meeting was to develop a prioritized list of data categories for inclusion in the data base. A list that resulted from the meeting is included in the ITM proceedings.

MMS GULFWIDE INFORMATION SYSTEM (GWIS): A CONSISTENT REGIONAL GIS DATABASE FOR OIL SPILL CONTINGENCY PLANNING BASED ON INTERAGENCY AND INDUSTRY CONSENSUS

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Mr. Ed Vigil, Ms. Lynda Wayne,
Ms. Karen Westphal,
and Mr. Chris Zganjar
Center for Coastal, Energy, and
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ABSTRACT

The Minerals Management Service (MMS) established the Coastal Marine Institute (CMI) at Louisiana State University as part of the Center for Coastal, Energy, and Environmental Resources (CCEER) to promote environmental research related to the oil, gas, and mining industries. One of the primary initiatives of CMI is to create an environmental information program to support government and industry oil spill contingency planning needs in order to fulfill the Oil Pollution Act of 1990 and MMS compliance regulations. The MMS/Gulfwide Information System (GWIS) database will contain critical information about the location and character of environmental resources, infrastructure, and administrative boundaries that occur within the coastal region of the U.S. Northern Gulf of Mexico. Information needed to support the program will be collected from state and federal resource agencies, industry, and other data providers.

INTRODUCTION

Accurate, current information and base maps are essential to successful oil spill contingency planning and environmental analysis in the Gulf of Mexico (GOM). The GOM coastal zone will face an increasing risk of a major oil spill impacting the shoreline over the next decade as oil imports continue to increase and domestic oil and gas activities continue. The GOM will be one of the few regions in the United States where offshore oil and gas leasing will continue to pose new environmental challenges in the future. The environmental pressures on the coasts and waters of the Gulf of Mexico will continue to accelerate as population increases present greater demands for resources. Environmental data are therefore crucial to the accurate assessment of risks posed to these resources by the exploration, production, and transport of hydrocarbons in the GOM, and to the development of adequate oil spill contingency plans. In addition, conflicts in response actions and damage assessments can be minimized by developing needed data sets in cooperation with both government and industry. Over the past five years, government and industry have debated the accuracy and resolution of information on resources at risk used in oil spill contingency planning. All parties through the regulatory process agree on the need to develop a common system to distribute environmental information that meets the regulatory requirements and needs of both government and industry. The objective of the Minerals Management Service (MMS) Gulfwide Information System (GWIS) database is to create and manage mutually agreed-upon data sets for use by government and industry in meeting oil spill contingency planning and environmental analysis requirements.

The Regional Technical Working Group (RTWG) of the MMS Gulf Region also recognizes the importance of accurate environmental data and the need to establish an information center to support oil spill contingency planning and GIS environmental analysis by government and industry. In 1992 RTWG nominated a project to develop a regional center for oil spill contingency planning and environmental analysis (Regional Study No. GOM-A008). This project was ranked in the top five projects for the 1993 Regional Study Plan of the Environmental Studies Program (ESP). In addition, the Oil Pollution Act of 1990 and Executive Order 12777 have mandated a greater role for the MMS in oil spill contingency planning and environmental analysis.

The MMS GWIS database project will develop an information system for oil spill contingency planning and environmental analysis to support the requirements of government and industry. Vast amounts of environmental, infrastructure, and administrative and political information will be required to support the intended activities. To compile and manage such a complex data set, it will be necessary to utilize the advanced spatial data management capabilities of geographic information systems (GIS) technology, which enables users to map critical information with geographic positional accuracy. More important, however, a GIS provides a highly efficient framework for storing, retrieving, and analyzing both the maps and associated databases of information used to describe the maps.

GIS technology also provides a mechanism for maintaining spatial data in dynamic environments and enables the power of spatial associations to be more fully realized. By utilizing this advanced technology, the system will provide a substantial environmental data base that can be accessed by the MMS, other government agencies, and industry for various analyses and products that may be used for contingency planning, environmental assessments, leasing activities, regulatory decision-making, and other general management purposes.

GULFWIDE SUPPORT AND CONSENSUS FOR DATABASE

The objective of GWIS is to develop an authoritative database that will be used by MMS for oil spill contingency planning, as mandated by the Oil Spill Act of 1990, and by industry and other regulatory and resource protection agencies for oil spill planning and response. The current practice of using disparate data sources for oil spill planning and response fosters inconsistent interpretations and contention among the involved parties. To encourage consensus, GWIS has established a Steering Committee with members from industry, Federal agencies, and each Gulf state. The Steering Committee is involved in all major decisions concerning the design and composition of the database (Table 1D.1). Furthermore, many Steering Committee members have contributed cash and in-kind resources to the project. The Steering Committee members of the GWIS program are listed in Table 1D.2.

REGIONALLY COMPLETE AND CONSISTENT 'BOTTOM UP' DATABASE

The Gulf of Mexico coastal states are providing much of the data for the project. MMS and LSU are compiling and augmenting the data using an enhanced environmental sensitivity index (ESI) mapping framework to assure regional completeness and consistency. The enhanced ESI concept includes additional items in the database, expanded offshore geographic coverage, metadata for each geographic feature, information on level of effort and area covered by surveys, and procedures to assure regional consistency and completeness from local data sources.

APPLICATION INDEPENDENT DATABASE

While the primary purpose of GWIS is to develop a database to support oil spill contingency planning, another important objective is to compile a database that can be used for other environmental and planning applications. To assure this capability, the project, to the extent that resources permit, emphasizes the robustness of the data itself, not the specific application for which the data will be used. The objective is to have GWIS serve as a model and a first step toward developing a flexible and complete Gulf of Mexico database based on primary data.

Table 1D.1. The GWIS priority data layers for oil spill contingency planning identified by interagency and industry consensus.

I. Level One Priority Layers

A. Base Maps
- 1:2,000,000
- 1:100,000
- Texas 1:24,000
- Louisiana 1:24,000
- Mississippi 1:24,000
- Alabama 1:24,000
- Florida 1:40,000
- *Enhanced - ESI* Base Map 1:24,000

B. Shoreline Habitat Type
- exposed vertical rock shoreline/seawall
- sheltered/rock platform
- exposed rock platform
- exposed rip-rap
- sheltered rip-rap
- gravel beaches
- mixed sand and gravel beaches
- shell beaches
- coarse sand beaches
- fine sand beaches
- exposed mud flats
- sheltered mud flats
- mangroves
- salt-brackish marsh
- fresh flotant marsh
- fresh marsh
- swamps
- developed/upland

C. Aquatic Habitat Type
- sea-grass beds
- oyster reefs
- coral reefs
- artificial reefs

D. Terrestrial Biological Resources
- mammals
- birds
- reptiles

E. Aquatic Biological Resources
- mammals
- fish
- mollusc
- crustaceans
- reptiles

F. Regulated Endangered & Threatened Species
- type and distribution

G. Recreational Areas
- beaches
- marinas
- boat ramps
- diving areas
- boating/fishing

II. Level Two Priority Data Layers

A. Location of Protected Areas
   special management areas
   state parks
   state preserves
   state wildlife refuges
   federal preserves
   federal wildlife refuges

B. Coastal Marine Processes
   wave data
   currents
   hydrography
   water temperature
   meteorology data
   climatic data

C. Transportation Infrastructure
   roads
   airports
   helipads

D. USCG Area Contingency Plans
   MSO boundaries
   MSO Protection Priorities
   MSO Response Strategies

E. Access and Staging Areas
   ramps
   hoists

F. Modern, Historical, and Prehistorical Cultural Resources

G. Bathymetry

III. Level Three Priority Data Layers

A. Sources of Public/Commercial Water Supplies
   water in-takes

B. Oil and Gas Infrastructure
   platforms
   wells
   pipelines
   facilities
   service bases
   terminals
   refineries
   gas processing plants
   ports

C. Political and Administrative Boundaries and Locations
   federal
   state
   municipal
   federal lease block
   state lease block

D. Pre-Approved Zones
   dispersant
   in-situ burning zones
   exclusion areas

E. Navigable Shipping Routes/Channels
   navigable shipping routes/channels
   navigation markers
   anchorage
   lightering zones

F. Response Equipment Location
   sources
   inventory

G. Topography
   minimum 5' contours

H. Place Names
   names from USGS quads (GNIS)

I. Permitted Waste Disposal Sites
   incinerators
   landfills

IV. Not Prioritized

A. Land Use
   USGS landuse/landcover

B. Database of Historical Spills
   risk analysis
   location of spill source
   spiller

C. Utilities
   lines
   generation stations
   power plants
   phone
   power cable crossings

D. Population Data
   census data
   residences
   camps

Table 1D.2. Steering Committee members of the MMS GWIS program.

Minerals Management Services
Louisiana State University
Texas General Land Office
Louisiana Oil Spill Coordinator's Office
Mississippi Department of Environmental Quality
Alabama Department of Environmental Management
Florida Department of Environmental Protection
U.S. Coast Guard
National Oceanic and Atmospheric Administration
Environmental Protection Agency
Clean Gulf Associates
Marine Industry Response Group
Marine Spill Response Corporation
Aramco
Exxon
Chevron
Amoco

MISSISSIPPI OIL SPILL PLANNING GIS: CURRENT STATUS AND FUTURE PLANS

Mr. Stephen M. Oivanki
Mississippi Office of Geology

INTRODUCTION

Oil spill response in Mississippi is handled by the Emergency Services Division of the Department of Environmental Quality (DEQ). Personnel from Emergency Services act as on-scene coordinators to direct clean-up activities and evaluate post-spill remediation. Oil spill planning in Mississippi is also seen as a tool for field response, and therefore efforts are under way to build a Geographic Information System (GIS) at DEQ which meets both planning and response requirements.

CURRENT OIL SPILL PLANNING/RESPONSE DATA

The only oil spill planning and response data currently available in Mississippi are found in a document developed by the Mississippi Department of Marine Resources (formerly the Bureau of Marine Resources) in 1984. The "Contingency Guide to the Protection of Mississippi Coastal Environments from Spilled Oil" was prepared by Cornell M. Ladner and James S. Franks with numerous contributions of data and expertise from personnel at other scientific and academic institutions in the state. The Guide is in a large, atlas format with the entire Mississippi coastal environment divided into a series of 11 maps. Each map is based on the NOAA nautical chart for the area at that time.

The Guide was designed to rate the protection priorities for oil spill response from high to low according to the degree of negative impact an oil spill would have on a particular section of coastline and its interior environments. Seven protection priority levels from 1 (highest) to 7 (lowest) are identified, and within each level several smaller rankings are subdivided. The highest priority identified is 1A, openings to rivers, bays and estuaries leading to sheltered salt marshes. The lowest priority, 7R, is given to the concrete seawalls, bulkheads, and wharves. In the case of unusually high tide conditions, some priorities would move from lower to higher levels based on the exposure of interior habitats under those conditions.

The entire shoreline of the mainland and the barrier islands is both color-coded and labeled to correspond with the matching priority level given to the particular section of shoreline. Offshore habitats, such as oyster beds and grass beds, are also ranked and located on the maps, as are the locations of seasonal or migratory waterfowl habitats.

Appendices in the Guide provide tables of spawning seasons for all commercial and recreational species and areas and seasons for relative abundance of those species in coastal waters. Vital descriptions and life-cycle highlights for representative species are also given, as are endangered species known to occur in the coastal environment. Tides, currents, and other oceanographic information are listed with references for further research.

This Guide has served as an excellent planning and response tool since its publication; however, much of the data is now out of date, and the coastal environment and economic climate in Mississippi have changed. The current effort to produce a comprehensive oil spill planning/response GIS will remedy these deficiencies.

FUTURE OIL SPILL PLANNING/RESPONSE GIS

The Office of Geology, Coastal Section, of the Mississippi Department of Environmental Quality currently maintains a large GIS operating in ARC/Info on a SUN Sparc Station. Base map data include the most recent digitized USGS 1:24,000 topographic quadrangle maps with shoreline positions for the mainland and the islands updated annually by GPS surveys. Geomorphic characteristics of the mainland and island shorelines are classified and cataloged utilizing interpretation of oblique video surveys flown periodically along the coast. Land use/land cover classifications for all the USGS quadrangles in the coastal zone of Mississippi have been identified and mapped using a condensed Cowardin interpretation of 1991-92 color-infrared vertical photography. Bathymetric data for the Mississippi Sound are updated using in-house bathymetric mapping equipment.

At the request of the DEQ Emergency Services Division, this GIS will be modified to incorporate additional data necessary for oil spill planning and response. Additional data layers planned include the following:

- Offshore grass beds and shellfish beds (1) (2)
- Migratory waterfowl habitats (1)
- Endangered species habitats (1) (2)
- Seasonal marine species nesting areas (1) (2)
- Habitat and wildlife management areas (1)
- Boat ramps and staging areas
- Critical transportation facilities and routes
- Environmental Sensitivity Index (ESI)
- Cultural/economic priority areas
- Key response personnel notification data
- Critical boom lengths for estuary protection
- Critical water depths for boat operations
- Up-to-date census data

Data supplied by: (1) Department of Marine Resources, (2) National Park Service.

Other data layers will be updated and added as needed or specified by users of the GIS.

The Environmental Sensitivity Index for Mississippi shorelines will be designed according to NOAA standards in cooperation with their ongoing national ESI mapping effort. Mapping will be done within the next year using the geomorphic shoreline mapping system already developed for Mississippi. GPS base map accuracy along the shorelines of +/- 2 meters will allow detailed large-scale maps of critical response areas to be developed for use in field activities.

Future access to the GIS will be available either by export through ARC/Info files to other systems, or through ArcView II on personal computers. Data will be subdivided into manageable segments for easy access through ArcView, either on a desk-top PC in the office or on a portable PC in the field during actual spill response activities. Hard-copy maps and documents will also be produced for distribution to industry and regulatory personnel as needed. By maintaining the GIS at DEQ in the Office of Geology, the Emergency Services Division can have quick and hands-on access to and input into the database.

DEVELOPMENT AND APPLICATION OF THE FLORIDA MARINE SPILL ANALYSIS SYSTEM

Mr. Christopher A. Friel
Florida Marine Research Institute

Successful emergency management is highly dependent upon the availability of succinct information that accurately describes the crisis conditions at hand. In 1992, the Florida Department of Environmental Protection's (DEP) Florida Marine Research Institute (FMRI) received a legislative appropriation to develop an "automated marine spill sensitivity atlas" to generate targeted information for oil spills emergency response decision. After soliciting proposals, CAMRA contracted with Environmental Systems Research Institute's (ESRI) Application Development Group to initiate development of the Florida Marine Spill Analysis System (FMSAS).

The principal goal of the FMSAS project was to design and develop a prototype GIS application that integrates a variety of information (digital maps, imagery, and tabular data) with targeted analytical routines needed to implement an oil-spill contingency planning, response, and damage assessment strategy focused on natural resource protection. An additional requirement was to implement a selected set of these requirements for a pilot study area in the Florida Keys and develop a strategy for expanding the prototype to a statewide, fully operational system. The project included a needs assessment, conceptual and physical application design, database integration, interface development, and the formulation of a user's guide, program maintenance manual, and statewide implementation plan.

A specific requirement of the FMSAS project was the ability to portray real-time spill conditions relative to marine resources at risk such as bird rookeries, turtle nesting beaches, or prime fisheries habitat. From an information content perspective, environmental sensitivity index (ESI) maps provide the fundamental base map series of the FMSAS. Prior to the FMSAS development the only available map series that targeted oil spills was the "Sensitivity of Coastal Environments and Wildlife to Spilled Oil in Florida" series, developed in 1979-80. These atlases consist of 7.5-minute United States Geological Survey (USGS) topographic maps annotated with Environmental Sensitivity Index (ESI) shoreline types, wildlife-resource areas, and spill-response staging areas and strategies. The ESI rankings of shorelines is critical because it cartographically indicates the vulnerability of specific shorelines to oil spills. Explosive urbanization and coastal alteration over the last decade in Florida rendered these ESI ranking obsolete in many areas.

From the onset of the project, FMRI decided that at a minimum the FMSAS should be capable of keeping the ESI maps relatively current and should provide the ability to combine traditional ESI information with other spill-related information. ESRI conducted interviews at the FMSAS with various representatives from selected agencies involved in marine spill management in Florida and the United States, including the National Oceanic and Atmospheric Administration (NOAA), the Marine Spill Response Corporation (MSRC), and the United States Coast Guard (USCG) to define these requirements. These interviews were made during a week-long "rapid prototyping" workshop in which the existing application software and geographic databases developed by ESRI for spill management groups in the United States and abroad were utilized. The needs expressed during the rapid-prototyping process were used several ways. They helped us determine the functional requirements of and formed the basis for the FMSAS database design.

In July 1993, one year after contract initiation, FMRI took final delivery of a user-friendly prototype spill analysis system that included over 30 natural resource and spill response-related databases for South Florida including threatened and endangered species, ESI shorelines, benthic habitats, bathymetry, managed area boundaries, National Wetland Inventory (NWI), satellite imagery, aerial photography, and on-line tabular reference material with response strategies for specific shoreline types. A potentially catastrophic oil spill in Tampa Bay in 1993 provided the ultimate test of the FMSAS design. Coast Guard officials received a distress call the morning of 10 August 1993 after an outbound freighter collided with two inbound tugs a few miles from the Sunshine Skyway Bridge near St. Petersburg, Florida. One barge, carrying 8 million gallons of Jet A fuel, burst into flames and burned for more than 14 hours while the other barge lost an estimated 388,000 gallons of Number 6 fuel oil before the leaking slowed and stopped. A bulk carrier transporting phosphate was also damaged and began taking on water. The leaking chemicals moved with the tides toward some of Florida's ecologically sensitive habitats and pristine beaches.

Technological advances enabled several divisions and bureaus of the DEP teamed with local, state, and federal agencies to respond to the spill in an unprecedented manner. From almost the moment the ships collided, responding officials wanted very detailed information on the bay's natural resources such as bathymetry, sea grass beds, mangroves, marshes, turtle nesting sites, and sites of endangered wildlife, displayed in conjunction with the current location and extent of the spill. GIS and Global Positioning Systems (GPS) played an important role in generating real-time maps for analyzing changing spill conditions, logistical alternatives, resources-at-risk, and environmental sampling strategies. Many data resources were combined to create maps for simultaneous evaluation and monitoring efforts of the response.

To assimilate spill-boundary information in real time, FMRI staff used GPS receivers in helicopters to record locations of the vessels and the changing perimeter of the spill. GPS files were immediately imported into the FMSAS. The first map was plotted just hours after the spill occurred and hand-carried to the Coast Guard command center so each agency could formulate its response plans. Maps produced during the first three days were considered critical aids in developing possible scenarios. The helicopter-based GPS cres flew several times a day throughout the project and as the spill continues, air-to-plot time decreased significantly. Various databases and images were combined to create maps that were used by command center staff, the media, and individuals involved in response, environmental sampling, and damage assessment.

Many of the lessons learned during the Tampa Bay spill are being used to further refine the conceptual design and physical characteristics of the FMSAS. Assumptions made during the design process were tested in a crisis setting, and additional databases and functionality were identified. For instance, it would have been helpful to have all licensed landfills and incinerators in the vicinity in the system to identify disposal options for recovered product and soiled clean-up materials. To focus future refinements, the Institute is holding debriefings of involved parties to identify functions the FMSAS performed well and those that need enhancements. Unanticipated uses for the system continue to emerge.

Following the successful response in Tampa Bay, the DEP is investing considerable resources to refine the FMSAS by adding databases, enhancing functionality, equipping DEP field offices, and implementing mobile oil spill response capabilities. The FMSAS full-scale implementation report prepared by ESRI described a long-term plan for the incremental development of a statewide, GIS-based oil spill response system for Florida. The plan prioritizes key databases, and the challenge is to assemble and automate the data for each region of the state before a spill occurs there. Several paths for extending the functionality of the FMSAS are also included in the plan. Several governmental agencies, utility companies, and private firms have obtained the FMSAS. The DEP is exploring the possibility of cooperative agreements and Memorandums of Understanding (MOU) with other agencies such as the Minerals Management Service (MMS), to foster a collective investment so that the FMSAS design and prototype application can be shared and improved without redundant expenditures. It has become apparent that the basic design, natural resource sensitivity databases, and "resources-at-risk" analyses that form the basis of the FMSAS have widespread utility for analyzing a variety of marine and coastal impacts such as dredge-and-fill and coastal construction proposals. Significant database development efforts are underway stateside and resources are being dedicated to enhance the modeling functionality of the FMSAS. The long-term goal is to continue the development of the FMSAS to provide maximum protection from oil spills for Florida's natural resources statewide.

As a research administrator, Mr. Friel directs geographic information systems (GIS) and remote sensing activities at the Florida Marine Research Institute headquartered in St. Petersburg, Florida. Prior to this appointment, he used GIS for environmental research at many levels of government in Michigan, Illinois, and Florida. His areas of research interests are automated cartography, spatial analysis, and GIS applications for environmental

management. Mr. Friel received his B.S. in geography from Northern Michigan University and his M.S. in geography from Western Illinois University.

SESSION 2A

GOOMEX PROGRESS REPORTS, PART I

Session: 2A - GOOMEX PROGRESS REPORTS, PART I

Co-Chairs: Dr. Pat Roscigno and Dr. Mahlon C. Kennicutt II

Date: November 16, 1994

Presentation	Author/Affiliation
Introduction	Dr. Pat Roscigno U.S. Minerals Management Service Gulf of Mexico OCS Region Dr. Mahlon C. Kennicutt II Geochemical and Environmental Research Group Texas A&M University
The GOOMEX Phase I Study Design and Progress to Date	Dr. Mahlon C. Kennicutt II Geochemical and Environmental Research Group Texas A&M University
Results of Statistical Analyses Based on the GOOMEX Study Design	Dr. Roger H. Green Department of Zoology University of Ontario London, Ontario, Canada
Hydrocarbon Contaminants Associated with GOOMEX Study Sites	Dr. Terry L. Wade Dr. Mahlon C. Kennicutt II Geochemical and Environmental Research Group Texas A&M University
Trace Metal Contaminants Associated with GOOMEX Study Sites	Dr. Paul N. Boothe Dr. Bobby J. Presley Trace Element Research Laboratory Texas A&M University
Meiofauna Ecology at GOOMEX Study Sites	Dr. Paul A. Montagna Marine Science Institute The University of Texas at Austin
Macroinfauna Ecology at GOOMEX Study Sites	Dr. Donald Harper Marine Laboratory Texas A&M University at Galveston

INTRODUCTION TO THE GOOMEX STUDY

Dr. Pasquale R. Roscigno
U.S. Minerals Management Service
Gulf of Mexico OCS Region

Dr. Mahlon C. Kennicutt II
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The aim of the Minerals Management Service's (MMS) Outer Continental Shelf (OCS) Environmental Studies Program is to characterize the effects of offshore oil and gas development. This characterization has been done either through a comparison of current ecosystem data with earlier benchmark data or through special studies oriented towards monitoring specific parameters. These studies have shown that the acute impacts of OCS development are localized. There is less certainty regarding the nature of consequences of the subtle, chronic, long-term stresses that may be associated with OCS development in areas with a history of activity.

The MMS awarded a competitive contract to the Geochemical and Environmental Group (GERG) of Texas A&M University for a study entitled *Gulf of Mexico Offshore Operations Monitoring Experiment (GOOMEX) - Phase I.* GOOMEX study sties are all off the coast of Texas. These are Matagorda Island Field Block 686, Mustang Island Area East Addition Block A-85, and High Island Block A389 (which includes the East Flower Gardens).

GOOMEX Phase I is a multidisciplinary investigation to examine the impacts of sublethal, chronic exposure to discharges from oil and gas production facilities on marine ecosystems. The initial phase seeks to develop a suite of environmental indicators that will be refined in subsequent phases. This information will be useful in the preparation of Environmental Impact Statements and provide future guidance for stipulated activity on the OCS. GOOMEX can lead to the creation of mitigation measures and the modification of the scope of proposed lease sales in the Gulf of Mexico. GOOMEX will feed directly into the operational aspects of OCS. Activities such as the discharge of effluents, site clearance, mandated sea-bottom surveys and archaeological surveys, have resulted from previous studies.

GOOMEX attempts to quantify natural variability associated with Gulf marine ecosystems so that perturbations caused by chronic exposure to contaminant discharges can be measured. In the future, early warning indicators developed from studies such as GOOMEX can alert managers and operators before damages to marine ecosystems become obvious. Some levels of interaction examined in this study range from responses at the molecular up to the community level.

The information generated from this study is analyzed and synthesized in a comprehensive final report. This information provides a database on the fate and effects of hydrocarbons and metals from the operations of platforms on the OCS. The environmental benefits that will result from the incorporation of knowledge learned from GOOMEX will benefit the daily operations on the OCS, making them more environmentally safe.

Presented in this session are a series of papers that report on the results of last year's efforts.

Dr. Pasquale F. Roscigno is a program manager in the MMS Environmental Studies Section in New Orleans. Previously, he held several positions in the Department of the Interior's Fish and Wildlife Service.

Dr. Mahlon C. Kennicutt II, Senior Research Scientist, is Chief Chemist of the Geochemical and Environmental Research Group with the College of Geosciences and Maritime Studies at Texas A&M University. Dr. Kennicutt has expertise and research interests in marine chemistry, environmental chemistry, and organic geochemistry. He received a B.S. in chemistry in 1974 from Union College and a Ph.D. in oceanography from Texas A&M University in 1980. Dr. Kennicutt has published over 100 peer-reviewed papers, numerous book chapters, and has made scientific presentations world-wide.

THE GOOMEX PHASE I STUDY DESIGN AND PROGRESS TO DATE

Dr. Mahlon C. Kennicutt II
Geochemical and Environmental Research Group
Texas A&M University

The objective of GOOMEX Phase I is to assess sublethal effects associated with chronic exposure of marine organisms to contaminants derived from offshore oil/gas exploration and development activities. A chronic impact is defined as an effect on the biota that is caused by exposure to the "long-term" accumulation of chemicals in the environment. "Long-term" is defined as locations with a ten-year or longer history of production after exploration. Sedimentology, chemistry, and oceanographic work elements describe the areal and temporal distribution of contaminants, sediment characteristics, and water quality. Biological work elements identify responses to chronic chemical contamination as reflected in induction of detoxification enzymes, life history, reproductive success, reproductive effort, community structure and genetic diversity. The sampling plan was designed to detect and describe nearfield impacts and contaminant gradients extending out from each site. All study components are linked by a common statistical design.

The field program includes four sampling activities conducted over a one-and-one-half year period. The study initially evaluated five test sites and narrowed the longer-term study to the three most appropriate sites. The sampling design included a radial pattern with sample stations at 30-50, 100, 200, 500, and ≥3000 m. Station locations were chosen based on a dose-response model and used to test the hypothesis that chemical and biological parameters vary with distance from the platform. Comparisons of data from stations close to platforms (≤2000 m) to stations distant from platforms (≥3000 m) are used to evaluate the significance of the observed variations. Sediment collection was by boxcore and megafauna were collected by otter trawl.

The study includes the analysis of contaminants in sediments, pore waters, and biological tissues (trace metals and hydrocarbons). All trace metal and hydrocarbon analytical protocols are those used in the NOAA NS&T program. The associated QA activities were similar in scope to those of the NS&T program.

Biological effects were monitored in a wide range of important species from meiofauna to megafauna including infauna, epifauna, mobile invertebrates and demersal fish. The biological measurements cover a range of potential markers of impact from induction of detoxification enzymes to traditional assemblage analysis. Assemblage information was collected for meiofauna and macroinfauna. Reproduction and life history studies for meiofauna emphasized harpacticoids. Megafauna (invertebrate) reproductive effort and health was also assessed. All biological studies were coordinated with measurements of tissue contaminants. Demersal fish were examined for chronic impacts at several levels of detail including necropsies (gross pathology), histopathology of representative tissues, stomach content food analysis, liver and stomach content contaminant analysis, and biliary PAH metabolites. Megafauna (invertebrates) were also examined for histopathologies.

Biological exposure to contaminants was evaluated using a series of biochemical biomarkers that measure P4501A induction. *In vivo* biomarkers included catalytic enzyme assays for ethoxyresorufin-O-deethylase (EROD) and aryl hydrocarbon hydroxylase (AHH) activities. Levels of P4501A mRNA in fish livers were also assessed. PAH metabolites were measured in the bile of demersal fish as an indicator of PAH exposure. Highly Ah-responsive *in vitro* cell bioassays (i.e., rat hepatoma H4IIE cells) were also used to determine the inductive potency (as measured by EROD activity) of extracts from invertebrates.

Additional work elements were added to the core program to (1) assess pore water toxicity based on sea urchin embryological development tests and (2) develop an immunological probe to estimate reproductive effort in megainvertebrates. A series of other techniques are also being developed including measures of meiofauna genetic diversity, utilization of more appropriate organisms for bioassays, and evaluation of various *in vitro* toxicological assays presently utilized for mammalian systems.

Data synthesis includes contour maps of important physical, chemical, and faunal characteristics, correlations, regressions, and plots of dependent versus independent variables. Variations in benthic faunal assemblages are described by power diversity (rare fraction curves) and multivariate analysis. Principal component analysis (PCA), analysis of variance (ANOVA), multivariate analysis (MANOVA), covariate analysis (ANCOVA) and general linear modeling (GLM) form the basis for the statistical interpretations.

At present (November 1994) all field activities have been completed. All of the data has been collected and collated into a central database for synthesis. Data synthesis emphasizes cross work element interpretations and rigorous statistical hypothesis testing.

Dr. Mahlon C. Kennicutt II, Senior Research Scientist, is Chief Chemist of the Geochemical and Environmental Research Group with the College of Geosciences and Maritime Studies at Texas A&M University. Dr. Kennicutt has expertise and research interests in marine chemistry, environmental chemistry, and organic geochemistry. He received a B.S. in chemistry in 1974 from Union College and a Ph.D. in oceanography from Texas A&M University in 1980. Dr. Kennicutt has published over 100 peer-reviewed papers, numerous book chapters, and has made scientific presentations world-wide.

RESULTS OF STATISTICAL ANALYSES BASED ON THE GOOMEX STUDY DESIGN

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THE GOOMEX STUDY DESIGN REGARDING STATISTICAL ANALYSIS

A primary concern in the design of the GOOMEX Phase I study was to collect a data set that would provide a statistically rigorous test of the major hypotheses. The study design facilitates the description of patterns in space and time of the biological, toxicological, chemical, sedimentological, and oceanographic characteristics of each of the platforms.

The original general null hypothesis for the study is as follows:

> H_0: There are no differences in any of the sedimentological, chemical and/or biological parameters measured among platform sites (at distances less than 2,000 m from the platform, or platform group) and comparison sites (located a minimum distance of 3,000 m from any present or historic platform, or platform group).

Many variables are being measured, and biological responses can be related to aspects of the environment that may be causing the response. We can think of the biological response variables as dependent variables, and the environmental variables that may be causing the responses as independent variables. However one can also think of the ANOVA design variables (P = platform, C = cruise, D = distance from platform, R = radius (direction) from platform) as predictors. Thus the environmental variables, as well as the biological variables, can be thought of as response variables predicted by the design variables. However, as far as causality is concerned, we visualize a pattern of contaminants determined by direction and distance from a platform at a given time (i.e. the design variables), whereas the biological variables measure a biological response caused by the contaminant concentration rather than by position relative to the platform *per se* (Technical Proposal June 1991, Figures 2.1–2.3, p.9). Therefore the logical analysis sequence is to first examine relationships of contaminant concentrations to the design variables, then (given that those relationships provide evidence of "platform–centered" spatial/temporal pattern) evaluate the importance of time (among–cruise variation) in those relationships, and finally (given that among–cruise variation is relatively unimportant whereas among–platform variation is meaningful) pool over cruises, and examine relationships between biological variables and contaminant environmental variables (with "natural" environmental variables e.g. sediment type, water chemistry taken into account) platform–by–platform, in the context of the within–platform design variables (D and R). If among–cruise variation is meaningful and cannot be ignored, then the last step in the sequence would have to be done for each platform–by–cruise combination.

The outermost distance category (FAR = >3,000 m) was intended to provide a control in the sense that it was chosen to be beyond any likely platform–related impacts. Thus it represents natural, baseline conditions. Our design does not allow for an *a priori* test to answer the question: how far away from platforms do effects extend? This would have to be answered with a *post hoc* test, e.g., a multiple comparison test where distance from the platform is treated as a categorical variable. In fact, the actual distance of a sample from a platform is available as a continuous variable so that the pattern of effects can be modeled and graphed. The sampling plan was designed to detect near-field impacts and contaminant gradients extending out from a platform. Oversampling within the near field (<3,000 m) is designed to define the spatial scale of the impact based on an exponential decline in contaminant concentrations. The sampling design includes *5* radii, *5* distances per radius, and *n* pseudoreplicates (e.g. *n*=2 from a boxcore) per each R–by–D combination.

The study design is based on a dose–response model. Contaminant concentrations should decline exponentially with distance away from the platforms. Biological responses should be a function of the contaminant gradient; thus a detectable response would dissipate with distance from a platform also. The basic form of a dose response model is:

$$Y = e^{-kX}$$

Where Y is the response, and X is the dose. This non–linear response can be transformed so that linear models can be used to analyze the data with the following formula:

$$\log Y = a + bX$$

This suggests that contaminant and organism abundance variables should be transformed logarithmically. One would also come to the conclusion to use log transformation on most variables from an entirely different line of logic. An important assumption for using ANOVA is homogeneity of sample variances. Based on the data from the first two cruises, it has been found that the variances of contaminant variables and organism abundances are stabilized with log transformations.

All data from boxcores; e.g., contaminant concentrations, grain size, meiofauna, macrofauna, and pore water toxicity tests are analyzed using the same statistical procedures. Data from trawls are a subset of the same design, since there are just two stations per platform (NEAR and FAR on one radius). Some data elements require additional analyses that are unique to their particular area of science (e.g., size frequency analysis).

There are four different categories of study design within the overall GOOMEX sampling scheme. These are summarized in the following table. Any cruise–by–platform subset of the data could be analyzed by itself (Case 1). Platforms could be compared on any given cruise (Case 2). The total design can be analyzed with all C*P*R*D interactions (Case 3). If among–cruise variation is relatively unimportant whereas among–platform variation is meaningful, we can pool over cruises and do analyses platform–by–platform (Case 4). In all four cases, if D is treated as a continuous variable (i.e., an ANCOVA) and Y is a log–transformed variable, then we are using the dose–response model.

	Platforms	
Cruises	1	>1
1	Case 1: Unique C*P analyses	Case 2: Unique C analyses
>1	Case 4: Unique P analyses	Case 3: Total design analyses

Case 1 implies that there is no generality: every C*D combination is unique and has to be analyzed by itself. In SAS notation the analysis would be by the model: Y = R D R*D; BY C P. The residual error (among pseudoreplicates at each R*D) would be used as the error to test R, D, and R*D. There is really no other choice.

Case 2 implies that we can generalize over platforms, but not over cruises. This is unlikely; it is much more likely that the reverse will be true (Case 4). The R are unique to particular P, so R is nested within P. The D, on the other hand, are crossed with both P and R(P). The SAS analysis model is: Y = P R(P) D P*D D*R(P). P is tested against R(P) which tacitly assumes R are random within a P. R(P), D and P*D are tested against D*R(P). D*R(P) is tested against replicate error.

Case 3 implies full generality, over platforms as well as cruises. In other words it implies that patterns of effects re. D and R can be described independent of which platform it is or which cruise it is. This is unlikely, but it is our starting point. Its use will probably demonstrate that platforms are heterogeneous, and then we will move on to Case 4. Again R is nested within P. Here D and C are crossed with both P and R(P). The SAS model is: Y = C P C*P R(P) C*R(P) D P*D D*R(P) D*C P*D*C D*C*R(P), P is tested against R(P), and D and P*D against D*R(P). C and P*C are tested against C*R(P). R(P) is tested against a composite error term. D*R(P) and C*R(P) are tested against D*C*R(P), which is tested against replicate error.

Case 4 implies that we can generalize over cruises but not over platforms, which is likely. Cruises may be "significantly different" but we hope that among–cruise variation is relatively unimportant (whereas we expect among–platform variation to be substantial and meaningful) so that we can pool over cruises, and examine relationships platform–by–platform in the context of the within–platform design variables D and R. The SAS model is: Y = C R C*R D C*D R*D C*R*D, When R is declared as random, C is tested against C*R, R is tested against a composite error term, and D is tested against R*D. The double interaction terms, C*R, C*D, R*D are tested against C*R*D. Only the triple interaction term is tested against replicate error.

THE STATISTICAL ANALYSIS FLOW & EXAMPLES OF ANALYSIS RESULTS

The data analysis flows in the following sequence:

- Input phys/chem and design variable data, and label levels of some design variables.
- Sort data by design variables.
- Check data by determining minimum & maximum values for variables.
- Evaluate variables for appropriate transformations.
- Transform the variables as appropriate.
- Do a PCA and interpret results, regarding original variables and regarding the design variables.
- Keep dominant Principal Components as new synthetic predictor variables.
- Input biological data.
- Do as in lines 2–5 above for the biological data.
- Merge the phys/chem data with the biological data.
- Do Case 3 GLM analyses (ANOVAs & ANCOVAs).
- Do Case 4 (or Case 1) GLM analyses (ANOVAs & ANCOVAs).
- Do descriptive analyses to show what is going on at each platform (e.g. tables of means and SEs for each D*R combination, bivariate scatterplots labeled by D and R, model predictions of response variable values plotted against distance from platform as a continuous variable, P–by–P contour plots for variables with positions of D*R stations shown).

The need for and the choice of transformations of variables was assessed by determining the relationship of residual variance to residual mean (and thus the transformation needed to stabilize the variance), using the Taylor's Power Law model. The results agreed with the common practice and logic of transforming such data, so we recommend the following routine transformations: All contaminant concentration and organism abundance data should be log–transformed, or log(Y+1) transformed if zero values are present. Recall that log transformation of response variables also allows use of linear models to describe the non–linear (exponential decay) dose–response model. Percentage data (SANDP, SILTP AND CLAYP) should be "arcsin square root" transformed. Transformations are either inappropriate or unnecessary for the variables REDOX and O2.

The PCA performs several functions here. It can be used to provide guidance in selection of a subset of variables. It can also provide new synthetic variables, the "PC scores," which can be used as response or predictor variables in GLM models. And PCA efficiently and effectively displays the multivariate data in relation to the design variables, i.e. as "PC2 vs. PC1" plots with points coded by CRUISE, DCODE, SITE or RADIUS. Such plots can show some obvious patterns, even before formal hypothesis–testing statistics are done. They do so here and examples are shown. It is clear that cruises differ trivially if at all, that platforms differ a great deal and mostly on PC2 and PC3, that distances differ mostly on PC1 and fall out in the order that would be expected. Properly interpreted PCA results can help tease apart confounded environmental gradients, such as contaminant concentrations versus substrate types. Here among–platform variation in substrate type loads heavily on PC2, and the distance–from–platform gradient in substrate type on PC1.

Case 3 analyses show that platforms have meaningfully different patterns of response variables re. distance and direction from the platform, but that cruises – though often statistically significant in various regards – account for a relatively small amount of the variation. We then show some examples of Case 4 (and some Case 1) analysis results. For example, ANOVAs done at a platform with D and R as design variable predictors typically show significance for the D*R interaction, indicating that contaminants go different distances from the platform depending on the direction. This is shown in contour plots, and also in plots of model predictions against distance as a continuous variable, with points labeled by R. We also show that ANCOVAs done to predict a biological response variable from various contaminant variables (the covariates), in a D– by–R ANOVA design context, typically show a highly significant interaction between D and the covariate. This indicates among ring (distance category) differences in the relationship between the biological response and the contaminant. We then use plots of model predictions against distance as a continuous variable, with points labeled by R, to show that the source of the interaction is a strong and consistent negative relationship between biological response and contaminant at the NEAR distance category (the innermost ring) but no relationship further away from the platform. For example, above–baseline contaminant concentrations go out to 500–1,000 m from the platform (e.g. for Cd at HI-A389), but a relationship between harpacticoid copepod abundance and [Cd] is seen only at the innermost (NEAR) ring, i.e. distances of 30–50 m from the platform, and one can see that the relationship is driven by the highest [Cd] values. The same pattern is seen for harpacticoid abundance versus [Pb] and [Zn].

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HYDROCARBON CONTAMINANTS ASSOCIATED WITH GOOMEX STUDY SITES

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As a consequence of offshore oil/gas exploration, development and production activities, contaminants are released to the environment. Discharges of muds and cuttings during the drilling phase contain chemical contaminants including hydrocarbons, barium, and other trace metals. In addition to contaminants discharged during drilling activities, chronic long-term discharge and releases during the development and production phases may result in the accumulation of contaminants in the surrounding benthos. One objective of the GOOMEX program was to test the hypothesis that contaminants and other chemical parameters are not significantly different near to as compared to far from platforms. Sediment contaminant distributions were also used to support studies of biological effects related to chronic, sublethal contaminant exposure. An extensive field program was conducted at three sites, High Island A389 (HIA-389), Mustang Island A85 (MU-A85), and Matagorda Island 686 (MAI-686). Sediment samples were collected by boxcore on a radial pattern with sampling stations at 30-50, 100, 200, 500, and ≥3,000 m. Megafauna were collected by otter trawl. The ≥3,000 m stations served as controls in the study design.

Hydrocarbon concentrations in sediments, pore waters, and biological tissues were determined. Hydrocarbon analyses were performed by protocols developed for the NOAA National Status and Trends (NS&T) Program and EPA Environmental Monitoring and Assessment Program (EMAP) and include aliphatic (i.e., n-C_{10}-C_{34} isoprenoids) and polycyclic aromatic (i.e., C_0-C_4 alkylations) hydrocarbons. The associated analytical quality assurance program was similar in scope to NOAA NS&T and EPA EMAP programs and included the analyses of blanks, surrogates, internal standards, matrix spikes, calibration checks, and Standard Reference Materials with sample batch of samples.

Compared to marine settings impacted by spills and coastal areas that experience long-term chronic contamination, hydrocarbon sediment concentrations were low at the platform sites studied. Indicators of petroleum contamination are highest near, and decrease rapidly with distance away from, a platform. The contaminant field in general exhibits a significant directional orientation in response to bottom current transport processes. These effects are most apparent at MU-A85 and HIA-389. Based on the barium concentration and grain size distribution (high sand content), the high sediment hydrocarbon concentrations appear to be caused by disposal practices during the drilling phase. Pyrolytic hydrocarbons are more generally distributed over the study areas, indicating possible atmospheric transport and deposition of these PAH.

Selected megafauna were also analyzed for contaminants including PAHs. Generally, only low concentrations of PAH, near the method detection limits were observed in these organisms. The low contaminant burdens in tissues may reflect the low sediment PAH concentrations detected as well as the ability of vertebrates (i.e., demersal fish) to metabolize PAH. Statistical testing supported the hypothesis that invertebrates and vertebrates tissue contaminant concentrations were not significantly different at control stations (≥3,000 m) as compared to organisms collected close (less than 100 m) to a platform. No significant increase in bioaccumulation related to proximity to a platform was apparent. The lack of an indication of induction of detoxification enzyme systems in demersal fish in close proximity to platforms also confirms that biotic exposure is minimal if present at all.

Hydrocarbon contamination associated with the platforms studied is low and localized within the immediate vicinity (< 200 m) of the platform. The localization of contaminants at MU-A85 and HIA-389 is attributable to the practice of bottom shunting of platform discharges during drilling and the low energy (deeper water) environment. MAI-686 exhibited little or no hydrocarbon gradient related to the platform probably due to a combination of surface shunting of the platform discharges and the high energy (shallower water) setting. The volume of discharges during drilling and the discharge history of the location must also be considered in interpreting the resultant contaminant distributions. Sediment PAHs contained two and three ring PAH and little of the higher molecular weight, more carcinogenic PAHs. The PAH detected in sediments can in large part be attributed to hydrocarbons indigenous to cuttings and not platform additives, discharges, or spills.

Principal component analysis allows for the description of a consortium of independent variables. The first principal components which explains 35.4% of the variance, is related positively to several contaminants including aliphatic hydrocarbons, alkylated PAH, Ag, Ba, Cd, Hg, Pb, Zn and negatively to Al. The second principal component, which explains 13.2% of the variance, is positively related to sediment parameters including pyrogenic PAH, grain size, Al, Fe, Cr, Ni, and Se and negatively related to sand content. The use of principal components shows that many of the contaminants measured co-vary and that the observed differences in sediment contaminants at near versus far stations are statistically significant.

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TRACE METAL CONTAMINANTS ASSOCIATED WITH GOOMEX STUDY SITES

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Trace metals are added to the sediment column in significant amounts by discharges from offshore petroleum drilling activities. The metals represent a source of enhanced, chronic contaminant exposure which can potentially impact both infauna and epifauna in the vicinity of drilling platforms. GOOMEX is a large-scale study aimed at rigorously evaluating near and far field differences at petroleum drilling sites. The purpose of the trace metal work element was to determine the spatial and temporal distribution of trace metals in sediments and interstitial waters around each GOOMEX study site, and to rigorously define statistically significant differences in the inorganic exposure regime between near ($<$ 2,000 meters) and far ($\geq$ 3,000 m) fields at each site. In addition, trace metal levels were determined in resident biota (fish and invertebrates) to look for statistically significant differences in bioaccumulation between near and far fields.

Five drilling sites were sampled during the first winter cruise (January 1993). Sediment samples were collected in a radial pattern from 30-50 to $\geq$3,000 m around each site (2 replicates at 25 stations = 50 samples). Approximately 60 megafauna samples (30 near field and 30 far) were collected by trawling at each site. The three study sites with the strongest chemical gradients (MAI-686, MU-A85, HI-A389) were sampled in the same way three more times (June 1993, January and June 1994). Over 800 sediment samples (818) and 847 biota samples were analyzed. Thirty selected pore water samples from each of the first two cruises were also analyzed.

Most of the trace metals selected for analysis are priority pollutants (Ag, As, Cd, Cr, Cu, Hg, Ni, Pb, Sb, Se, Zn) which are known to be toxic to organisms. Tin (Sn) was also included because of its potential toxicity. Barium (Ba) was selected because it is sensitive tracer of the particulate, settleable fraction of drilling discharges. Barium (as barite) is the dominant component of drill mud (up to 90% on a dry weight basis) and the background concentration of sediment Ba in the Gulf of Mexico is low (200-500 ppm dry weight). Aluminum (Al) and iron (Fe) were chosen because they vary as a function of grain size (i.e. high in clay, low in sand) and can be used to characterize variations in sediment type around each platform. Vanadium (V) was included because it can occur in high concentrations in crude oil. All 16 elements were measured in sediment, 14 in biota (except Al, Sb) and seven in pore water (Ba, Cd, Cu, Hg, Pb, V, Zn).

Analytical methods, proven and accepted through use in national environmental monitoring programs (NOAA NS&T and EPA EMAP), were used in this study. These are sensitive methods capable of accurately determining actual trace metal concentrations even in uncontaminated, pristine areas. To insure the highest data quality, a comprehensive quality assurance (QA) program was conducted as part of the study. This QA effort involved extensive additional field and laboratory QA samples as well as stringent QA acceptance criteria.

Since Ba is the major elemental tracer in drilling muds, much of the data interpretation focuses on inter-relationships with Ba. Figure 2A.1 shows the average spatial distribution for Ba.

Ba trends observed in this study are highly significant (except MAI-686) with distance (≤ 500 m) and consistent with previous platform studies. Sediment Ba levels vary greatly among the study sites. These differences are a function of both the amount of barite discharged and the degree of sediment transport (scouring) at each site (Boothe and Presley 1985). Analysis of sediment cores shows that the Ba is mixed deeper in the sediment column at the shallow water sites (MAI-686, MU-A85, ≥ 20 cm) than at HI-A389 (10-15 cm). Mass balances of excess Ba, using sub-surface Ba profiles, show that only 1-10% of the Ba discharged is retained in near field (< 500 m) sediments (Boothe and Presley 1985). The spatial distribution of Ba is highly directional at all sites. The contaminant field appears to be temporally stable despite inter-cruise differences. Pore water data showed little correlation with corresponding solid phase trace metal levels.

Principal component analysis (PCA) was used to assess systematically inter-relationships among the numerous contaminant, sedimentology and water quality parameters in the large GOOMEX data set. One component (PC1) includes Ba, several covarying metals (Ag, Cd, Hg, Pb and Zn), hydrocarbons and sand. The positive correlation between coarse sediment and contaminants is unusual but reflects the drill cuttings "halo" present at each site. A second

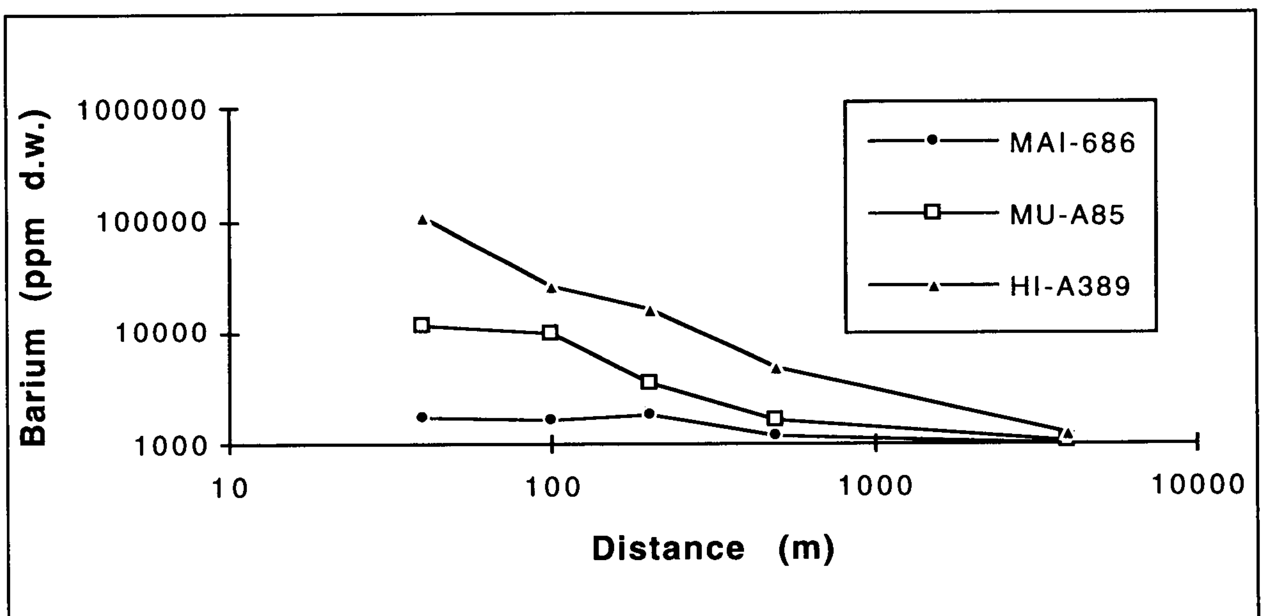

Figure 2A.1. Mean surficial (0-2 cm) sediment Ba as a function of distance at the final GOOMEX study sites.

component (PC2) includes Al, Cr, Fe which track fine-grain sediment.

Invertebrate soft tissue (278 samples; shrimp, crabs, bivavlves, polychaetes), fish livers (248) and fish stomach contents (321) were analyzed from both near field (~ 100 m) and far field (≥ 3,000 m) trawls made at each study site during all four sampling cruises. Contaminants in organism tissues exhibited significant inter-cruise and inter-site variability due in part to variability in the species composition. Few significant differences due to distance (i.e. near vs. far) were observed. The stomach contents of fish collected in near field trawls at HI-A389 exhibited significantly higher Ba concentrations than those of far field fish. Ingestion of Ba-enriched sediments is the most likely explanation for this observation. Iron levels were higher in certain types of organisms (e.g. stomach contents, invertebrates) collected in the far field trawls at MAI-686 and HI-S389. Again, ingestion of iron-rich sediments at these sites is the likely cause. The elevated far field Fe trend has been observed in a previous study (Boothe and Presley 1987).

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Dr. Bobby J. Presley is a Professor of Oceanography at Texas A&M University and has been active in marine geochemical research for more than 15 years. He has been the Principal Investigator on more than 25 different research projects, funded by NSF, NOAA, BLM, COE, API, and ONR. These projects have addressed fundamental problems concerning the behavior of chemicals in the environment and pollutant effects of inorganic chemicals. Dr. Presley was a Principal Investigator on the original (1971) NSF/IDOE Pollutant Baseline Survey in the Gulf of Mexico, and since that time he has directed numerous pollution-related studies. He is currently conducting the trace metal component of an American Petroleum Institute on the *"Fate and Effects of Drilling Fluid and Cutting Discharges in Shallow, Nearshore Waters."*

MEIOFAUNA ECOLOGY AT GOOMEX STUDY SITES

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The goal of GOOMEX is to develop and recommend sensitive and appropriate techniques to assist monitoring activities of offshore oil and gas production. To accomplish this goal, a range of biological, biochemical and chemical methodologies are being tested to detect and assess chronic sublethal effects of offshore oil and gas production. Documentation of detoxification response to contaminant exposure is defined as the primary objective of GOOMEX. A secondary objective is to document the impacts of any contaminant exposure at the organism, population, or community level. Benthic infauna studies are designed to fulfill the secondary objective.

The benthic infauna component of the GOOMEX program focuses on organisms that live in sediments. Both meiofauna and macrofauna are being studied. Meiofauna are the smallest living metazoans, passing through a 500 µm sieve and retained on a 63 µm sieve. Macrofauna are larger, being retained on a 500 µm sieve. Although the operational definition of these two groups is based on sieve sizes, the groups are dominated by different taxa. The meiofauna are composed primarily of nematodes and harpacticoids.

Macrofauna are composed primarily of polychaetes and amphipods.

Samples for meiofauna come from subcores of box cores. As described previously (Kennicutt), the box core stations are located at five distances from the platform along five different axes, yielding 25 stations per platform in a radial design. The boxcore is subdivided into 25 subcores. Two meiofauna cores (area=2.8 cm^2) are taken from two different subcores of each boxcore. Samples are preserved in the field and analyzed back at the laboratory. Five separate meiofauna studies are being performed: community structure (abundance and diversity), harpacticoid life history and reproduction, harpacticoid toxicity, harpacticoid genetics, and nematode feeding guilds and trophic dynamics. We are testing hypotheses to detect changes in benthic infauna with respect to distance from the platforms. Abundance changes are detected using analysis of variance procedures (Green). Community structure changes are detected using diversity and eveness indices, cluster analysis, and multivariate statistical procedures. Meiofauna data is compared and correlated to changes in other biological and environmental data. Relevant biological data are abundance of macroinfauna and sea urchin pore water toxicity test results. Relevant environmental data are water depth, bottom water salinity, temperature, and oxygen content; and sediment grain size, total organic carbon, trace metals and hydrocarbons.

During the first cruise, two stations at each platform,

100% change (a doubling) among stations. Variance components analysis was performed to determine if using subcores as replicates from one box core is sufficient. Alternatively, one subcore from 2 boxcores might be a better sampling design. Most of the variability in the study is among platforms (54%) and the platform*station interaction (33%). Practically, none of the variability is due to replicate boxcores (0.1%). Therefore, one boxcore per station and using replicate subcores is a sufficient sampling protocol.

The overall average density at all study sites during for all cruises was 1,170 individuals core-1 (which is equivalent to 4,127 10 cm-2) to a sediment depth of 2 cm. This density is much higher than previously reported in the Gulf of Mexico. Overall, nematodes comprise 69% of the organisms, harpacticoids are 15%, and 11 other taxa represent the remaining 16%. None of these "other" taxa occur in large numbers. Eight different variables were examined: total meiofauna density, Nematoda density, Harpacticoida density, other meiofauna taxa density, the Nematode:Copepod ratio, nematode biomass, nematode diversity, and harpacticoid diversity.

The first statistical analysis was performed to test the sample design to detect interactions among cruises, platforms and distances from platforms. Interactions among cruises, platforms and distances mean that overall analyses can't be interpreted simply, i.e., the overall test for a distance effect would not be valid. Harpacticoid diversity was the only variable where

The second statistical analysis performed was an analysis of covariance for each platform, where the actual distance from the platform is a covariate in the model. The advantage of using this model is that it removes interactions due to platform, distance, and radial uniqueness. Directionality of a response is tested by the distance*radii interaction. The specific null hypothesis being tested is that there is a logarithmic change with respect to distance from a platform.

Platform effects are clearly evident at HI-A389 (Table 2A.1). Every variable, except the density of other meiofauna taxa exhibited a statistically significant response with respect to distance from the platform. Platform MAI-686 had significant differences for all abundance measures and harpacticoid diversity. Platform MU-A85 had only one significant measure: nematode biomass. Total abundance measures and harpacticoid diversity were significant at the two platforms where effects were found.

A factor analysis was performed on the species composition data for nematodes and harpacticoids todetermine what was correlated with changes in community structure. For nematodes, differences were mainly due to platforms. There were also differences due to inner ring at all platforms. For harpacticoids, differences were due to platforms and to inner rings at all platforms except MU-A85.Harpacticoid body length and reproduction studies were also performed. If animals have to divert energy for growth and maintenance to detoxification then there should be smaller body sizes and less reproductive effort as a sublethal response.

Two species were chosen and adult body lengths were measured. Because individuals were not found at every station, body length measurements were pooled into near and far categories by comparing the inner ring (>50 m) versus all outer rings (>50 m). There were no interactions for cruises, platforms and stations (near and far). There were also no significant distance effects for body lengths.

All gravid harpacticoid females found were reserved; egg numbers were counted and egg diameters were measured. There were no significant distance effects for clutch size. However, there was a significant difference for total reproductive effort (clutch volume) at two platforms (MAI-686 and MU-A85). Since, egg numbers were the same among stations, differences in reproductive effort are due to smaller egg sizes near platforms. Statistical relationships are

Table 2A.1. Summary of analyses covariance by platform. Asterisks (*) indicate significance levels for the test that there are no significant distance effects at platforms. Abbreviations: *P<0.05, **P<0.01, ***P<0.001, ****P<0.0001.

Variable	HI-A389	MAI-686	MU-A85
Total meiofauna density	*	****	-
Nematode density	**	****	-
Harpacticoid density	*	****	-
Other meiofauna taxa density	-	****	-
Nematode:Copepod ratio	**	-	-
Nematode biomass	**	-	***
Nematode diversity	**	-	-
Harpacticoid diversity	*	**	-

related to sample size. It appears that at least 100 females must be included to detect change.

Toxicity of pore water extracted during the first cruise was estimated using nauplii of the harpacticoid species *Longipedia americana*. There were no significant difference in survival after 96 hours at platforms MU-A85, GA-288, MAI-686, and MAI-622. At HI-A389, there were significant differences in the number of surviving nauplii between near and far sites (P=0.0001). These results are similar to the results obtained using sea urchin gametes.

Meiofauna, particularly Harpacticoida, are restricted to the surface of Gulf of Mexico shelf sediments. Therefore, meiofauna are affected by deposition of contaminant materials associated with platforms. The current sampling regime has sufficient power to detect small changes in the meiofauna community. Harpacticoids are the best indicators of platform effects. This is true for both total abundance and species diversity and reproductive effort. Harpacticoid abundance, diversity, reproductive effort and survivability declines as we sample nearer the platforms. Nematode diversity does not appear to be useful for detecting platform effects, since there was only one no discernable trend at HI-A389. The nematode:copepod ratio was only an effective indicator at the HI-A389 platform, suggesting that this is not a good general index of platform affects. All platforms have completely different abiotic characteristics in terms of depth, oxygen content, and sediment grain size (except for the two MAI platforms, which are identical). Within a platform area, factor analysis using PCS of environmental measurements indicates that there seems to be little influence due to these environmental characteristics on community structure, but most differences among platforms can be attributed to natural variation and gradients in theses abiotic components.

Changes in meiofaunal responses are noticeable only within 50 m of platforms. Strongest response was found at MAI-686, probably due to local hypoxia events during the summer sampling seasons. The response at HI-A389 is probably due to shunted effluent. There was no community response at MU-A85.

The best indicators of change are the following: total meiofauna density (which indicates potential lethal responses (if other hypotheses, e.g., fish predation and sediment grain size effects are rejected), harpacticoid diversity (which indicates a sublethal community response), harpacticoid genetic diversity (Street; which indicates response at the population level) and harpacticoid reproductive effort (which indicates a sublethal organism response). The ability to detect differences in harpacticoid community, life history, and reproductive parameters demonstrates that we will be able to develop reliable indicators of sublethal responses. Coupled with genetic and toxicity studies, the study of the biology of the Harpacticoida should prove to be a powerful tool monitoring purposes.

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MACROINFAUNA ECOLOGY AT GOOMEX STUDY SITES

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Macroinfaunal samples were collected from three subcores in each box core. The subcores to be used for macroinfauna were randomly assigned prior to collecting the samples. The sediment in each subcore was extruded to a depth of 10 cm. The sediment was washed on a 0.5 μm mesh sieve, placed in a pre-labeled jar, and fixed with 5% seawater-formalin. In the laboratory, samples were rinsed with fresh water and preserved in rose bengal-stained 70% ethanol. They were subsequently examined using low power magnification. All specimens were removed, sorted to polychaete and non-polychaete categories, and placed in clean 70% ethanol. Specimens were subsequently identified and counted.

A factor that may confound the results of this study to some extent is the small size of the sub-cores -- 100 cm^2 each. In the course of data analysis, it was determined that in 11% of the stations (30 of 330) the species composition of each of the three subcores was unique, i.e., there was no co-occurrence of species. Very often there was only one individual of each species present. The number of stations at which no co-occurrence occurred were Cruise 1 - 17, Cruise 2 - 5, Cruise 3 - 2, Cruise 4 - 12.

Seasonal trends in macroinfaunal abundance were similar at MU-A85 and MAI-686. Raw numbers of infauna were in the 700-900 range during Cruises 1 and 2, increased to 1,600-1,800 during Cruise 3 and then decreased to about 600 individuals by Cruise 4. At HI-A389 infaunal numbers increased only slightly from Cruise 1 to Cruise 3 (900 to 1200 individuals) and then decreased agai,n to 600 during Cruise 4.

The areal distribution of total numbers of species at each site suggested that no trends could be detected. Comparison of abundances along radii indicated no consistent trends. However, when the data for each ring was summed and averaged, a distinct trend emerged. At all three sites, the 50-m ring had a slightly depressed number of species compared with the 100-m stations. Mean numbers of species per ring were similar at MAI-686 and HI-A389: numbers of species were in the mid-40 range at the 50-m ring, increased to the low-50 range at the 100-m ring, and then decreased to near or below the 50-m ring totals with increasing distance from the platforms. Although the pattern was similar at MU-A85, numbers were higher. The number of species increased from 63 on the 50-m ring to 78 on the 100-m ring. The number then decreased to 56 at the 200-m station and then returned to 63 by the 5,000-m station.

Plots of areal distribution of macroinfauna at each site indicate that all three platforms had halos of various sizes surrounding them in which infaunal abundances were greater than in the far-field region. In order of increasing halo size, the sites were MAI-686, MU-A86 and HI-A389. MAI-686 had elevated abundances of 200 individuals or more at four stations close to the platform. There were also far-field stations to the south with 200 or more individuals. Between 100 and 200 individuals were collected at most of the stations. MU-A85 had 11 stations with 200 or more individuals in the near-field region. Most of the remaining stations yielded between 100 and 200 individuals. The largest abundances were found at HI-A389. This site also displayed a nearly symmetric pattern of decreasing abundances with increasing distance. Total abundances of >400 individuals were collected at three near-field stations. Abundances between 200 and 400 occurred at four slightly more distant stations. Abundances between 100 and 200 individuals occurred at nine near- and intermediate-field stations. Stations at 500-m and 5,000-m distances yielded <100 individuals. Comparison of abundances along radii indicated a fairly uniform trend. The 100-m and/or the 50-m station had larger numbers of individuals than the more distant stations. When data from rings are summed and averaged, a similar pattern emerges at all three sites. Near-field abundances were generally higher than at more distant rings. At MU-A85 abundances were slightly higher at the 100-m ring, while at MAI-686 and HI-A389, abundances were highest at the 50-m station.

The numerically dominant species differed at each platform. At the shallower MAI-686 site *Mediomastus californiensis*, a soft bottom dwelling, direct deposit-feeding polychaetous annelid was the numerical dominant at most stations. *Paraprionospio pinnata* (Polychaeta) and *Ampelisca agassizi* (Amphipoda) were numerically dominant at two stations. At MU-A85, *Paraprionospio pinnata* was the numerical dominant species at most stations. *P. pinnata*, a polychaetous annelid which typically inhabits temporary tubes in muddy to sandy mud sediments, is a surface deposit/suspension feeder which extends its palps over the substrate or into the water column to collect detrital and sediment particles. *Tharyx annulosus*, Foram A and *Xenanthura brevitelson* were each dominant at one station, all at 5,000-m distance. At site HI-A389, no species was numerically dominant throughout the study area. At four stations on the 50-m and 100-m rings cirratulid polychaetes (*Cirratulus cirratus* and *Cirriformia* sp. A) were numerically dominant; these two species accounted for the very large (>400 individuals) abundances found in the near-field region at this site. Cirratulids inhabit the surficial sediments and use palps and tentacular filaments for surface-deposit feeding. The HI-A389 site was also unusual in that 11 of the 25 stations had no species which was numerically dominant. Eight of these stations occurred on the 500-m and 5,000-m rings, and were characterized by having relatively small numbers of individuals.

The numerically dominant taxa were the Polychaeta, Amphipoda, Nemertea, Bivalvia, Decapoda, Isopoda and Foraminifera. These groups comprised about 85% of all individuals collected. The data for each group was summed and averaged for each ring to determine if trends could be detected. The Polychaeta were more abundant at the 50-m and 100-m rings than at more distant stations; at HI-A389 the abundances were considerably higher because of the contribution of cirratulid polychaetes. Amphipod abundance distribution was essentially the inverse of the polychaete distribution. Very low numbers were collected at the 50-m stations and the largest numbers mostly occurred at the 500-m and 5,000-m stations. Nemertean abundance trends were similar to the polychaete trends. Highest numbers were collected in the near-field area and lowest numbers in the far-field area. Bivalves showed no consistent distribution trend between sites. Largest numbers were collected on the 500-m ring at MAI-686 and MU-A85, but on the 50-m ring at HI-A389. Decapod trends were likewise mixed. Numbers were low on all rings at MAI-686. Largest abundances occurred on the 50-m ring at HI-A389 and on the 100-m ring at MU-A85. Isopods were absent at MAI-686 and present in very low numbers at HI-A389 on all rings. At MU-A85 the largest numbers were collected on the 50-m ring and the abundances decreased almost logarithmically to the 5,000-m ring. Foraminiferans were absent at MAI-686. At the other two sites, foram abundances were low in the near-field region and increased toward the far-field region, similar to the amphipod distributional patterns.

Cluster analysis, using the Bray-Curtis dissimilarity index, flexible sorting and log transformation of abundance data, was used to produce site group dendrograms. If all data at one station (e.g. station 1A) are summed over all cruises and all platforms, two site groups are produced. One group contains all 500-m and 5000-m ring stations, and some of the 200-m ring stations. The second group, which is quite distinct from the first, contains 50-m and 100-m ring stations and the remaining 200-m ring stations. All data summed for site HI-A389 produced essentially the same dendrogram, except that only one 200-m ring station was included with the 50-m and 100-m ring stations. MU-A85 data produced a two-group dendrogram in which the second group contained only 50-m and 100-m ring stations. MAI-686 was quite different. Again, two major site groups were produced, but one 50-m and one 100-m ring stations were included with the far-field stations, while the near-field group contained one 5,000-m station and two 200-m stations.

COMPARISON WITH DATA FROM OTHER STUDY COMPONENTS

Low oxygen occurred at MAI-686 during both summer cruises. There is no evidence that the oxygen levels decreased enough to drastically affect the benthos. Abundance trends at both MAI-686 and MU-A85 were similar. Furthermore, abundance trends were downward at all three sites during summer 1994.

All three sites had sand halos around, or near, the platforms; sand content in the sediments decreased with distance from the platform. The sands at MU-A85 and HI-A389, both deep-water stations, were large and angular, typical of cuttings.

Contaminants at MAI-686 were in low concentrations and did not vary significantly with distance from the platform, while at MU-A85 and HI-A389 hydrocarbon contaminants were significantly elevated in sediments collected near the platforms. The increase in hydrocarbon contaminants from site to site correlates with the increased macroinfaunal abundances on the 50-m ring from site to site. The highest concentrations of hydrocarbons were observed close to HI-A389. This site is also where the largest numbers of near-field infaunal organisms were collected. It is possible that microbiological assemblages in the sediment, which utilize hydrocarbons, may be providing a food source for the macroinfauna.

Pore water toxicity tests (defined as success of fertilization of sea urchins eggs and normal larval development) were conducted on pore water extracted from sediments. Pore water from several stations in the HI-A389 near-field region showed toxic effects. Most of these stations coincided with large populations of cirratulid polychaetes. The "toxicity" does not appear to inhibit the settlement and survival of the infauna at these sites. Ophiuroids, the only echinoderm present in large enough numbers to permit averaging, were generally most abundant at the 50-m and 100-m rings. HI-A389 assemblages contained the smallest numbers of ophiuroids of the three sites.

RECOMMENDATIONS FOR FUTURE STUDY

1. Select the one or two sites where abiotic variables (i.e. hypoxia, scour, etc.) have minimum impact.

2. Reduce the number of stations sampled for biological components.

3. Establish a microbiologial program to investigate the possibility that hydrocarbon degrading bacteria are supporting the large populations of macroinfauna near the platforms.

4. Collect at least three replicate samples of at least 300 cm^2 each at each station for macroinfaunal analysis.

5. Remove meiofaunal and microbiological samples from the macroinfaunal samples.

6. Continue monitoring the various taxa of macroinfauna

7. Conduct experiments on selected taxa that show a negative correlation with the near-field area, e.g. amphipods. Establish breeding populations. Expose amphipods to newly collected sediment. Determine if, in the absence of predation, mortalities occur.

Dr. Donald E. Harper, Jr. is an Associate Professor of Marine Biology at Texas A&M University at Galveston. Dr. Harper has been studying macrobenthic assemblages in the northern and western Gulf of Mexico since 1968. These research projects have had two major aims: to determine the long-term natural changes in species composition and abundances in relation to changes in physical, chemical and geological characteristics, and to determine the effects of man-made perturbations on the biota. He has participated in several field studies pertaining to petroleum production, including the Buccaneer Field Study (Harper *et al.* 1981), the Texas Bays Study (Mackin 1971), and the New Bayou Study (Nance 1984), and has conducted literature reviews and synthesis on unpublished reports pertaining to oilfield brine disposal (Harper 1986). He has also studied the effects of dredging and spoil disposal and brine disposal.

SESSION 2B

INNOVATIVE APPROACHES TO MARINE AND ENERGY EDUCATION

Session: 2B - INNOVATIVE APPROACHES TO MARINE AND ENERGY EDUCATION

Co-Chairs: Dr. Robert Rogers and Ms. Gail Rainey

Date: November 16, 1994

Presentation	Author/Affiliation
Innovative Approaches to Marine and Energy Education: Introduction and Overview	Dr. Robert Rogers U.S. Minerals Management Service Gulf of Mexico OCS Region
The Gulf of Mexico Program's Approach to Environmental Stewardship Through Public Education	Ms. Belinda Duke Extension Environmental Specialist Mississippi Cooperative Extension Service for the Gulf of Mexico Program
Energy Education for the 90s and Beyond	Mr. Gerard Katz National Energy Education Development Project (NEED)
Marine Minerals: America's Undiscovered Treasure	Martha Wise Hall
Teaching Science for the 21st Century	Dr. John Dindo Assistant Director Dauphin Island Sea Lab
Stimulating Knowledge of Marine Ecology Through Innovative Strategies	Dr. Robert Thomas Vice President for Environmental Policy Audubon Institute

INNOVATIVE APPROACHES TO MARINE AND ENERGY EDUCATION: INTRODUCTION AND OVERVIEW

Dr. Robert Rogers
U.S. Minerals Management Service
Gulf of Mexico OCS Region

The Minerals Management Service (MMS) needs more emphasis on public education. As has often been mentioned during this year's Information Transfer Meeting, the MMS has an extensive program of information-gathering through the environmental studies program and an extensive network of users who utilize this information in lease sale decisions, oil and gas operations, stipulations formulation, and emphasis on safety in production and development activities.

Despite the fact that the MMS has an extensive environmental studies program that began in 1973 and covers a wide variety of disciplines, the public knows very little about the program and about the knowledge accumulated. Over $150 million has been invested in this program, making it one of the largest in the Gulf of Mexico. More emphasis is needed on educating the public about this information base.

In the interest of fostering exchange of information, the MMS has entered into a number of projects emphasizing cooperation between decisionmakers needing the information and academicians researching the technical disciplines. The University Research Initiative is a cooperative agreement between the Louisiana Universities Marine Consortium (LUMCON) and the MMS. This program emphasizes the long-term impacts of OCS activities. MMS has benefitted not only from the information gathered but also from an infusion of information to the academic community on issues related to the oil and gas industry. A significant number of researchers, graduate students, and technicians have been trained in research related to these issues and sensitized to the complexities of oil and gas activities, from exploration through production and development.

More recently, a similar program has been initiated with Louisiana State University. This program, the Coastal Marine Institute, is in its second year and is designed to provide a framework for environmental research of joint interest to the state of Louisiana and the MMS on OCS oil and gas and marine mineral issues.

Historically the MMS has used its information base in decisionmaking related to a variety of in-house decisions. Clearly in a time of reinventing government and information highways, information must be shared not only for internal utilization but also for information exchange with users outside of MMS and outside of the federal government.

The need for more effectively reaching the public with an understanding of the MMS, its studies program and its mandate for existence, is the purpose of this ITM session. This is the first time that we have had an ITM session designed expressly for emphasizing the need for public education.

Presentations during this session will be made by individuals who are active in outstanding programs of public education emphasizing marine or energy awareness. These programs reach a wide variety of target audiences, from individual citizens and students to state and federal decisionmakers. What makes them effective will be discussed in this session.

Dr. Robert Rogers is a Biological Oceanographer serving on the Environmental Studies Staff of the Gulf of Mexico Regional Office, Minerals Management Service. In this position he has participated in the development and administration of many ecological surveys of the Gulf of Mexico. This has included studies of the Flower Garden Banks of the Western Gulf, coastal wetlands of the Central Gulf, and seagrass beds of the Eastern Gulf. Dr. Rogers received his undergraduate and masters degrees from Louisiana State University and his Ph.D. from Texas A&M University. He has been involved in ecological research on the continental shelf and coastal wetlands of the Gulf of Mexico.

THE GULF OF MEXICO PROGRAM'S APPROACH TO ENVIRONMENTAL STEWARDSHIP THROUGH PUBLIC EDUCATION

Ms. Belinda Duke
Extension Environmental Specialist
Mississippi Cooperative Extension Service for the Gulf of Mexico Program

The Gulf of Mexico is undeniably one of the most valuable ecosystems in the world. The Gulf, "America's Sea," covers over 600,000 square miles. Its commercial fisheries annually produce nearly two billion pounds of seafood, and almost 90% of U.S. offshore oil and gas comes from Gulf waters. Four of our nation's busiest ports are on the Gulf, and other nations of the world fish its waters.

But our treasure is troubled. The health and vitality of the Gulf has declined—in part because of increasing population along its coast and the accumulation of years of abuse, neglect and depletion of its resources. By ignoring the Gulf's limitations, we have reduced its ability to regenerate in the way that nature intended.

In 1988, the Gulf Program (GMP) was established by the U.S. Environmental Protection Agency in response to public concern expressed about certain environmental issues in the Gulf of Mexico—specifically the designation of a site in the Gulf for the incineration of toxic wastes.

Other Federal partners also recognized the need to protect this treasure and joined the EPA in its response. Federal agencies involved currently in the Gulf of Mexico Program include Soil Conservation Services; Army Corp of Engineers; U.S. Fish and Wildlife; NOAA/National Marine Fisheries; U.S. Food and Drug Administration. State staff participation is provided by Mississippi Cooperative Extension Service and Mississippi Soil and Water Conservation Commission for the five Gulf states. A number of other agencies, citizen groups, and organizations make up the membership of the varying Gulf of Mexico issue committees.

The Gulf of Mexico Program's vision is of a Gulf flourishing in all its natural beauty; but the beauty and the resources of the Gulf are threatened. Our challenge is to meet this threat by interweaving the diverse interests of the various pertinent entities and focusing on the Gulf to protect, preserve, and restore America's Sea.

To address this challenge, the Gulf of Mexico Program focuses its attention on the eight most crucial concerns involving the Gulf. Technical issue committees were established to develop strategies for implementing solutions to these environmental problems: Coastal and Shoreline Erosion; Freshwater Inflow; Habitat Degradation; Living Aquatic Resources; Marine Debris; Nutrient Enrichment; Public Health; and Toxics and Pesticides. In addition to the issue committees, a Data and Information Transfer and a Public Education and Outreach Committees were established as operating Committees.

The goal of the Public Education and Outreach Committee is to format the technical data and information gathered from the technical committees into "citizen-friendly" outreach and educational materials and presentations. This information is to be disseminated to every county and parish in the five Gulf coast states to create greater public awareness of environmental issues for the Gulf of Mexico.

In recognition of the need to achieve greater public awareness of the issues the Gulf faces, the Gulf Program recently established the "The Gulf of Mexico Public Information Center."

The Gulf Program's Public Information Center (PIC) is located at NASA, Stennis Space Center, Mississippi, along with the NASA Visitor Center. Over 100,000 visitors per year visit the NASA facility from all 50 states and over 60 countries. This center offers educational programs, tours, displays, and demonstrations for all ages.

The Gulf of Mexico Public Information Center is a distribution center for materials concerning Gulf environmental issues. These materials, such as brochures and pamphlets, are made available by EPA and the other Gulf of Mexico Program Federal Agency partners. The Public Information Center provides an excellent point of exchange and is the focal point for Gulf of Mexico Program technical and characterization information.

Currently under formation, the Public Information Center will be open, providing visitors with a "hands-on" approach to Gulf environmental learning. Visitors will have the opportunity to view displays and demonstrations, interact with high tech equipment, have outreach and educational materials available, and receive instruction on the computer on-line Bulletin Board System (BBS). Tours for students, teachers and the general public can be arranged.

Other available outreach activities include the Electronic Bulletin Board System. Available by dialing the BBS 1-800 number to the on-line Bulletin Board System (BBS) is a Gulf of Mexico Program Specialists Directory and Catalog of Environmental Databases. Gulf-related information can be obtained through this directory and catalog, which provides over 8,000 contacts, 2,000 organizations, and over 100 databases. A wide array of environmental outreach and educational materials are available for downloading by use of the BBS. These materials are currently in English, but plans are in the works for the materials to be also available in Spanish.

The Gulf of Mexico Symposium, celebrated biennially, is a report card to the nation highlighting innovative projects and programs throughout the Gulf region. The next Symposium will be in Corpus Christi, Texas, from 29 March to 1 April 1995. There will be an educator's track, a student track and a challenge track (technical participation). International involvement is being highlighted.

"Gulfwatch,"our bi-monthly publication/newsletter, is available by mail or by dialing the BBS. The purpose of this newsletter is to inform interested agencies and individuals of current activities and findings related to the Gulf of Mexico.

Workshops are conducted in coordination with NASA to teach environmental education to teachers and other interested groups. These consist of specific, topic-related seminars or Gulf general information seminars and are held at the facility. Continuing education workshops are coordinated with schools, aquariums, senior citizen groups, 4-H, minority groups, and other environmental organizations/associations or agencies, at those particular sites.

Contacts for GMP/PIC are as follows:GMP/PIC—Lynn York, Information Coordinator, Johnson Controls, (601) 688-7940; BBS Sysop—Kay McGovern, System Operator, Lockheed, (601) 688-7671; Workshops, Outreach and Educational Programs—Belinda Duke, Extension Environmental Specialist, MS Cooperative Extension Service for the Gulf of Mexico Program, (601) 688-1519.

REFERENCE

The Gulf of Mexico Program—A Partnership for Action Document, 1992. Gulf of Mexico Program, Stennis Space Center, Miss., EPA Document.

Belinda Duke is an Extension Environmental Specialist at the Mississippi Cooperative Extension Service for the Gulf of Mexico. Ms. Duke has been with the Gulf of Mexico Program since July 1993. She is a member of the Public Education and Outreach Committee and the Technical Advisory Committee and will serve as Education's Track Leader for the 1995 Symposium.

ENERGY EDUCATION FOR THE 90S AND BEYOND

Mr. Gerard Katz
National Energy Education
Development Project (NEED)

The National Energy Education Development (NEED) Project is the flagship organization in the country dedicated to implementing comprehensive, non-biased energy education programming in the nation's schools. Established by Congressional Resolution in 1980, the NEED Project is now a vital force in more than 5,000 schools nationwide. Networks of educators, students, and government and industry leaders have been established in 28 states and the program is expanding every year.

The NEED Project's goal is to prepare the next generation to make responsible energy decisions by developing the critical thinking and leadership skills of students. NEED's educational philosophy is to encourage students to take responsibility for their own learning and that of others through hands-on activities and cooperative learning groups.

The NEED Program provides teachers with comprehensive, up-to-date resources on all the major energy sources and activities to use with these resources. The activities are designed to encompass different learning styles, using art, drama, music, language arts, math and science skills. All students are given opportunities to be leaders and to work in groups as they learn about energy issues and their economic and environmental consequences.

Student leadership is one of the key components of the NEED program. Students are encouraged to become involved in the training of others and in the implementation of their programs. Several state programs are run by veteran NEED students, and students serve as staff at all NEED training and awards conferences.

The NEED Project also publishes *Energy Exchange* magazine three times a year. This magazine provides the most current information and discusses the latest issues in energy. Articles are written for teachers and students at different reading levels, with suggested activities for further exploration. NEED also conducts a national Youth Awards Program for Energy Achievement to recognize outstanding energy programs throughout the country. State programs submit their best school programs to the national judging and all outstanding schools are invited to attend the four-day National Recognition Ceremonies held in Washington, D.C. each June.

The NEED Project has been working with MMS to implement partnership programs in several coastal regions, including Alaska, California, Texas, Florida, Alabama, and North Carolina. These programs provide teachers and students with leadership training workshops, class sets of materials to implement three to six week energy units, hands-on experiment kits, and evaluation tools.

In Panama City, Florida, one of the training programs included a Let's Talk Energy Show dealing with the issue of oil and gas exploration on the OCS. A representative from MMS was one of the panelists on the show. Teachers and students were surveyed before and after the 45 minute activity to ascertain any changes in their knowledge and opinions about the issue. The survey results dramatically illustrate how information and education can make an impact on emotional energy issues. A copy of the survey results is attached.

This year, in addition to implementing these school programs, the NEED Project is working with INTERMAR to develop an activity for high school students dealing with non-energy marine minerals. This activity should be available for distribution in the spring of 1995. The fall issue of *Energy Exchange* magazine, scheduled for distribution in early December, will feature an article for teachers and high school students on marine minerals in the EEZ. A draft of this article is also included here.

Panama City - Middle School Workshop
16 February 1994

"Let's Talk Energy Show" OCS Survey

Students and teachers were asked to respond to each question with responses from 0 - 10, as follows:

Strongly Disagree	Not Sure	Strongly Agree
0	5	10

1. Efforts should be made to increase the supply of domestic energy sources.

Before	7.2
After	7.6

2. Efforts should be made to increase the supply of domestic, clean burning, natural gas.

Before	7.0
After	7.0

3. Exploration and production of natural gas should be undertaken in the panhandle area of Florida.

Before	2.2
After	3.6

4. The development of offshore energy resources will hurt the fishing industry in the Florida panhandle.

Before	7.9
After	5.6

5. The construction of offshore drilling and production platforms will be an ugly site when viewed from the shore.

Before	8.5
After	5.8

6. The construction of offshore drilling and production platforms will have a bad environmental effect on the quality of the beaches.

Before	8.3
After	5.0

MARINE MINERALS: AMERICA'S UNDISCOVERED TREASURE

Martha Wise Hall

Draft of Article for
Energy Exchange

EEZ AND OCS—THE LIE OF THE LAND

When most people think of the United States, a map of the country comes to mind. Everyone recognizes the outline of the USA and its borders. But our resources aren't confined to those borders—they reach much farther. Our borders extend 200 miles into the water from our coastlines and encompass an area bigger than the country itself. The submarine area claimed by the United States includes 3.9 billion acres, whereas the land area of the country includes only 2.3 billion acres.

This vast underwater area is called the Exclusive Economic Zone (EEZ) of the United States. By proclamation of the President in 1983, the United States claimed jurisdiction over all the areas within the EEZ and is responsible for protecting and developing its natural resources, both living and non-living. Other countries are free to travel and fish in the international waters of the EEZ to within 12 miles of the coast, where territorial waters begin. The U.S. has exclusive jurisdiction over this area and foreign vessels cannot enter without permission.

The undersea world extending away from the shore is a fascinating place. In most places, the continent extends into the ocean on a broad shelf that gradually descends to a sharp drop, called the continental slope. This continental shelf can be as narrow as 20 kilometers along the west coast and as wide as 400 kilometers along the northeast coast. The water on the continental shelf is shallow, rarely exceeding a depth of 150 to 200 meters.

This shelf drops off dramatically at the continental slope, ending in abyssal plains that are three to five kilometers below sea level. Many of the plains are flat and featureless, while others are marked with jagged mountain ridges, deep canyons, and valleys. The tops of some of these mountain ridges form islands where they extend above the water. Some ridge crests contain hydrothermal vents—underwater geysers. Rich deposits of minerals and amazing plants and animals have been discovered around these vents.

The EEZ regions surrounding the Pacific and Caribbean islands have different topographies. The island shelves are composed of volcanic rock on which coral reefs or carbonate sediments have developed. These shelves are very narrow and shallow, dropping off sharply to abyssal plains or deep ocean trenches. The Hawaiian Archipelago, for example, is a chain of volcanic mountains rising from plains five to 7.5 kilometers deep.

Much of this submarine world has not been explored—it is the Earth's last frontier—but scientists do know about some of the resources in many areas. Most of us are aware of the rich deposits of oil and gas on the outer continental shelf (OCS), especially off the coasts of California and in the Gulf of Mexico.

OIL, GAS, AND PHOSPHORITE

Oil and gas reserves on the OCS are located in sedimentary rock basins, where organic matter settled millions of years ago. If the sediments that contained this organic matter produced the proper conditions of temperature and pressure, petroleum and/or natural gas was formed. Thirty basins in the EEZ have been identified that could contain enormous oil and gas reserves. Several of these basins have been explored and are producing oil and gas at this time.

There are other marine minerals in the EEZ that can provide a wealth of resources to the United States in the future. They are located in or on the sediments of the subseabed and underwater mountain ridges. There are even resources in the muds and oozes, and dissolved in the seawater itself.

The most important marine minerals are sand and gravel, shell, phosphorite, placer minerals such as gold and platinum, and heavy minerals such as titanium, chromium, and magnetite *(Placers are minerals that were deposited in the ocean by the movement of water or glaciers.)* Sand, gravel, and shell are widely distributed along the OCS. The other minerals are found only in certain areas or formations.

Phosphorite is found in deep depressions and sedimentary basins along stable regions of the continental shelf. It is mainly used in fertilizers, but is also an important ingredient in feed supplements, fireworks, and water treatment. At the present time, there are abundant onshore resources, and the U.S. exports some of its production. By the turn of the century, however, it is predicted that we will need to import phosphorite, based on remaining onshore reserves and consumption estimates. As onshore resources become more difficult and costly to extract and the land is valued more for other uses, offshore deposits may become an important resource.

GOLD, PLATINUM, AND HEAVY MINERALS

Deposits of placer minerals and heavy minerals are also located in pockets throughout the OCS. The United States has limited onshore deposits of most of these minerals and must import a significant percentage of its demand. Titanium is the only important mineral in this group that the U.S. exports in significant amounts, and its supplies are limited. Titanium is an essential mineral in the aerospace industry because of its ability to withstand high temperatures and is widely used as the white pigment in paints, paper, and plastics. There is no effective and economical substitute for titanium at this time.

The United States imports almost 100% of the platinum we use, mostly from South Africa and the former Soviet Union. Most people think of jewelry when platinum is mentioned, but 97% of its demand is for industrial applications, especially in the auto industry. With the federally mandated phase-out of leaded gasoline, the demand for platinum has increased dramatically in the last few years. Automobiles that run on unleaded gasoline require catalytic converters, which are made with platinum. The demand for platinum will continue to increase in the near future, unless breakthroughs occur in experimental technologies for catalytic converters.

Chromium is another mineral essential to the economic welfare of the country. Chromium is used in the manufacture of stainless steel and for other industrial purposes. It is considered a National Defense Stockpile item because of its importance in the production of cars, planes, and trains. At present, the U.S. imports more than 80% of the chromium it requires, mostly from South Africa.

Gold is used for many purposes. Jewelry accounts for 70% of U.S. use, but gold is also important to the electronics and aerospace industries, as well as to medicine and dentistry. Currently, the United States is the second leading producer of gold after South Africa and exports a small amount to other countries. Two dozen gold mines account for most of the gold production in the United States today.

In today's economy, there is little incentive to recover offshore resources of platinum, chromium, and gold. Considering the limited onshore resources and the political instability of major suppliers, however, they may become important resources for the United States in the future.

METALLIC SULFIDE ORES

The hydrothermal vents located along volcanic ridges contain metallic sulfide deposits that are rich in zinc, manganese, iron, lead, and silver. Active vents (smokers) produce new deposits whenever they erupt. These minerals are used in many products, including batteries, paint, weights, crystal glass, jewelry, photographic and electronic equipment, plastics, and in the construction and transportation industries. Recently, deposits have been discovered off the coast of Oregon and around the Pacific Islands. Most of these deposits are located in water as deep as 10,000 feet and are considered uneconomical to mine at the present time, but their potential is significant.

The crust deposits associated with hydrothermal vents are rich in cobalt, manganese, and phosphorite. Cobalt is especially important to the aviation industry to make lightweight superalloys that can withstand high temperatures. The United States produces no cobalt—we import 75 percent of our supply and the remaining fourth is recycled from scrap. There has been some interest in recovering cobalt from offshore deposits near Hawaii.

Manganese is also found in nodules on the Blake Plateau off the southeast coast and on the abyssal plains of the Pacific Ocean floor. It is used extensively in the manufacture of steel and in other industrial products, and is considered critical to national security. Nearly 100 percent of U.S. supply is imported and there is no satisfactory substitute.

SAND AND GRAVEL

The most abundant and important marine mineral resource for the near future is sand and gravel. These minerals are found in large quantities along the seabed of the OCS. The sand and gravel can be mined using several types of dredges that remove it from the ocean floor and deposit it on barges or even pipe it directly to shore. Some dredges use suction to bring the sand and gravel to the surface, while others raise it in large buckets or scoops.

Mixtures (*aggregates*) of sand and gravel are used in huge quantities in the construction of buildings, roads, railroad beds, dams, and airports, and in the restoration of shorelines. Historically, construction aggregate has been produced onshore in the United States because land resources have been plentiful and cheap. This situation is changing, however, for several reasons: economical sources are being depleted, lands with resources are more valuable for other uses, environmental concerns preempt use, and available resources are too far from markets.

Construction aggregate is a low-cost item. A very small increase in price per ton can add dramatically to the total construction cost of a project. Transportation of the aggregate from the production site to the construction site is the largest cost—most aggregate is transported by truck. Therefore, to keep the transportation cost down, the aggregate must be produced locally. In many areas, there will soon be no local, land-based deposits, especially in big cities.

The greatest demand for construction aggregate is in major metropolitan areas, where land prices are high and land use is restricted. Land development has made many of the local deposits unreachable; furthermore, the land is so valuable that communities don'twant to use it for aggregate production. In New York City, for example, aggregate costs are now three times the national average and researchers have predicted that available resources will be completely depleted within ten years.

New York is not an isolated case. In the United States today, half of the population now lives within 50 miles of a U.S. coastline, mostly in metropolitan areas. Since 1980, the biggest increase in population growth has been in the coastal states. And where population increases, construction increases. Where will the construction industry get the materials it needs at reasonable prices?

One answer is from the oceans. The United States extracts very little sand and gravel from the OCS right now, but other countries have been doing it for years. Almost 25 percent of the sand and gravel produced in Japan comes from off-shore mining. The United Kingdom has been mining sand and gravel from the ocean since 1925; 15 percent of their total production is from marine mining. The Netherlands and Denmark also obtain much of their sand and gravel from off-shore sites. These countries have developed sophisticated mining equipment and have conducted numerous studies to determine the impacts of marine mining on the fishing industry and the environment.

The technology is available to recover sand and gravel from the OCS economically, but the United States' sand-dredging industry is comparatively small and designed for near-shore work. Federal law at this time requires that any equipment used to mine minerals in the EEZ or transport them must be built in the United States; therefore, America's ship builders may have to adapt equipment for deeper water projects. U.S. companies cannot buy the barges and dredges from countries already well-skilled in the business.

Transportation of the aggregate is another consideration. Transportation costs will continue to increase for land-based mines, as production sites are located farther from metropolitan areas. Marine transportation by barge, on the other hand, costs about one-third as much per ton as trucking.

TODAY AND TOMORROW

One established area in which the United States uses marine sand is in the restoration of beaches. A substantial portion of the nation's coastline is eroding severely, causing damage to beaches, wetlands, and coastal properties. The traditional approach of building jetties has become very expensive and has often proved ineffective in the long run.

Many coastal communities have been restoring their beaches using sand dredged from the ocean or from nearby navigational channels as part of their maintenance programs. Restoring the beaches with sand from the ocean is a cost-effective approach, though studies are showing that sand cannot be dredged too near the shoreline without altering the current and wave patterns, which could intensify erosion.

Crushed shell from the OCS is also used in some areas as a foundation for roadbeds and in the manufacture of fertilizer. Shell is not evenly distributed along the OCS, but in areas where it is abundant, it can be an economical alternative to onshore products.

ECONOMIC AND ENVIRONMENTAL IMPACTS

Of course, the mining and transport of marine minerals does have an impact on the environment of the oceans, just as land-based mining affects the environment. During the period of active mining, there are disturbances of the water, with an increase in turbidity and noise. *(Turbidity is the amount of sediment suspended in the water.)* These disturbances may affect the plant and animal populations near the site.

Effects that should be considered before permitting any dredging activity might include changes to the topography of the sea floor and changes to marine plant and animal communities on the site, as well as broader changes to the composition of the area's ecological systems. Studies are being conducted to determine how quickly the plant and animal communities in dredged areas reestablish themselves.

Sometimes alterations caused by the mining cause problems for the local fishermen; discarded mining equipment and rough terrain can damage their nets. Fish populations can also be disturbed, at least during the time of active mining, and breeding grounds can be affected. Studies have shown that many of the changes to the marine environment appear to be short-term or can be mitigated with careful management.

The ecology of the different areas of the EEZ is varied and complex. Marine mining in some areas will produce completely different effects than in others. Site by site environmental impact studies will need to be undertaken to protect the integrity of the EEZ, as is required of land-based mine sites. In many cases, the effects of marine resource recovery will be more economical and less damaging to the environment than the effects of recovering the same resource from the land.

The EEZ contains an underwater treasure of resources for the United States. With careful management, these resources can be wisely and economically used and protected.

As the founder of the National Energy Education Development (NEED) Project, Gerard (Jerry) Katz has guided the project's growth since its inception in 1978. Jerry received his B.A. in physics from Herbert H. Lehman College in New York in 1973 and he completed graduate courses in education, curriculum development, and instruction from the State University at Albany and New Paltz. He taught physics and directed student activities for five years at Greenville High School in Greenville, New York, before dedicating himself full-time to the development of the NEED Project into a national organization.

TEACHING SCIENCE FOR THE 21ST CENTURY

Dr. John Dindo
Assistant Director
Dauphin Island Sea Lab

Dr. Bruce Alberts, a former president of the National Academy of Sciences states, "Schoolchildren should learn science the way scientists do, not by memorizing definitions in boring textbooks, but by doing science." Vice President Gore and Commerce Secretary Brown are trying to find support for a national information network utilizing fiber optics, yet the majority of all Americans have trouble programming their own VCR. Carl Sagen writes, "Less than half of all Americans know that the Earth moves around the Sun and takes a year to do it." It is true today that there are scientist in the unemployment ranks, yet the United States still ranks seventh in science and math when compared to other industrialized nations.

Teaching science teaches the pathways to critical thinking. We are told today that our value system is lost, both at home and in schools. Mr. Hunter wrote a book in 1990 titled *A Question Of Values: Six Ways We Make The Personal Choices That Shape Our Lives*. In his book Lewis points our that we use six different cognitive methods to establish our value judgments:

1.	Authority	taking someone else's work, having faith in that work
2.	Logic	subjecting beliefs to the variety of consistency tests/deductive reasoning
3.	Senses	gaining direct knowledge through our own five senses
4.	Emotion	feeling something is right although we do not know it
5.	Intuition	unconscious thinking
6.	"Science"	synthetic technique relying on sense experience to collect observable facts, intuition to develop a testable hypothesis about the facts, logic to develop the test, and sense to complete the test

Science allows us to utilize all five of Lewis's lenses to help shape our lives. If used at an early critical thinking stage, techniques can be established as a foundation for education. George Will, a *Washington Post* syndicated columnist wrote an article titled "Educators Place Children At Risk." The article referenced the Chicago late openings in 1993 and the 1,069 schools closed on opening day of the academic year in New York this year due to asbestos testing. These days add up to fewer and fewer days in the classroom . The United States already has the lowest number of classroom days per year as compared to the rest of the industrialized world. As we move closer to the twenty-first century our children graduating today will not be able to cope with the world of technology that lies ahead of them. As a scientist and an educator I know that to truly be able to understand the life sciences, mathematics, and technology we must invest in time, a commodity that will continue to be the most limiting as we move into the twenty-first century. Going back to the basics is not the answer, only a convenient one for politicians. No one in the twenty-first century will be doing long division by hand, but a student must still understand the principles of long division.

We have long assumed that true science should be taught when a student matures, so we leave it for middle school. Middle school is too late to be teaching the principles of conceptual thinking and application of trial and error experimentation. The inquisitiveness of early childhood, including kindergarten, is the time that science should be initiated. Young children love to ask why, and show me, and how did you do that? Teachers can introduce science techniques and the concepts of scientific investigation at this age because the students are eager to learn. Dr. Alberts, National Academy of Sciences, states, "We subject millions of American children every year to this mindless curricula of memorization." It becomes so boring that it discourages them from pursuing science and leaves them with the belief that science is nothing but memorization at an age that sets standards and initiatives for the future. Students learn by doing experiments they do every day in their play, yet we fail to apply it in the classroom.

Students of all ages are fascinated by the oceans and the life that they hold. By capitalizing on this fascination, we teach the principles of scientific investigation using the marine environment as our focal point. As a consortium of 22 colleges and universities, we were founded to conduct marine research and education at the undergraduate and graduate level. But for the past 15 years we have expanded our educational program to include offering marine education to over 15,000 K-12 students a year. Nine thousand of these students are in the elementary grades. Our teaching centers on the scientific approach to understanding the environment and the plants and animals that coexist in that environment. By using hands-on learning at all grade levels we stimulate the critical thinking pathways that help establish a foundation for the future. Our classes involve both instruction within a classroom as well as instruction out in the environment, not just a show-and-tell but rather total involvement by the students themselves. It may involve watching the movement of a hermit crab along the shallow bottoms or measuring wind-derived waves, but students are challenged to ask the questions and seek answers to what ever aspect they are studying. In addition we constantly try to emphasize that this process of utilizing critical thinking skills can be applied anywhere, from a drainage ditch next to the school, to the city park, or a lake or stream. It only takes imagination and stimulus by the teacher to capture the interest of students. The best way to understand science is to experience it first-hand by doing it. It is not enough just to read about past scientists and what they did; it is important to challenge students to think about science and then go about the learning process of doing science. Utilizing Eisenhower monies from the federal government, we teach teachers how to teach science better and how to introduce science at an early level.

A USA/Times report indicates that by the year 2000 over 14,000 jobs will be available for individuals who have a Ph.D. in science, math, or engineering, yet only about half of those positions will be filled with students from the Unites States. The 21st century will be one of technology-based information and learning techniques. We must advance our teaching beyond the old methodologies and stimulate students early. Just because a methodology worked in the past does not mean its applicable now or in the future. Ron Kreigel has written a book titled *If It Ain't Broke, Break It*, which highlights change in our teaching to prepare our students better for the future. I believe that our approach to teaching science at the Dauphin Island Sea Lab establishes a foundation of inquisitiveness that can carry forth into the future.

Dr. John J. Dindo is Assistant Director of the Dauphin Island Sea Lab, where he has worked for 18 years. He received is B.S. in fisheries ecology from the University of Alaska, his M.S. in physiology and biochemistry and his Ph.D. in marine ecology from the University of Alabama at Birmingham. His research interests include artificial reefs, hardbottom reefs, and coastal ecology.

STIMULATING KNOWLEDGE OF MARINE ECOLOGY THROUGH INNOVATIVE STRATEGIES

Dr. Robert Thomas
Vice-President for Environmental Policy
Audubon Institute

Project CEED is a multidimensional educational effort taking place in coastal Louisiana. Its focus is expressed in the acronym: Coastal Education for Economic Development. The concept is that citizens who understand that their livelihood is dependent on a healthy coastal ecosystem will be motivated to show stewardship toward the environment. In Louisiana, as in all coastal states, children who drop out of school are likely to seek employment in the coastal zone, usually in a fisheries related field. As a consequence, Project CEED is directed toward that group that is most likely to drop out of school: middle school at-risk students.

Project CEED is a collaborative effort between the staffs of the Audubon Institute (operator of the Louisiana Nature Center) and faculty members from the Department of Special Education and Habilitative Services of the University of New Orleans. Project CEED's educational approach combines the talents and expertise of hands-on environmental educators (who know what to teach) and special educators (who know how to teach atypical learners). A wide variety of materials has been developed to accomplish the objectives of Project CEED. Many local teachers participated as members of the writing team. Business involvement guarantees that the economic perspective is maintained (the first program in this area of Project CEED is under development).

Project activities are "teacher friendly," i.e., they do not require massive preparation time for use, and the teacher does not have to be science-oriented. The activities are designed for use in several different disciplines such as English, math, art, and history. Teaching elements include concept mapping, decision making, asking provocative questions, Bloom's taxonomy, Taylor's Multiple Talent Model, poetry, scamper, synectics, and more. A videotape (*Wetlands Blues*) with accompanying teacher's guide, and a Macintosh computer game that models a wetland are available. Several independent teacher's guides have been developed, each of which focuses on a wetlands related topic (e.g., beaches, wetland values, etc.) and a specific student-generated product (e.g., designing a bumper sticker, designing t-shirts, etc.).

Project CEED is a continuing program, with many new phases being considered. For information about acquiring the program products, contact: Office of Environmental Policy, The Audubon Institute, P.O. Box 4327, New Orleans, LA 70178-4327.

SESSION 2C

COASTAL MARINE INSTITUTE PROGRESS REPORTS, PART I

Session: 2C - Coastal Marine Institute Progress Reports, Part I

Co-Chairs: Dr. Richard Defenbaugh and Dr. Robert S. Carney

Date: November 16, 1994

Presentation	Author/Affiliation
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A Numerical Modeling Study of the Gulf of Mexico Under Present and Past Environmental Conditions	Ms. Susan E. Welsh Department of Geology and Geophysics Louisiana State University Dr. Masamichi Inoue Department of Oceanography and Coastal Studies Louisiana State University
Digital High Resolution Acoustic Data for Improved Benthic Habitat/Geohazard Evaluations	Dr. Harry H. Roberts Coastal Studies Institute Louisiana State University
A Socioeconomic Outer Continental Shelf Issue Analysis of Stakeholders in the Central Gulf of Mexico	Dr. Robert Gramling University of Southwestern Louisiana
Characteristics and Possible Impacts of a Restructured OCS Oil and Gas Industry in the Gulf of Mexico: Preliminary Results	Dr. Ruth Seydlitz Mr. John W. Sutherlin University of New Orleans Dr. Thomas R. Hammer Dr. Edward M. Bergman University of North Carolina
A Management Overview for Resource Development in Continental Slope Habitats	Dr. Robert S. Carney Director, Coastal Marine Institute Louisiana State University
Development and Application of Sub-Lethal Toxicity Tests to PAH Using Marine Harpacticoid Copepods	Mr. Gui Lotufo Dr. John Fleeger Department of Zoology Physiology Louisiana State University
Modeling the Behavior of Integrated Producers and Independent Producers: Implications for Offshore Oil and Gas Development and Policy	Dr. Allan G. Pulsipher Dr. Wumi O. Iledare Center for Energy Studies Louisiana State University

Role of Bottom Sediment Redox-Chemistry Near Oil Production Facilities on the Sequester/ Release and/or Degradation of Metals, Radionuclides and Organics

Mr. B.C. Banker
Mr. T.Z. Guo
Dr. J.H. Pardue
Dr. R.D. DeLaune
Dr. C.W. Lindau
Wetland Biochemistry Institute
Louisiana State University

INTRODUCTION

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

Dr. Robert S. Carney
Director, Coastal Marine Institute
Louisiana State University

On 30 September 1992 the MMS and the State of Louisiana signed a Cooperative Agreement establishing the first Coastal Marine Institute (CMI). This CMI addresses the parallel OCS information needs of both parties in a timely, cost effective manner, while taking full advantage of the academic talents in the immediate OCS planning area.

Under the terms of this agreement, the MMS and the State of Louisiana provide matching funds to conduct environmental research of joint interest. The State, through Louisiana State University (LSU), provides matching funds of at least one dollar for each dollar provided by the MMS (up to $10 million over a five-year period). All funds obligated are used to support studies that fall within a general framework.

The CMI framework provides broad boundaries for guidance in the development of specific research projects. This framework was designed to include the following: technologies for extracting and transporting non-energy resources; environmental responses to changing energy extraction and transport technologies and spills; analyses and synthesis of existing data/information from previous studies; modeling of environmental, social, and economic processes and systems; new information about the structure/ function of affected systems via application of descriptive and experimental means; and projects that improve the application and distribution of multisource information.

The framework also serves to foster the continuing education and training of the academic and the regulatory communities, as well as MMS professional and management staff (e.g., short courses, workshops, seminars, etc.)

Studies proposed for support under the CMI are reviewed by the CMI Technical Steering Committee, on which MMS and LSU are equally represented. The LSU participants include Drs. Robert Carney and Chip Groat. The MMS members include Dr. Richard Defenbaugh, Acting Regional Supervisor of the Office of Leasing and Environment, Gulf of Mexico OCS Region, and Dr. Ken Turgeon, Chief, Environmental Studies Branch. Dr. Carney, who serves as the CMI director, administers the daily activities of the program from LSU's Baton Rouge campus.

This session and its continuation (Session 3C) reflect the diversity of issues and interests that are of mutual concern to the State of Louisiana and to the MMS. The range of topics extends from socioeconomics to the development and application of sub-lethal aquatic toxicity tests. The information resulting from these and other CMI research efforts will provide managers at both the federal and state levels with some of the information necessary to develop the oil, gas, and mineral resources of our outer continental shelf in an environmentally sound manner.

Dr. Richard Defenbaugh is Acting Regional Supervisor for Leasing and Environment within the Gulf of Mexico OCS Regional Office. His graduate work at Texas A&M University on the natural history and ecology of Gulf of Mexico estuarine and continental shelf invertebrates led to a M.S. in 1970 and a Ph.D. in 1976. He previously worked in the Bureau of Land Management's New Orleans OCS Office. At MMS he served as Chief, Environmental Studies Section for ten years and then moved to the position of Deputy Regional Supervisor for Leasing and Environment. He was appointed Acting Regional Supervisor in July 1993, following the accidental death of Mr. Ken Adams. Dr. Defenbaugh serves as one of two MMS representatives on the CMI Technical Steering Committee.

Dr. Robert Carney, an associate professor in LSU's Department of Oceanography and Coastal Studies, has served as director of LSU's Coastal Ecology Institute since 1986 and has been director of the LSU-MMS CMI program since its inception. He received his M.S. from Texas A&M University and his Ph.D. from Oregon State University. Prior to LSU, Dr. Carney was employed at Moss Landing Marine Labs, the National Science Foundation, and the Smithsonian Institution.

A NUMERICAL MODELING STUDY OF THE GULF OF MEXICO UNDER PRESENT AND PAST ENVIRONMENTAL CONDITIONS

A NUMERICAL MODELING STUDY OF THE GULF OF MEXICO UNDER PRESENT AND PAST ENVIRONMENTAL CONDITIONS

Ms. Susan E. Welsh
Department of Geology and Geophysics
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Dr. Masamichi Inoue
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Department of Oceanography and Coastal Science
Louisiana State University

INTRODUCTION

The Gulf of Mexico (GOM) is a highly suitable domain for paleoceanographic study using an eddy-resolving, ocean circulation model. This modeling project features two distinct phases. The circulation in the Gulf of Mexico is first modeled under present environmental conditions in order to calibrate model parameters and verify model output. This part of the project is of significance not only as a necessary step in creating a model for past environmental conditions, but it also provides a valuable tool in the study of Loop Current behavior and general circulation in the Gulf of Mexico. The next step is to lower sea level in the Gulf of Mexico to approximately that which occurred during the Last Glacial Maximum. New surface boundary conditions will be applied that reflect the glacial environmental conditions. The circulation generated by the paleoceanographic model will be compared to circulation inferred by several paleontological and sedimentological studies of the Gulf of Mexico. This paleoceanographic model should help interpret the distribution of glacial fauna and sedimentation patterns found in the geologic record.

NUMERICAL MODEL DESCRIPTION

The bathymetry of the Gulf of Mexico features several broad, gently sloping shelves, steep escarpments and relatively shallow sill depths in the Yucatan and Florida Straits. Circulation in the Gulf of Mexico is dominated by the presence of the Loop Current (LC) and anticyclonic eddies that are shed from the LC. The Modular Ocean Model (MOM), a three-dimensional primitive equation model, allows us to include the effects of bottom topography as well as adequately resolve eddy dynamics.

During the 20-plus years that MOM has been under development, it has been thoroughly tested and improved. The Bryan/Cox/GFDL model is the precursor to MOM and was described in detail by Semtner (1986). The MOM version, produced by R. Pacanowski, K. Dixon and A. Rosati (1991) at the Geophysical Fluid Dynamics Laboratory at Princeton University, retains the basic physics of the Bryan-Cox code, but it has been modified for more efficient use with a UNIX operating system. The model was most recently updated and available for use in August 1993.

The finite-difference method was used to construct the model on a staggered grid referred to as the Arakawa B-grid. Temperature, salinity, actual depth and transport stream-function lie at the center of the grid box, and velocity points lie at the centers of the vertical edges. The model grid is derived from the ETOP05 1/12° resolution, world topography data set available from the National Ocean Data Center (Figure 2C.1). The bathymetric values are interpolated to $1/8_{o}$ and then smoothed using a coastline-preserving scheme to prevent topographically-induced instabilities in the numerical solution.

The model grid extends outside the GOM into a synthetic return flow region that links the Straits of Florida with the Yucatan Straits. The bathymetry in this region has been altered to connect the Florida Straits with eastern portion of the Caribbean and does not represent actual bathymetry. The inflow into the GOM is achieved by forcing the flow through the western Caribbean to acquire the observed geostrophic values, thus eliminating the need to model the entire North Atlantic. Another benefit of allowing the flow to recirculate around Cuba is to avoid the implementation of open boundaries.

A factor in the choice of the 15 model depths is the preferred use of evenly-spaced levels, which results in a higher-order computation of the vertical modes. It was necessary to use bimodal spacing of the depth levels, such that the upper 4 levels are 75-meters

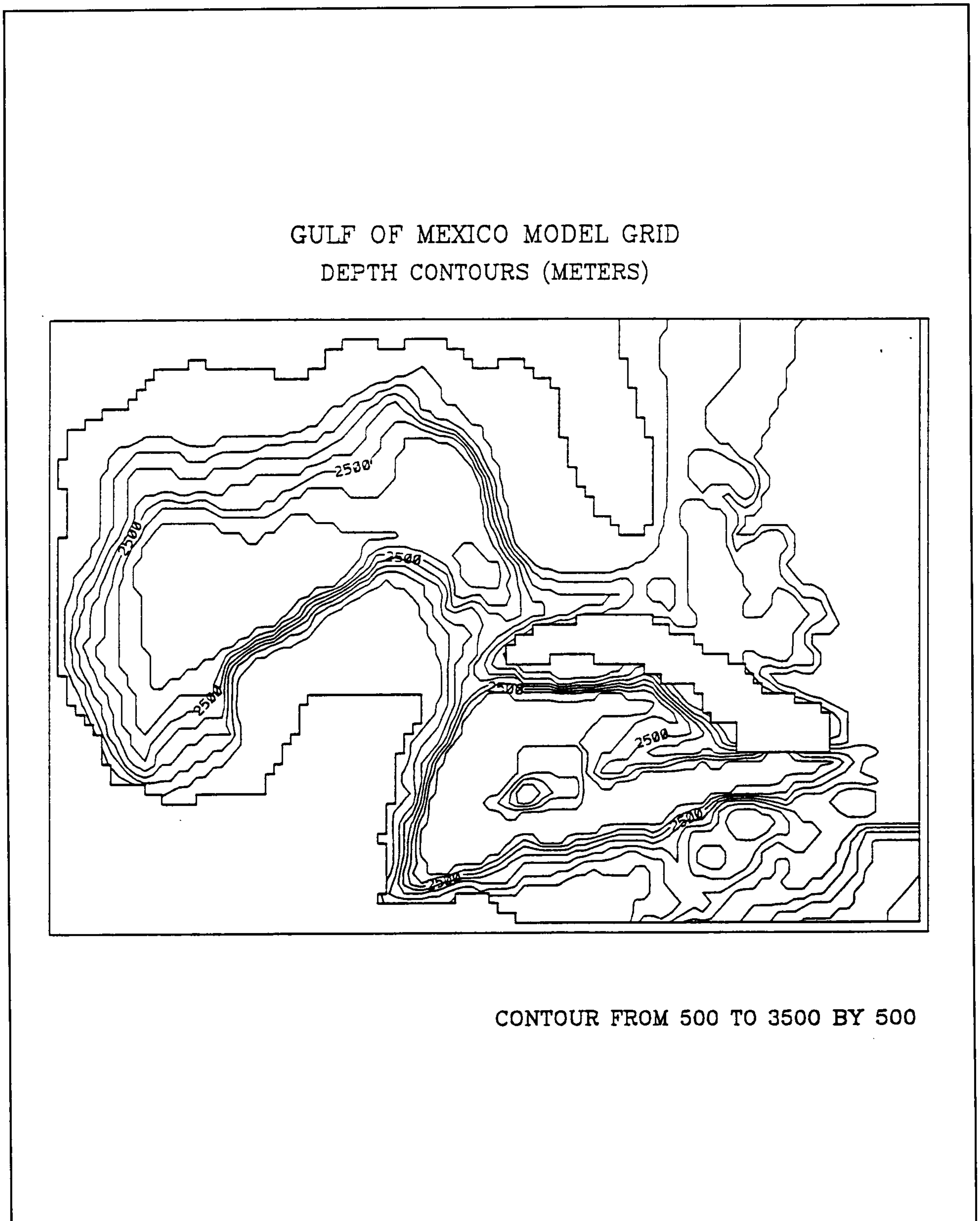

Figure 2C.1. Contour plot of model depths (meters) superimposed on an outline of gridded land values for model domain.

thick and the lower 11 levels are 300-meters thick for a total depth of 3,600 meters. These depth levels still allow for higher vertical resolution on the shelf.
The initial runs of the model simulate present-day environmental conditions in order to calibrate the model and determine the ability of the model accurately to simulate the GOM circulation. The three-dimensional annual mean temperature and salinity fields used to initialize the model have been interpolated from the Levitus Climatological Atlas of the World Ocean (Levitus 1982). The surface temperature and salinity fields are restored to Levitus annual mean values with a relaxation time scale of six weeks. The surface wind stress field has been interpolated from the Hellerman and Rosenstein (1983) annual mean wind data.

The volume flux through the Yucatan Straits is controlled by adjusting the barotropic u-component of velocity along a longitudinal band center at 82.375°W in the Caribbean. The desired vertical shear is achieved by relaxing the temperature and salinity along this same vertical cross section to the observed values on a time scale of one week. The temperature and salinity fields used for this purpose are derived from the Levitus climatology. The inflow condition into the Gulf of Mexico is illustrated by a contour plot of the v-component of velocity with depth across the Yucatan Straits (Figure 2C.2).

Maximum velocities of 100-105 cm/s occur in the upper level (37.5 meters) in the Yucatan Straits. The volume flux through Yucatan fluctuates between 25 and 29 Sverdrups with an average of approximately 27 Sverdrups.

RESULTS

The model has been successfully initialized with the three-dimensional temperature and salinity fields, wind forcing, quadratic friction, a 5-point conjugate gradient solver, a surface boundary condition on temperature and salinity and adjustment of the flow to geostrophic values in the Caribbean. The values of viscosity and diffusivity are 20 m^2/s and 10 m^2/s respectively. Bottom stress is applied with a coefficient of C_D =.001. This case was run for over eight years of model time on an IBM 3090. The cpu time per time step is approximately 4.3 seconds (using 30-minute time steps) or 21 cpu hours per model year of simulation.

Approximately three years of model integration were necessary for the model to become sufficiently spun-up. At this point a five-year integration was made to verify the results. A snapshot of the model output was made every twelve weeks that included the transport stream function, u- and v-components of velocity, temperature, and salinity at every grid point. These snapshots are used to look at model output in extreme detail. Velocity vectors are plotted at several levels to determine circulation patterns. A map of temperature contours and velocity vectors for the LC and a detached eddy is provided in Figure 2C.3. The vertical temperature and salinity structure of these same features are provided in Figures 2C.4 and 2C.5.

The difficulty with analyzing the output from a three-dimensional model such as MOM is the tremendous amount of model data that is generated. We have been fortunate to obtain software that uses the graphics capabilities of our Silicon Graphics Indigo workstation to animate the temperature fields generated by the model. This animation/visualization software was written by Lingsong Bi of the Computer Science Department at LSU as part of his Master's thesis and is call Data Viz. These animations are extremely useful tools for describing the process of LC eddy formation, as well as their westward migration and final dissipation. The surface temperature and total velocities were saved every three days during the five-year integration for use in the animation software.

The temperature and velocity signals of the eddies are easily traced into the Western Gulf where the eddies appear to be entrained by the northward-flowing current. The eddies are about 450 km in diameter at the surface after they become detached from the Loop Current. Time series of temperature at several locations around the Gulf were analyzed to determine the eddy shedding period, which is approximately every 30 weeks.

The model was then run for another 60 weeks for the purpose of saving some of the lower level data for analysis using the animation software. Temperature and velocity fields were saved for levels 1, 3, 5, and 6 with depths of 37.5m, 187.5m, 450m and 750m, respectively. Animation of the lower level temperature fields is interesting because the temperature signal of the eddies is very large compared to the ambient fluid.

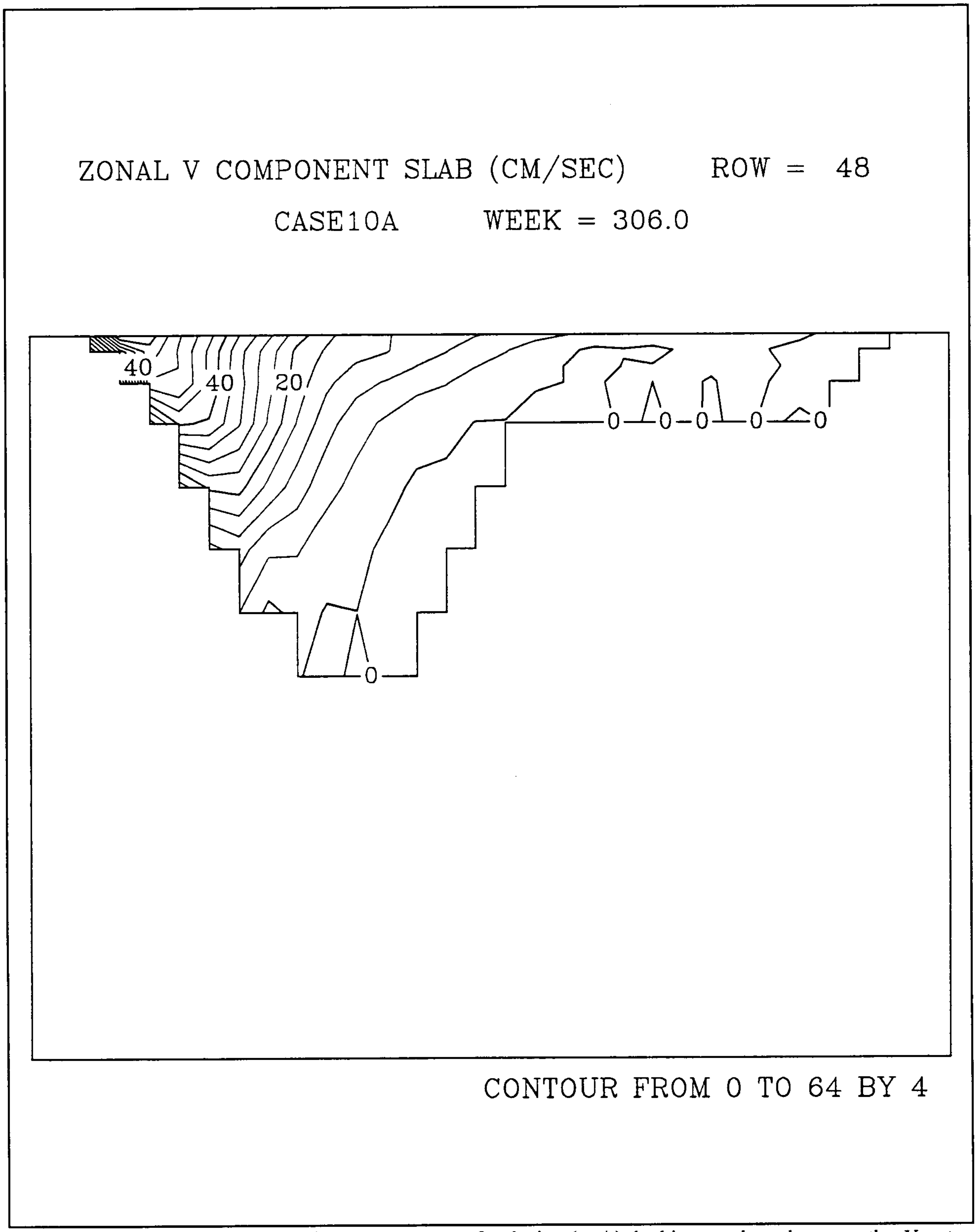

Figure 2C.2. Contour plot of the v-component of velocity (cm/s) looking northward across the Yucatan Straits.

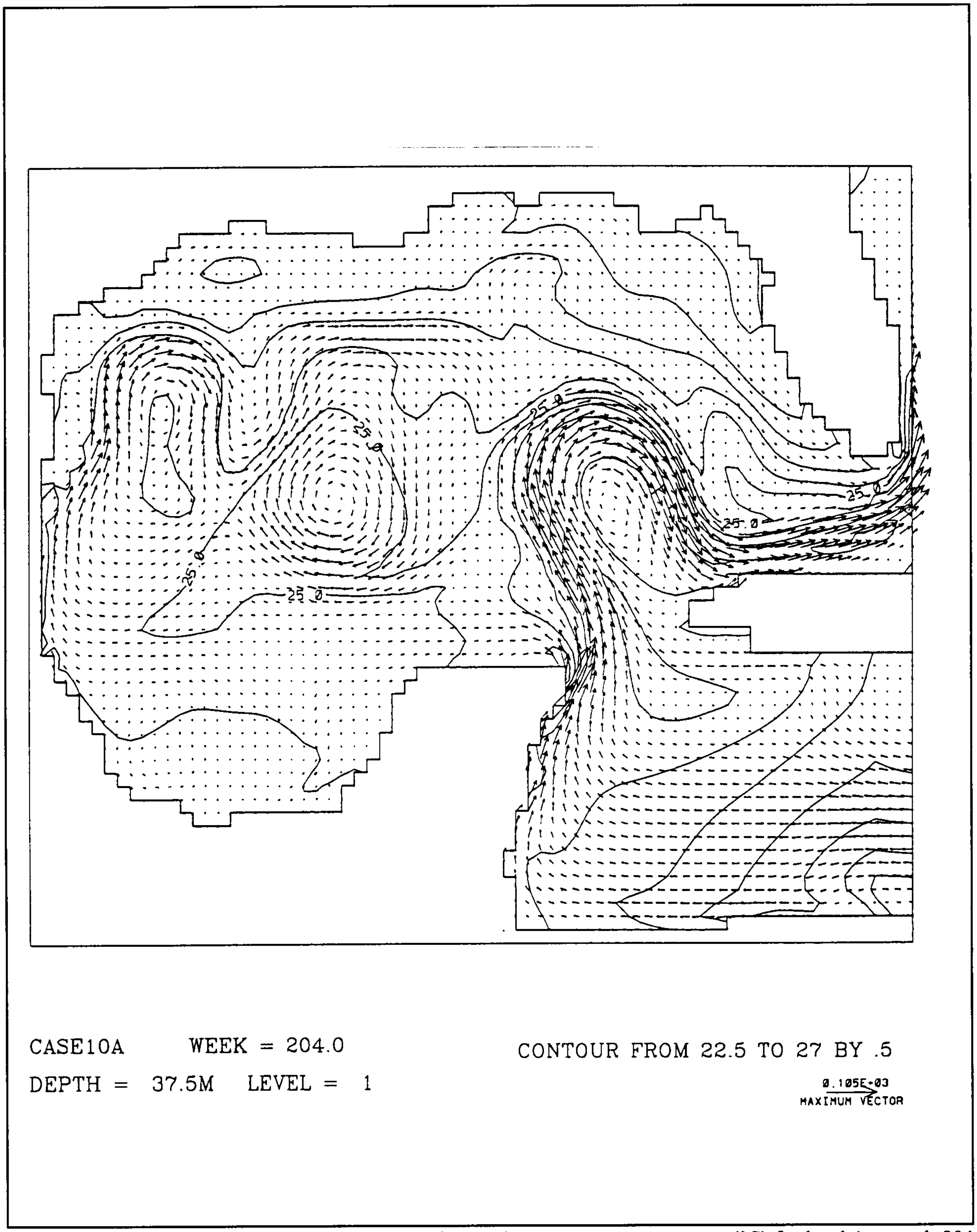

Figure 2C.3. Velocity vector plot (cm/s) superimposed on temperature contours (°C) for level 1 at week 204 of model integration showing the Loop Current and detached eddy.

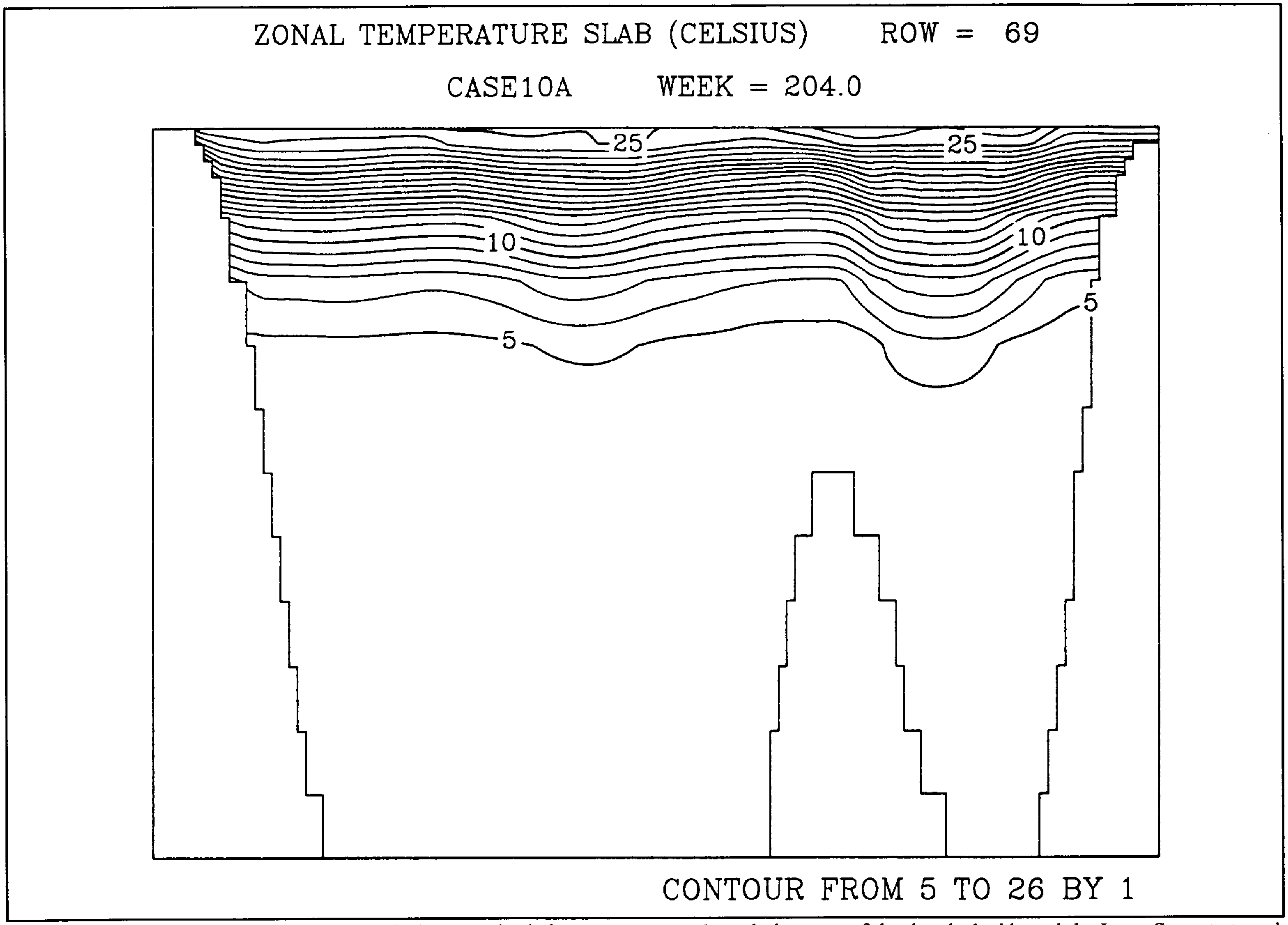

Figure 2C.4. Contour plot of temperature (°C) versus depth from west to east through the cores of the detached eddy and the Loop Current at week 204 of model integration.

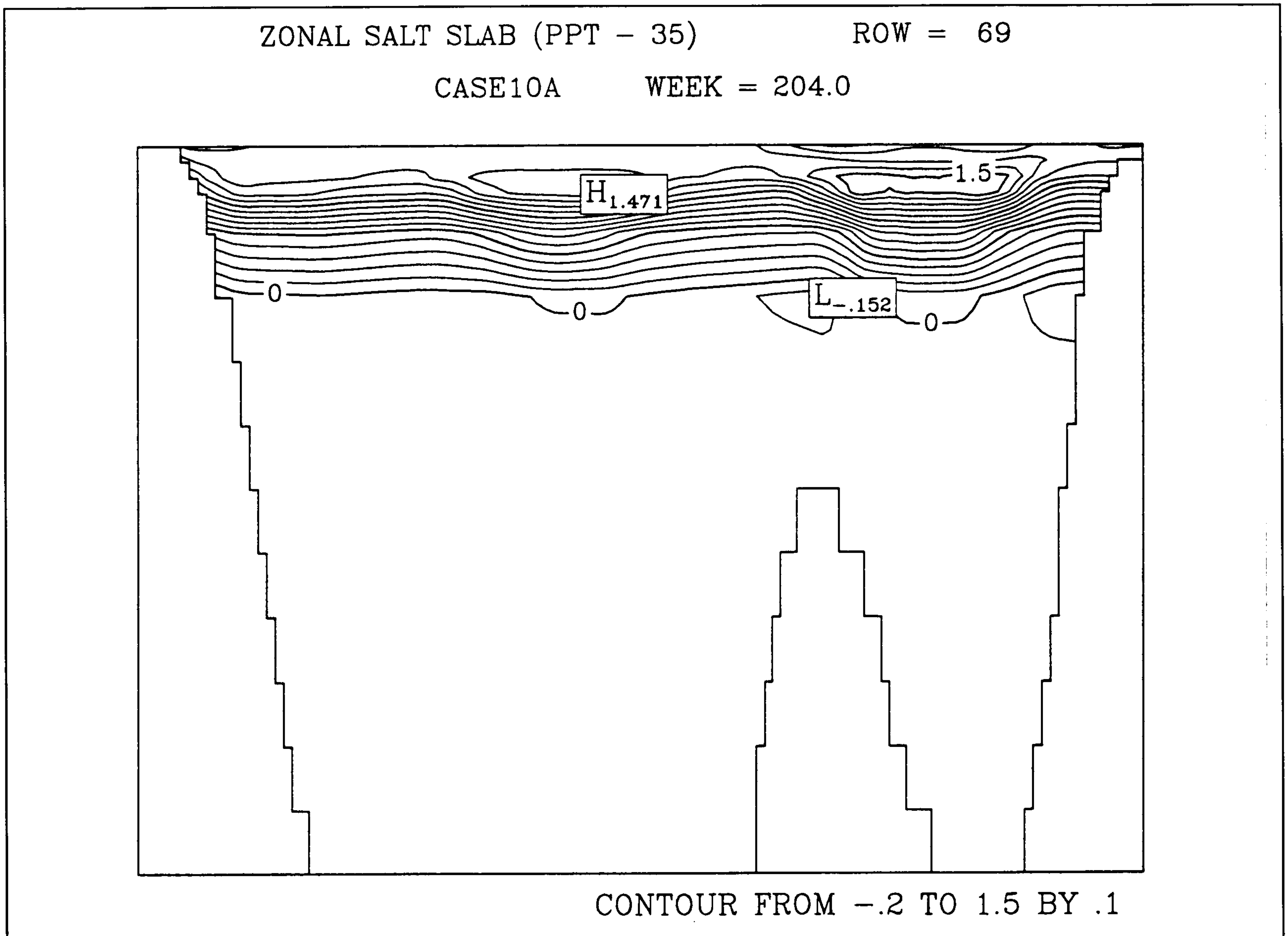

Figure 2C.5. Contour plot of salinity (PPt - 35) versus depth for week 204 of model integration.

The next step in modeling the Gulf of Mexico for the present environmental conditions is to include the annual cycle in the forcing. The Hellerman monthly mean wind stress fields will be used to force the model. The surface boundary condition on temperature and salinity as well as the inflow condition in the Caribbean will be based on the Levitus monthly mean climatology.

The final stage of this project is to repeat the seasonal calculations with a bathymetry representing sea level at 124 meters below present and forcing with glacical surface boundary conditions. Seasonal wind stress and fresh water flux are available from the glacial atmospheric model of Kutzbach and Guetter (1985). The sea-surface temperature estimates made by CLIMAP (CLIMAP Project Members, 1976) are available on a 2° by 2° grid for summer and winter seasons. Output from these model runs will be compared with circulation inferred from studies of the distribution of glacial planktonic foraminifera and sedimentological studies made in the Florida Straits.

SUMMARY

The first stage of this GOM modeling project is necessary to develop and validate a model for use in paleoceanographic modeling of the GOM. The present-day simulations of the GOM will be of value to the GOM modeling community due to the increased grid resolution, a unique method of forcing that eliminates the use of open boundaries and implementation of one of the latest state-of-the-art numerical models. The model integration appears quite stable and the simulation of the Loop Current and associated eddies is very realistic. The implementation of the annual cycle in the forcing should produce even more realistic results. The goal of the second stage is to learn about the GOM circulation during lowered sea level and help interpret Late Quaternary sedimentological and paleontological studies of the GOM.

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Dr. Masamichi Inoue has worked at the Florida State University and at Australian Institute of Marine Science. He has been at Louisiana State University for the past eight years and is Associate Professor at the Coastal Studies Institute and in the Department of Oceanography and Coastal Sciences. His research interests include modeling ocean circulation and transport processes. Dr. Inoue received his B.E. in naval architecture from Tokai University in Japan, his M.S. in ocean engineering from the University of Rhode island, his M.E. in civil engineering and his Ph.D. in oceanography from Texas A&M University.

DIGITAL HIGH RESOLUTION ACOUSTIC DATA FOR IMPROVED BENTHIC HABITAT/GEOHAZARD EVALUATIONS

Dr. Harry H. Roberts
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INTRODUCTION

Both the petroleum industry and the Minerals Management Service (MMS) are mandated to understand the physical-biological-geological complexities of the Outer Continental Shelf (OCS) and Upper Continental Slope region of the northern Gulf of Mexico because of the combined demands for resource utilization and management. Within simple geologic frameworks, the tasks of both resource extraction-utilization and rational environmental management of these efforts are reasonably well understood. However, in extremely complex settings like the northern Gulf of Mexico OCS, MMS must anticipate environmental management problems in a geographic region that has received the least financial support to determine physical-biological-geological characteristics and spatial-temporal variability of these properties. With continuing interest in oil and gas exploration beyond the continental shelf edge, industry has met the challenge with innovative engineering concepts and design for drilling-production facilities and resource transport systems. In order to effectively manage OCS activities, MMS must incorporate the best possible information from industry and academia to develop new concepts and technologies for environment assessment. This document proposes to utilize digitally acquired and processed high resolution acoustic data to improve OCS habitat mapping, geohazards detection/evaluation, and chemosynthetic community identification/ classification.

The Outer Continental Shelf and slope of the northern Gulf of Mexico is arguably the most complex such setting in today's oceans. This region is an extremely valuable resource for the United States since it has produced more oil and gas than any shelf-slope complex in the world. However, exploration and production in this region has not been easy or inexpensive because of the region's extreme sea-floor and subsurface complexity. This intricate geologic framework has been imposed on the system by processes forced by high-volume sediment input and the compensating effects of thick and malleable underlying salt deposits (the Jurassic Louann Salt). Since Late Cretaceous times, the northern rim of the Gulf of Mexico has been receiving large volumes of river-borne sediments that collectively have prograded the shelf edge hundreds of kilometers to its present position (Woodbury *et al.* 1973; Worzel and Watkins 1973). As is now widely recognized by the geologic community, sediment input to the outer shelf and continental slope is strongly modulated by sea level changes (Suter and Berryhill 1985; Berryhill *et al.* 1986). During periods of lowered sea level, fluvial systems entrenched themselves as they prograded across the shelf eventually to deposit their sediments in thick and widespread shelf-edge deltas (Suter and Berryhill 1985; Roberts *et al.* 1991; Sydow and Roberts 1994). Sediment was deposited directly to the slope from these systems by turbid flows and delta-front instabilities. In addition, these rapidly deposited deltas loaded the shelf margin, an inherently unstable area, frequently causing large shelf-edge failures that contributed large volumes of sediment to downslope depositional sites (Coleman *et al.* 1983). The interplay between intense periods of sedimentation, largely at low sea level, and compensating salt tectonics has resulted in a present-day slope configuration that is characterized regionally by numerous domes and basins (Martin 1980). The domes are the topographic responses to allochthonous salt that can take many forms (Figure 2C.6). Their depositional counterparts, the sedimentary basins are the results of salt withdrawal or local deformation of shallow salt lobes or massifs (Figure 2C.6). These basins can be divided into interdomal (between salt domes, ridges and/or massifs), interlobal (between allochthonous salt lobes), and supralobal (above allochthonous salt lobes) (Simmons 1992).

Superimposed on the regional dome and basin topography are smaller scale features that reflect the extremely complicated nature of both the modern sea floor and the subsurface. Ironically, it is this high level of geologic complexity that provides the northern Gulf OCS with numerous reservoirs and hydrocarbon traps as well as a difficult arena in which to operate with regard to exploration,

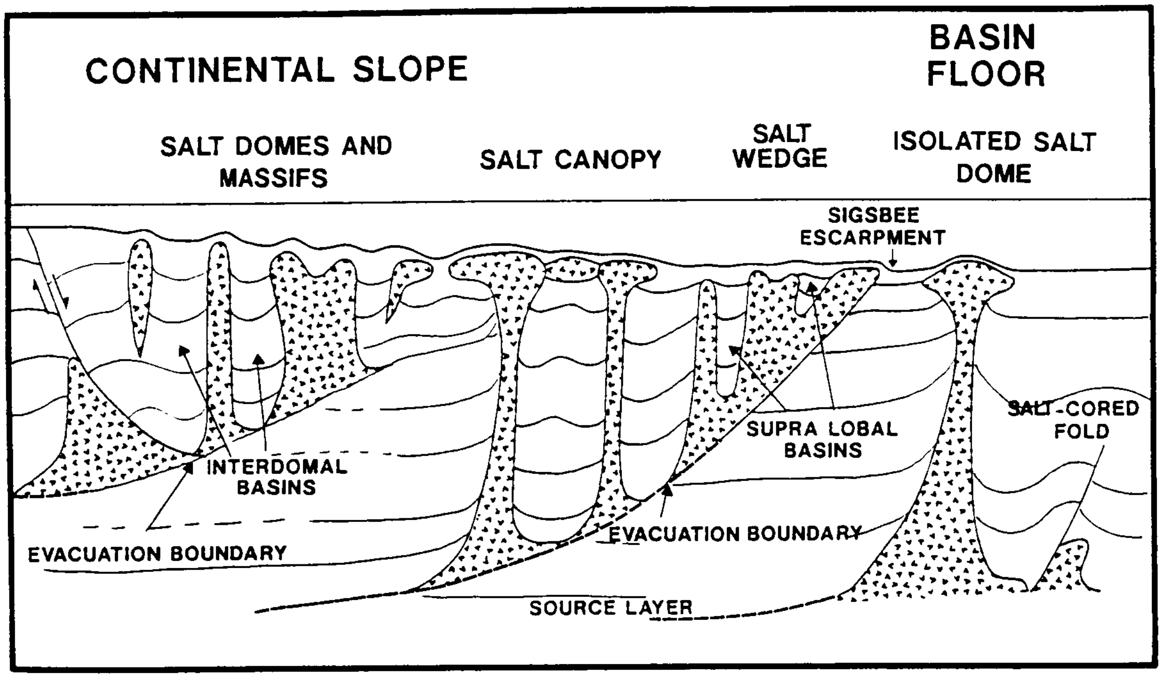

Figure 2C.6. Distribution of salt-related structures across the northern Gulf of Mexico continental slope.

production, and environmental management. Processes such as faulting, erosion-redeposition, sediment mass movement, fluxes of fluids and gases to the sea floor, hydrate formation, carbonate precipitation/diagenesis, and intense localized benthic community development impose an unmatched variability to the northern Gulf of Mexico slope. This myriad of surface processes and associated response features provide unique habitats for benthic communities, including specifically protected chemosynthetic communities that develop at sites of hydrocarbon seepage. In addition, these surface to near-surface processes produce conditions of variable geotechnical sediment properties over short distances, gas-charged sediments, substrates with highly variable small-scale topography, and other conditions that present practical problems for resource development. The challenge is to obtain, synthesize, and interpret the best data sets available in order to develop predictive capability about the modern sea floor. The goal is to transfer the criteria established by this means to standard forms of acoustic data that can be collected at a reasonable price and over large areas. Regional mapping of sea-floor type (e.g., Berryhill's MMS 84-0028 OCS Map Series) is not sufficient to add much information about the slope that we haven't known for a number of years. This proposal is the first step in developing a new and "higher resolution" and more in-depth understanding of surficial habitats, bottom features of various scales, and sedimentary characteristics of the slope by both directly acquiring new digital acoustic data and calibrating these data sets with five years of direct observations/sampling as well as results published by others (e.g. MacDonald 1992) from test areas. Results of this new approach will be compared to existing geohazards data sets in order to specify sea-floor conditions requiring new technologies for reliable interpretations.

Questions being asked by this research project are (1) Can we improve on our current level of understanding and predictability of the OCS sea floor by employing digitally acquired and processed high resolution acoustic data coupled with the best possible observations-samples collected by research submersible? (2) Can a set of interpretation criteria be derived from project activities that may be applied to existing and future surface-tow geohazards data (the industry standard) and deep-tow data as well as for improving our interpretive and predictive capability of sea-floor characteristics and conditions in this complex setting? If these questions are positively answered in view of project results, both MMS and industry will benefit. For example, although geohazards evaluations have traditionally been viewed by MMS as the responsibility of industry, for the first time MMS will have a rigorous and well-calibrated set of criteria for judging the geohazards interpretations of lease block areas submitted prior to drilling and production activities. In a management framework, a specific goal of this work is to produce new criteria for benthic habitat recognition with special emphasis on habitats supporting chemosynthetic communities (for compliance with MMS NTL 88-11).

THE PROJECT

Project Objective: To apply state-of-the-art digital data acquisition processing technology to high resolution acoustic data for the purpose of developing better criteria for geohazards and benthic habitat evaluations. The work will be carried out in three geologically distinct areas of the upper slope where standard geohazards data sets already exist and are available for comparison. The goal for this work is to develop a more reliable and objective set of criteria for identifying and evaluating sea floor characteristics that can be applied to operational and environmental management problems. The establishment of such criteria coupled to digitally acquired data could greatly increase the reliability of surface-tow data for geohazards evaluations and may be suitable for compliance to MMS regulations for chemosynthetic communities without the added expense of bottom video and/or photographic surveys. The hypothesis to be tested is this: acquisition and processing of digital high-resolution acoustic data coupled with submersible-acquired data can produce a set of interpretation criteria that will significantly improve capability to predict the character of the modern OCS sea floor.

Approach: The approach involves synthesis of existing analog data, high resolution acoustic digital data acquisition, acoustic vs digital data comparisons, research submersible verification of sea floor features, and development of criteria for feature detection from surface-tow data sets. Three areas off central Louisiana in the Green Canyon Lease Area (Area 1 - Blocks 52 and 53, Area 2 - Blocks 140 and 185, Area 3 - Block 272) and are in the Garden Bank Lease Area (Area 4 - Blocks 338, 382, 426, 427, 470, and 471) were selected as test sites. These areas were surveyed by Conoco and Shell in preparation for their Juliette and Anger platforms and pipelines. These companies have given access to these data sets for the purposes of this project. In addition, five cruises funded by NOAA's National Undersea Research Program (NURP) have provided specific observations and samplings utilizing highly maneuverable research submersibles to provide a working understanding between signatures on acoustic data sets and detailed characteristics of bottom features. The proposed project builds on these invaluable data sets by proposing a test utilizing newly acquired high resolution digital data against standard analog data sets acquired in surface-tow mode. These new data sets will be acquired with three different acoustic sources (ORE Geopulse, 15 in^3 water gun, and 50 in^3 air gun) using the DELPH 2 digital acquisition and processing system linked to differential GPS navigation/survey software developed at Coastal Studies Institute. Digital side-scan sonar data will also be acquired over test sites coincident with high resolution seismic data. An added bonus is that TAMU-2 (a medium-range side-scan sonar/subbottom imaging system developed at Texas A&M) data have been acquired as a test over Area 1. In addition to a test of standard surface-tow data, this project will allow evaluation of TAMU-2 data with permission of Dr. Richard Carlson, of the Geodynamics Research Institute. The four study areas contain a variety of sea floor conditions and features to make project comparisons a comprehensive test and a data set from which feature detection criteria can be reliably derived. Features found in these areas are (a) carbonate mounds, (b) regions of coarse carbonate sediments on the sea floor, (c) a variety of faults illustrating various levels of activity, (d) collapse depressions, (e) active and inactive mud volcanos, (f) hydrate mounds, (g) thick hemipelagic sediments, (h) lush and sparce chemo-synthetic communities, (i) mud flows, (j) mass movement features, and (k) areas of sea floor erosion.

Progress and Future Work: The project was funded as a three-year study. Year 1 involved two major tasks: (1) collection, review, and archiving of existing high resolution acoustic data to be used in developing sea floor features interpretation criteria, and (2) field testing of digital data acquisition systems for three separate high resolution seismic systems as well as a digital side-scan sonar system. Year two focuses on acquisition of high resolution acoustic data over specific features in the test areas (primarily Areas 1 and 4) utilizing the DELPH 2 system for comparison with standard analog data sets. Year 3 involves data collection with the DELPH 2 system primarily for Area 2 and 3. Feature-by-feature comparison of new and existing analog data sets, comparison of high resolution acoustic data plus submersible observations with surface amplitude data derived from 3D seismic surveys, development of a comprehensive set of criteria for improved feature identification, and the formulation of recommendations to both MMS and industry for future acquisition, processing, and interpretation of high resolution acoustic data sets are all part of the final year's activities.

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A SOCIOECONOMIC OUTER CONTINENTAL SHELF ISSUE ANALYSIS OF STAKEHOLDERS IN THE CENTRAL GULF OF MEXICO

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INTRODUCTION

This project will identify the levels of support for, and opposition to, Outer Continental Shelf oil and gas activities, by the various stakeholder groups in the coastal central Gulf of Mexico (Alabama, Mississippi, and Louisiana); the social and economic issues and concerns that are seen as being important by these groups; the underlying assumptions held by various stakeholders concerning the effects of Outer Continental Shelf activities; and suggest ways to focus research and management efforts effectively on significant issues of public policy.

The current project, an issue analysis of the Gulf of Mexico, was a high priority recommendation that came out of a Minerals Management Service funded workshop (see Gramling and Laska 1993), which was held in New Orleans in September of 1992. The workshop was designed to produce a recommended research agenda that could move toward addressing the appraisals made by the National Research Council (1989; 1992).

An issue analysis which can identify the social and economic issues and concerns of the major stakeholders, connected to the Gulf of Mexico oil and gas activity in the central Gulf of Mexico is important for two reasons. First, as noted above, the array of various levels of opposition to, and support for, the Outer Continental Shelf leasing program is not a simple one. The delineation of the various levels of support and opposition, and how they are distributed within the central Gulf, is the first step toward understanding this complex phenomenon. Second, and more importantly, an issue analysis will uncover the reasons behind the various levels of support for, or opposition to, Outer Continental Shelf activities. What are the assumptions that the various stakeholders and stakeholder groups make about the nature, both positive and negative, of various Outer Continental Shelf activities that lead to their support or opposition? This is a critical question not only for understanding the phenomenon, but also for predicting the socioeconomic impacts of various activities that potentially take place on the Outer Continental Shelf. As Gramling and Freudenburg (1992; see also Freudenburg and Gramling 1992) have shown, human social systems respond not only to alterations in the physical environment, such as those produced by various development projects, but also to changes in the social environment, such as those produced by new information concerning proposed actions. While there has been no physical development activity (e.g., exploratory or development drilling) associated with the federal leasing program in the vicinity of the Florida Keys since the 1950s, significant, empirically verifiable changes in the human environment have resulted simply from proposing these activities; changes which have had dramatic effects on the leasing program itself, including a Presidential moratorium. In short, knowing the assumptions that underlie the support or opposition to Outer Continental Shelf activities allows for a better understanding of what the effects of those activities will be, and consequently to more informed decision making.

Specifically, the objectives of this research are

- To identify and describe the various stakeholder groups in the coastal central Gulf of Mexico, define their interests degree of concerns about Outer Continental Shelf oil and gas activities.
- To identify the specific social and economic issues and concerns related to the central Gulf of Mexico oil and gas activity that are seen as being important by different major stakeholders and other knowledgeable individuals.
- To identify the underlying assumptions held by various stakeholders concerning the effects of Outer Continental Shelf activities, which determine the positions they take on the social and economic issues.
- To suggest ways to further enhance research initiatives by ensuring their relevance to stakeholders' concerns.

RESEARCH METHODOLOGY

With an issue analysis the research strategy is different from standard surveys where the interest is focused primarily on representativeness. With surveys the researcher wants to be able to statistically generalize to the public at large or some element of that public from the sample collected. But this presupposes you know what to ask them. Simple questions like do you support offshore oil aren't going to give much predictive power about what particular stakeholder groups will do. Issue analysis targets the issues as they are expressed by those who will later potentially act on the basis of their stand on the issue. In effect the population the researcher is interested in becomes the array of issues and positions on those issues of interest, rather than the individuals who hold positions on those issues. Another way to think of this is: with a standard sampling methodology the researcher must be very careful to sample all the elements of the population they want to generalize to, however, with issue analysis the researcher must be very careful to sample across all of the issues and positions on the issues of interest. In order to do this a "theoretical" sampling procedure (often called snowball sampling) is used, which allows the researcher to target issues.

Snowball sampling is a method through which the researcher develops an ever-increasing set of sample observations. One respondent in the population under study is asked to recommend others for interviewing, and each of the subsequently interviewed participants is asked for further recommendations (Babbie 1992). This is the only feasible type of sampling procedure which will fit the requirements of the project to: 1) identify various stakeholder groups through a referral process and, 2) retain flexibility in the field to identify and sample stakeholder groups as they are "discovered" through the sampling process. Sampling continues until the investigation exhausts the issues (i.e. no new ones are being found) when a content analysis of the interviews will allow the relative strength (i.e. proportionately how many individuals hold particular positions, and how strongly do they hold them), of the positions to be determined.

This type analysis is most useful in identifying the strength and organization of various stakeholder groups that may support or oppose an activity or identifying appropriate categories for use in a type of data collection that uses standard methodology where the interest is statistical generalization.

Specifically the research has nine major components:

1. A review of existing information on key stakeholder groups and their concerns. This involved both a literature review and initial telephone interviews with currently known key informants, in the central Gulf of Mexico.
2. The creation of a data base that allowed the comparison of employment, industrial sector, occupational, income, and household data at the state, county, and community level across the entire three central Gulf states using the recently available U.S. Census summary tables available on CD ROM. The data base covered the three central Gulf of Mexico states Louisiana, Mississippi, and Alabama, all counties/parishes in these states, and all "places" (cities) reported by the census.
3. The selection of relevant sample communities, and/or regions, based on the information obtained from components 1 and 2 above. After examination of the communities in the data base, initial contacts in the communities, and consultation with representatives from Minerals Management Service the target communities were selected. The area chosen for investigation ranged from Cameron to Gulfshore, and included the communities of Cameron, Lafayette, Morgan City, Grand Isle, Gulfport, Biloxi, Mobile (very limited sampling), Fairhope, Dauphin Island, Orange Beach and Gulfshore. Data collection was begun with a letter of authorization to spend funds, in June 1993 using Grand Isle as a test community.
4. The identification of additional key informants: In each of the selected communities key stakeholder informants were identified. In each community these informants were the start of the "snowball" sampling procedure. In each community or region our first key informants were public officials/community leaders who had detailed knowledge about the area. We asked these individuals what groups have interests concerning OCS activities in order to: 1) test and potentially expand our initial assumptions concerning stakeholder groups; and 2) obtain references as to specific individuals within these groups in order to interview them.
5. Key informant interviews. We interviewed a wide variety of individuals across oil, gas, and support sectors of the economy, commercial fishermen of various types, recreational fishermen and boaters in the sample communities during july and August of 1993. These interviews solicited information as to the important issues and concerns with respect to OCS activity, and how it is believed OCS activities have or will affect the community.
6. Examination and copy of relevant local documents noted by key informants. This was limited to instances where the position(s) of specific stakeholders have been put forth in writing (e.g., position papers, correspondence, reports), or the documents could provide important information about the group or the community.
7. Transcription of interviews. The interviews are currently being transcribed. When this process is completed the data will be loaded into an analytical software program for analysis.
8. Content analysis of interviews and relevant local documents. Content analysis is a process by which specific concepts that appear in the documents to be analyzed (here the transcripts of the interviews and the local documents) are used

to generate coding categories, and the resulting appearance of the concepts across categories of individuals or groups is analyzed. This is not simply a counting procedure. The key to content analysis is the identification of the appropriate concepts that are embedded in the relevant documents (in this case transcripts), and the analysis of the ways in which the concepts appear across the interviews. For example, a key concept that might emerge is that of "economic development." Once identified as a key concept in the interviews a variety of words would be chosen (e.g., economic, jobs, training, etc.) that would allow the researcher to electronically search the interviews for these key words, and determine if economic development is an issue in that document, and to what extent that issue dominates the transcript. Once instances of economic development have been identified then the researcher can (for example) see if this concept is more likely to be raised by individuals familiar with OCS activities than those relatively unfamiliar with OCS activities, or with certain stakeholder groups, and not with others.

9. Analysis of results and report writing.

PRELIMINARY FINDINGS

Although no formal analysis of the data has yet occurred, as the transcription is not complete, several trends seem to be emerging

1. Outer Continental Shelf activities are generally supported in Louisiana for most stakeholder groups. The exception to this are several environmental groups, and some of the alternative users of coastal waters. Most common among this latter group are shrimpers who contend that some areas (e.g., east of the mouth of Bayou Lafourche) can't be shrimped due to the amount of discarded oilfield trash on the bottom. Some of these areas appear to be in state waters, and some in the vicinity of some of the earliest Outer Continental Shelf development. In general it is somewhat difficult to tell without more careful analysis of the data the level of problems that shrimpers have with Outer Continental Shelf activities, because of the extent of the conflict and opposition that has arisen in the shrimping community over the use of TEDs.
2. Most business interests in coastal Mississippi aren't excited about offshore oil, but they aren't focused on the issue. Community leaders in Gulfport and Biloxi have in the past opposed Outer Continental Shelf activities, but they are currently so focused on gambling as an economic activity that Outer Cotinental Shelf concerns have shifted into the background.
3. Mobile Bay appears to be the dividing line for real opposition to offshore activity. Baldwin county took the state to court to stop the sale of state leases, and community residents in Orange Beach and Gulfshore voice frequent, strong opposition to offshore development. It is probably not coincidental that beach oriented tourism really begins west of the mouth of Mobile Bay and continues into Florida.
4. In general, most of the people we interviewed were ignorant of Minerals Management Service and its role in offshore development.

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CHARACTERISTICS AND POSSIBLE IMPACTS OF A RESTRUCTURED OCS OIL AND GAS INDUSTRY IN THE GULF OF MEXICO: PRELIMINARY RESULTS

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The restructuring of the OCS oil and gas industry in the Gulf of Mexico began shortly after the crash in oil prices in 1986. This restructuring consists of two shifts in the industry: a shift from the majors to independents and a shift from focusing on exploration and development as well as production to a focus on production. The first shift is seen in the decline in the majors' share of overall activity in the Gulf and the concomitant increase in the independents' portion of the operations. Between 1987 and 1991, the majors' share of production dropped slightly from 74 to 70% while their portion of exploratory wells has fallen from 40 to 21% and their part of developmental wells has decreased from 63 to 49% (Dodson and LeBlanc 1993). The second shift is also demonstrated by these numbers in that the majors' share of production has not declined as much as their share of exploratory and developmental wells.

THE PURPOSE OF THE STUDY

The purpose of the study is to examine the OCS oil and gas industry and to document evidence of a shift. Specifically, we are planning to do the following. First, we will describe the current business characteristics and environment of companies operating in the Gulf of Mexico and examine how the characteristics and environment have changed since 1986. Second, we will portray the present business practices of companies active in the Gulf, examine how these practices have changed since 1986, and investigate how changes since 1986 in the business characteristics and environment are related to changes in practices. Third, we will compare the business characteristics, environment and practices and the changes since 1986 in these three factors by type of company—major or independent. Fourth, we will compare the characteristics, environment, practices and changes since 1986 across the type of independent company—large integrated, small integrated, large nonintegrated, and small nonintegrated. (These four types of independents will be discussed below.)

DATA AND METHODS

The study consists of two data collecting stages. In the first phase, in-depth face-to-face interviews of representatives of 11 companies active in the Gulf were conducted. These 11 enterprises included three majors, five large integrated independents, one large nonintegrated independent and two small nonintegrated independents. In the second phase, we conducted structured phone interviews of executives in about 40 companies active in the Gulf—nine majors, nine large integrated independents, five small integrated independents (there are only five of these), nine large nonintegrated independents, and nine small nonintegrated independents.

The four groups of independents were determined using the following information. First, the independent companies were sorted by whether they are involved in downstream activities or not. The integration status of the companies is published in documents concerning oil and gas companies. Then, these companies were classified by size based on the number of employees; their exploration and development funds; and rankings of their assets, revenues, and world reserves. The companies selected for the phone interview were chosen using simple random sampling within each of the five categories of companies active in the Gulf. It was not possible to use stratified random sampling due to the distribution of businesses in the five categories (discussed below).

The procedure for the structured interviews was as follows. We faxed two letters describing the study—one from us and one from MMS—and a copy of the interview instrument to each of the chosen companies. In our letter, we asked the company representative to either call us and arrange an appointment for the interview or to delegate the interview to another person and have that person call us to arrange the appointment. This method worked quite well; we have had only two refusals thus far despite the oil and gas industry's reputation for secrecy. We suspect that our approach elicited a good response rate for the following reasons. First, the respondents could arrange a time for the interview that was convenient for them. Second, they had all of the questions in advance which enabled them to ascertain that the questions were not too sensitive and allowed them to prepare their answers in advance, thus reducing the amount of time to complete the interview. The respondents needed time to prepare their answers since some questions ask for specific information for 1986, and they were not likely to know these details without referring to company documents.

The structured interview collected data about the following. (1) We obtained information for 1986 and the present about company characteristics, such as the type of resource extracted (oil or gas or both), the amounts produced, exploration activities, spending on research and development, locations of regional offices, number and distribution of employees, and participation in joint ventures. (2) We got details about the companies' use of service companies in 1986 and the present. (3) We asked the respondents about their outlook concerning the future of activity in the Gulf. (4) The company representatives provided information about the impact of policies, technology, and regulations on their operations.

Preliminary Findings

Only stage one of the project, in-depth face-to-face interviews, has been completed. These interviews revealed the following. (1) The two categories of companies usually referred to when discussing the oil and gas industry—majors and independents—are not adequate. (2) There is too much diversity among independents in their production, reserves, integration, and staff, to discuss them as one group.

Second, the majors do not appear to be abandoning the Gulf of Mexico, with the exception of Tenneco. Instead, they are changing the manner in which they operate by engaging in asset rationalization, corporate restructuring, and downsizing. Asset rationalization refers to the establishment of core areas of operations. The majors are divesting properties outside their core areas and acquiring properties within these areas. Corporate restructuring is enabling the majors to become more efficient by altering their management structure, reporting relationships and geographic dispersion. They are giving divisions greater autonomy while they are also consolidating management and technical functions within the divisions.

The third finding from in-depth interviews concerns independents. Three factors enabled independents to become active in the Gulf of Mexico. The change from nominated leasing to area wide leasing and the reduction of the minimum bid enabled the independents to acquire properties in the Gulf. In addition, the infrastructure was already created by the majors; therefore, independents did not need the capital to develop the infrastructure necessary to participate in offshore extraction. Moreover, independents now have increasing access to new technology such as that used in subsalt exploration and deepwater drilling. Overall, independents are lean, efficient, and opportunistic; they contract out most activities; and they vary greatly in size and orientation.

Fourth, the majors and independents were found to differ in the following ways. On the whole, the majors incur higher operating costs and they contract out fewer activities than do most independents. The majors have financial advantages including greater access to capital, but large independents also have greater access to capital than do small independents. Further, typically, independents are more concerned about environmental regulations than the majors, particularly the financial responsibility provisions of OPA 90, the increases in lease bonding to cover plug-and-abandon liabilities, and the implications of the Clean Water and Clean Air Acts.

Yet there are many similarities among the majors and the independents. Like the independents, the majors are acquiring producing properties and are developing smaller fields, although they prefer larger fields. Similar to the majors, independents are doing subsalt exploration and are involved in deepwater projects. Further, majors and independents are complying similarly with environmental and safety regulations with a few caveats. Three of the respondents mentioned problems that the independents were having in terms of complying with the regulations. They stated that independents might have more difficulty complying and expend fewer resources to comply, have less ability to cope with infrequent crises, and be lax about reporting problems such as very small spills.

Fifth, the respondents expect a decline in production and activity in the western and central Gulf in the near future; however, this decline depends on deepwater technology and projects, subsalt exploration, and the viability of exploration and production in the eastern Norphlet Trend. Moreover, the respondents assessments about the likely future of oil and gas in the Gulf varied widely from pessimistic to optimistic. Pessimists portrayed the Gulf in 1998 as having low prices of oil ($15) and gas ($2.20); less exploration and production activity than exists at present; and lower employment in the majors, independents, and service and supply companies. Optimists predicted higher oil ($22) and gas ($3.00) prices; greater exploration and production activity than there is currently; the same employment in the majors and higher employment in the independents and service and supply companies.

The endeavors necessary to conduct the structured phone interviews resulted in the following findings. First, there are about 103 companies with telephones currently operating in the Gulf: 17 majors, 19 large integrated independents, 5 small integrated independents, 14 large nonintegrated independents, and 46 small nonintegrated independents. This distribution of independent companies across the four categories is reasonable. It is logical that most independents would be small and nonintegrated given that many of the companies are extracting from fields the majors left due to the small amount of oil and gas. Most large companies could not maintain a profit while obtaining small amounts of oil and gas. In addition, it is rational that there would be few small integrated companies since downstream integration represents additional activities that the company must undertake and this requires staff and resources that a larger company is more likely to have.

Current Status of the Project

We have completed 37 interviews and most of these have been coded. Interviewing and coding should be finished by 1 1994 December. The initial report will be submitted to Minerals Management Service at the end of May, 1995.

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A MANAGEMENT OVERVIEW FOR RESOURCE DEVELOPMENT IN CONTINENTAL SLOPE HABITATS

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As the oil and gas industry moves into progressively deeper water, regulatory agencies are faced with important questions. What is necessary? Devise a new environmental perspective? Modify the approaches taken at continental shelf depths? Or, simply manage deeper seafloor just like shallower? The review undertaken in this CMI project takes three approaches to these questions. First, not discussed here, is a review of previous U.S. efforts to address deep ocean environmental concerns. None were especially successful for a host of reasons. Second is to consider what we know about the deep Gulf of Mexico. In fact, we know a good deal. Third and the focus of this presentation, what is known about deep ocean ecology that is relevant to environmental regulation? Much of this presentation is based upon Gage and Tyler's (1991) excellent general reference on the deep ocean.

Four general patterns are seen in the deep sea.

BIOMASS DECREASES WITH DEPTH

The biomass of the deep-sea benthos decreases exponentially as a function of depth over most of the world ocean due to the consumption of nutritive detritus during transit from the photic zone to the bottom (Carney, 1989). This fundamental pattern has a variety of management consequences.

1. For equal areas shallow and deep, in most instances the number of animals threatened by environmental impact will be less in the deep sea. However, there are two complicating issues, one known and one speculative. Known is that while overall abundance may be low in deep water, diversity of organisms can be higher than in shallow water. Thus, more kinds of animals will be at risk. Speculation based upon this diversity pattern is that deep ecosystem structure is more complex and more sensitive to perturbation.
2. It is unlikely that secondary production in the deep-sea can support sustained commercial exploitation of fish stocks, thereby minimizing conflicts between fishing and seafloor development. A few deep water fisheries, however, must be considered. Orange roughy, *Hoplostethus altanticus*, common is U.S. is fished at 1500m and deeper (Anon. 1994).

FAUNA CHANGES WITH DEPTH

This has been seen in all areas so far studied. As with all zoogeographic gradients, causes of the change are linked to environmental difference. There has been considerable energy expended worrying about the exact nature of the change (see Carney *et al.* 1989), but the general pattern is clear. As you progress down the continental slope, each depth or depth zone is characterized by a distinctive combination of species. The management consequences are complex.

1. Species-specific concerns cannot be the same from shallow to deep, and they may even differ between sites on the continental slope. There will probably be less emotional attachment to deep-sea organisms on the part of the public. However, novel species, such as those at chemosynthetic communities, may attract public concern.
2. There may be more habitat specificity in deep water than in shallow, meaning that deep seafloor should not be managed as part of a very wide whole.
3. If deep-sea species are adapted to a relatively uniform environment, they may be more sensitive to perturbation.

SPECIES DIVERSITY IN DEEP WATER IS UNEXPECTEDLY HIGH

Modern ecological and evolutionary theory tells us that to have many coexisting species we need moderately high productivity and a combination of factors that prevent competition displacing species. The key aspect about such factors is heterogeneity. The physical environment, the food, etc., must be complex. Given this theoretical perspective, oceanographers were quite surprised when sampling along a depth transect between Woods Hole and Bermuda revealed a dramatic increase in overall species richness beyond the shelf-slope break (Sanders and Hessler, 1969). Explaining this has been an important topic in benthic ecology ever since. Although authors have proposed various explanations, the fact is that the pattern remains unexplained.

The diversity problem facing resource managers stems from lack of an explanation for a pattern that challenges widely held scientific points of view. Since we really do not know why the deep ocean is so diverse, we can neither accept nor refute hypothetical impact scenarios. The deep abyss may be robust in the face of impact or it may be especially fragile. We have little to base a conclusion on.

Real progress in explaining the causes of deep high diversity may come about when considerable effort is expended to describe the pattern found at many places in the world ocean. The few scattered studies now available provide only a sparse base for comparison. There is, however, indication that distinct global patterns exist (Rex *et al.* 1993). Until then, we can speculate about the few data available. Such speculation falls into general categories. First, the reporting of high diversity can be challenged on sampling and analytical grounds (Gray 1994). There is validity to some of this attack, but the fact remains that the deep sea is not a species poor environment. Second, theory can be amended. This was Sanders' (1969) original approach when he proposed the stability-time hypothesis. Third, we can say theory is correct but our perceptions are wrong; the deep environment is really highly heterogeneous. Since this heterogeneity is hard to demonstrate, it is sometimes postulated in quite complex ways involving transitory mosaics (Grassle and Maciolek 1992). There are also some well documented examples of temporal and spatial heterogeneity (Thistle *et al.* 1985), but their relevance on the larger scale is problematic. None of these categories of explanation provide much management guidance.

THERE ARE UNIQUE DEEP HABITATS

Over the decades in which the three above generalities about the deep ocean were developed, oceanographers thought of the deep benthos as a soft mud system. Rocks had been seen, but encrusting fauna was extremely rare at depths below 1000m. This view changed radically with discovery of chemosynthetic communities now known to be common at hydrocarbon seeps in the Gulf of Mexico. The results of a MMS study on these systems is underway at the Geochemical and Environmental Research Group, GERG, at Texas A&M, but a few preliminary observations can be made. These systems are reef-like in many regards and will probably be protected in a similar manner. Perturbations associated with sampling persist over at least five years, indicating slow recovery from disturbance. Finally, although these systems provide food for large predators and scavengers in the slope environment, links with surrounding benthos are poorly understood (Carney 1995).

CONCLUSIONS

In many respects the deep sea is different from shallow water and may be regulated according to different policies. Aesthetics and recreation will be minimal issues. Conflicts with bottom fisheries will be minimal or non-existent. Special habitats are there and will be afforded protection. However, limited understanding of the system makes it impossible to predict the overall sensitivity to perturbation.

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DEVELOPMENT AND APPLICATION OF SUB-LETHAL TOXICITY TESTS TO PAH USING MARINE HARPACTICOID COPEPODS

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INTRODUCTION

Petroleum drilling and production operations in the Gulf of Mexico have made a substantial impact on the local environment. A broad range of chemicals is used and largely discharged as produced water or as spills. As a result, the biota have been exposed to crude and refined oil for many years. Among all petroleum hydrocarbons, polynuclear aromatic hydrocarbons (PAHs) occur in high concentrations and are among the most carcinogenic, mutagenic, and toxic compounds of the pollutants discharged to the marine environment. An estimated 2.3 x 10^{5} metric tons of PAH enter the aquatic environment annually (Kennish 1992). PAHs are highly hydrophobic compounds and strongly bind to the organic fraction of sediment particles. Therefore, the PAH concentrations in sediments are typically much higher than those in the overlying water.

We propose to develop sub-lethal toxicity tests for sediment-associated PAH using harpacticoid copepods. Harpacticoids are wide-spread epibenthic and infaunal members of the meiofauna (invertebrates passing a 1 mm sieve but retained on a 0.063 mm sieve). They are very abundant in most marine sediments, second, among metazoans, only to nematodes. Harpacticoids play a significant role in food webs of juvenile fish and shellfish. Upon hatching, copepods mature through six naupliar stages, then metamorphose to six distinct copepodite stages, the last of which is the mature adult (Hicks and Coull 1983). Many benthic harpacticoids spend their entire cycle in the sediment. Their short life cycle (a few weeks) and easily distinguishable life stages facilitate rapid assessment of population growth and sublethal effects on reproduction (Coull and Chandler 1992). Harpacticoids have been used in toxicological studies of sediment-bound metals and PCBs and other pesticides (e.g. Green *et al.* 1993; DiPinto *et al.* 1993; Chandler *et al.* 1994); however few data are available on PAH effects.

MATERIAL AND METHODS

Selection of PAH

From the long list of PAH single compounds, two, phenanthrene and fluoranthene were selected to asses the toxicity of PAH to harpacticoids and for developing protocols of sub-lethal sediment tests for hydrophobic compounds. Both are medium molecular weight PAH and usually constitute a high percentage of total PAH in sediments. Sediment quality criteria (SQC) obtained from the equilibrium partitioning theory were derived for these two compounds using marine invertebrates (USEPA 1993 a, b). For a more realistic approach concerning natural PAH contamination in sediments, diesel fuel, a complex mixture of hydrocarbons, was also used.

Test Animals

Developing a toxicity test is very labor intensive. A series of experiments to evaluate and select several factors involved in detecting hazardous effects in living organisms must be performed. The main goals are to achieve maximal discriminatory power and repeatability. It is desirable to have high performance in the controls (i.e., good survivorship) and low variability within treatments. An "unlimited" supply of test organisms was made available by culturing one species of sediment-dweller harpacticoid representative of the local estuarine copepod assemblage from the Louisiana coast. *Schizopera knabeni* is a member of the Diosaccidae, the most speciose and diverse family in Harpacticoida. It has been cultured sediment-free at room temperature in static conditions in 2 L Erlenmeyer flasks. The water is partially renewed frequently and the culture fed with diatom paste mixed in water. Although cultured in the absence of sediment, the copepods always burrowed instantly when transferred to dishes containing sediment.

Contamination Procedures

Mud-flat sediment was sieved through a 125 µm mesh, cleaned and condensed after Chandler (1986). This sediment was homogenized with artificial seawater (25 ‰), sieved through a 45 µm mesh and allowed to settle for 24 h. The supernatant was removed via aspiration leaving reconstituted test sediment (solids content =14 %, total volatiles = 9 %). PAH (phenanthrene or fluoranthene) carried in 200 µl of acetone was spiked dropwise on a vigorously stirring slurry of 150 g wet-weight sediment. Mixing was maintained for 4 h and the PAH-amended sediment was stored at 4°C in the dark. The amount of PAH spiked was calculated on a dry weight basis. The expected concentrations for single compounds were: 0 (control), 0 acetone (200 µl, no PAH), 60, 125, 250, 500 and 1000 mg/kg (ppm). Contaminated sediments were stored for at least 5 days before use in the experiments to assure equilibration between PAH bound to organic carbon (of sediment particles) and PAH in solution in the pore water.

Diesel fuel was mixed with autoclaved mud-flat sediment and after tumbling for a week, was thoroughly washed with water to remove non-adsorbed hydrocarbons. The final total PAH concentration measured was 660 mg/kg (stock sediment). This full-concentration sediment was diluted with clean sediment from the same site on a dry weight basis and vigorously stirred for 12 hours. The resulting expected total PAH concentrations in 300 g of wet sediment (mg/kg) were: 5, 10, 25, 50, 100, 200 and 400.

Analytical Chemistry

PAH from all concentrations of phenanthrene, fluoranthene and diesel will be extracted from sediment and chemical analysis performed with a GC-FID. Definitive values are not available yet; however, this spiking procedure was tested with a freshwater sediment and found to be effective. Toxicity data are therefore reported as expected (nominal) concentrations.

Toxicity Test Protocols

Three toxicity tests were performed using *Schizopera knabeni,* each having a different end point: mortality, reproductive output, and grazing activity. Copepods were withdrawn from the culture flasks and sorted under a dissecting microscope. The same test chambers and procedures were used in all experiments. The chambers consisted of a 15 ml scintillation vials filled with 10 ml of 25 ‰ filtered artificial seawater. One ml of test sediment at each concentration was gently spread on the bottom of each chamber with minimal disturbance using a 1 ml Finnpipette to create a 2- to 3 mm sediment layer. Three hours later copepods were added to test chambers. Test chambers were placed in plastic storage containers in 2 cm of water. The containers were kept in the dark in an incubator at 25 °C during each experiment. At the end of each experiment, the contents of each chamber were sieved through a 45 µm mesh and retained copepods were enumerated and scored as live or dead.

To generate LC_{50} values for sediment-associated phenanthrene, fluoranthene and diesel fuel, copepods were exposed for 96 h to test-sediments and assessed for mortality. Thirty adult copepods in each test chamber in four replicates were used per treatment.

Two chronic or sub-lethal tests, in which mortality is not the endpoint, were developed and applied to *Schizopera knabeni.* The first assessed the effects of PAH on the reproductive capacity, by determining the average number of offspring produced by one fertile female. A second test explored PAH effects on grazing activity, by quantifying the amount of algae grazed on by copepods in a given period of time.

The reproductive-output test was performed by exposing one mating pair (sub-adult female and adult male) to PAH-contaminated sediment for the period of 14 days. This period of time was enough for the offspring produced from the first brood to develop into late copepodite stages and for the females to produce a second brood. Each sediment concentration was replicated with ten test chambers containing one mating pair in each. Each unit received a dose of food consisting of 0.2 mg of Microfeast Plus larval diet (yeast) after 24 h. At the end of the experiment, all life stages were recovered from the sediment, adult mortality was assessed and egg clutch size, nauplii and copepodites produced were enumerated.

In the grazing activity experiment, five adult females were placed and kept unfed for 24 h in the test chambers. Radiolabeled algae (the dinoflagellate *Isocrysis galbana* cultured in ^{14}C bicarbonate) was offered in a known amount and copepods were allowed to graze for a period of 3 h. Grazing was terminated by washing the copepods from the sediment and transferring to 4% formalin. Copepods from each experimental unit were solubilized in scintillation vials and radioactivity incorporated through ingestion of algae was measured in a scintillation counter.

RESULTS

In all phenanthrene and fluoranthene experiments, the carrier (acetone) treatment was never significantly different from the acetone-free control.

96-h Survivorship

Excellent performance in the controls was achieved, with survivorship close to 100% in both control treatments. There was a direct positive relationship between mortality and sediment PAH concentrations in the sediment with phenanthrene, fluoranthene, and diesel fuel (Table 2C.1). Significant mortality was observed at sediment PAH concentrations as low as 250 mg/kg of phenanthrene and fluoranthene, and as low as 100 mg/kg of diesel fuel.

14-Day Reproductive Output

Total offspring produced in 14 days by one fertile female was determined by enumerating eggs in the egg sac, and larval (nauplius) and juvenile (copepodite) stages. Nauplii and copepodites together comprised the so-called realized offspring, individuals that hatched from egg and survived until experiment termination. In the fluoranthene experiment (Figure 2C.7), a significant reduction in the total offspring produced was detected at 250 mg/kg. However, a significant reduction in the realized offspring was detected at a lower concentration, 125 mg/kg. In the phenanthrene experiment (Figure 2C.8), no statistically significant difference was observed in the total offspring between the control and all PAH treatments. But again, a significant reduction in the number of nauplii and copepodites occurred at 125 mg/kg. In the diesel experiment (Figure 2C.9), total reproduction and realized offspring were significantly reduced at 50 mg/kg, whereas total number of copepodites was reduced at 10 mg/kg. It was evidenced by the three experiments that besides an overall adverse effect on offspring production, PAH had a stronger impact on the normal development of eggs into nauplii and copepodites.

Grazing Activity

As determined by the total radiolabel incorporation in copepods via ingestion of radioactive algae, grazing activity was adversely impaired by phenanthrene in the sediment (Figure 2C.10). A mean decrease in grazing was observed in the 60 mg/kg treatment, but a significant decrease was detected at 125 mg/kg and higher. Incorporation of label into dead control copepods was minimal, indicating that the radioactivity in copepods is due to active ingestion of radiolabeled cells. Sub-lethal toxicity tests usually require long term exposures to contaminants, as for the reproductive output experiment described above. An adverse effect on feeding, an important physiological activity, was detected after a short term exposure of only 24 hours applying the test protocol developed in this project. Tests using fluoranthene and diesel fuel will be performed shortly.

CONCLUSIONS

The first part of this project provided test protocols that proved useful in detecting adverse effects of PAH on copepods, a ecologically important group of estuarine metazoans.

Table 2C.1. Mean percentage survivorship and corresponding standard deviation in the fluoranthene, phenanthrene and diesel 96-h survivorship experiments.

Treatment (mg/kg)	Mean survivorship (%)	Standard deviation
Fluoranthene		
0	10	0
60	100	0
125	96	0
250	87.5	6.16
500	67.5	9.88
1000	24	11.25
Phenanthrene		
0	99.25	1.5
60	97.75	1.5
125	96.75	2.87
250	77.5	33.93
500	34.25	23.21
1000	8.25	16.5
Diesel		
0	99.25	1.5
25	99.25	1.5
50	91.5	8.35
100	58.5	7.05
200	4	4.25

Four basic conclusions were drawn from the experiments performed with the harpacticoid *Schizopera knabeni*:

* PAH in the sediment phase had an adverse impact on survival, reproduction, development and feeding of a harpacticoid copepod.
* Sub-lethal tests, more sensitive than acute exposures, detected toxicity of sediment-associated PAH at lower concentrations.
* Diesel fuel, a complex mixture of PAH, had a more significant impact at lower concentrations than the single compounds phenanthrene and fluoranthene.
* The grazing activity test, performed first with meiobenthos, proved more sensitive and time-effective when compared to the reproductive-output test.

FUTURE RESEARCH AND TEST APPLICATIONS

Our future research will focus on performing the developed test protocols to detect and compare PAH adverse effects on three of the most abundant species of harpacticoids in the estuaries of the Gulf of Mexico. We also propose to test the hypothesis that pre-exposure to PAH increases tolerance to this compounds. This will be accomplished by comparing the sensitivity of two populations of the same species: one from Louisiana, subjected to historical chronic exposure to hydrocarbons; the other from a more pristine estuary, potentially in Florida. We will also test the hypothesis that PAH in the sediment may exert a selective pressure towards development of resistance. Laboratory experiments will be performed to compare the tolerance across generations of a population of harpacticoid chronically exposed to PAH in laboratory-controlled conditions.

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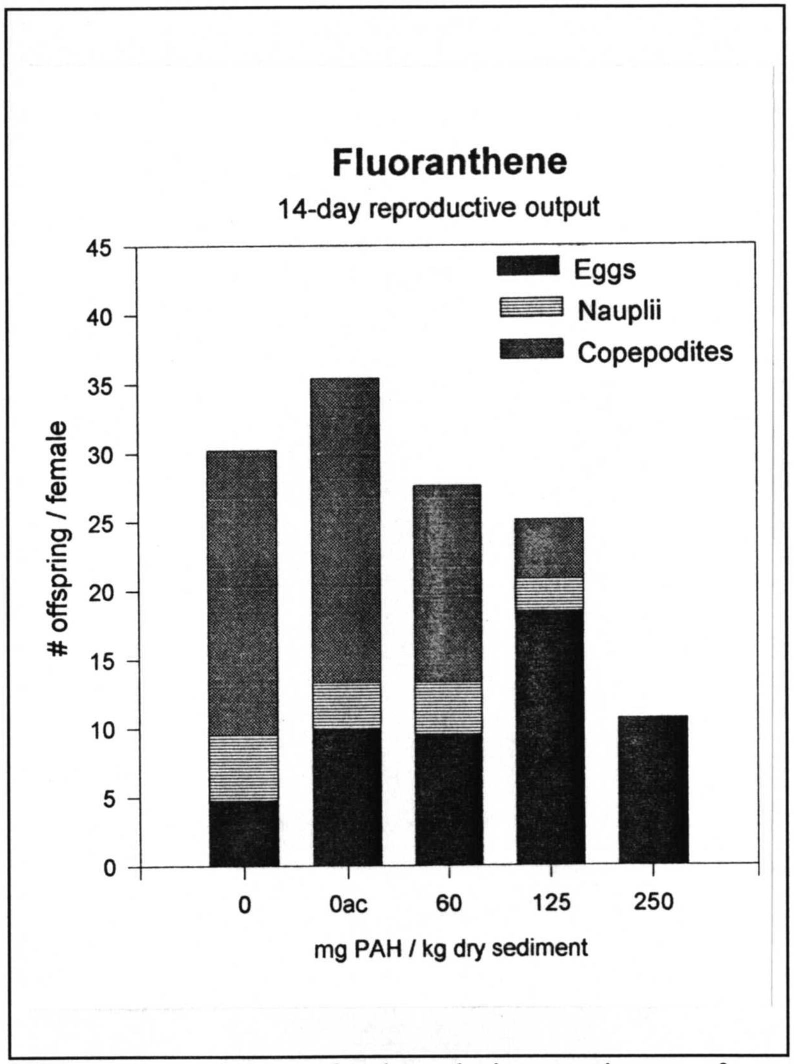

Figure 2C.7. Histogram of total reproductive output in terms of mean number of offspring produced by one mating pair in the **fluoranthene** 14-day reproductive output experiment with *Schizopera knabeni*. Total is fractionated into number of eggs, nauplii and copepodites. 0ac = acetone control.

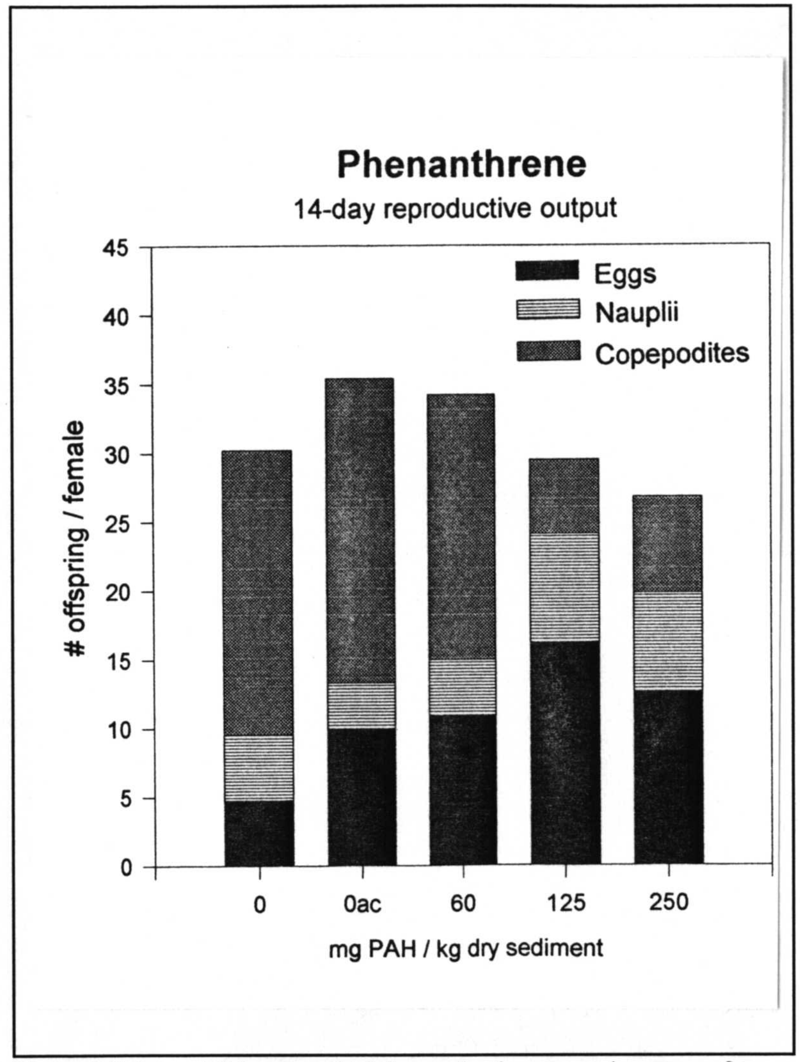

Figure 2C.8. Histogram of total reproductive output in terms of mean number of offspring produced by one mating pair in the **phenanthrene** 14-day reproductive output experiment with *Schizopera knabeni*. Total is fractioned into number of eggs, nauplii and copepodites. 0ac = acetone control.

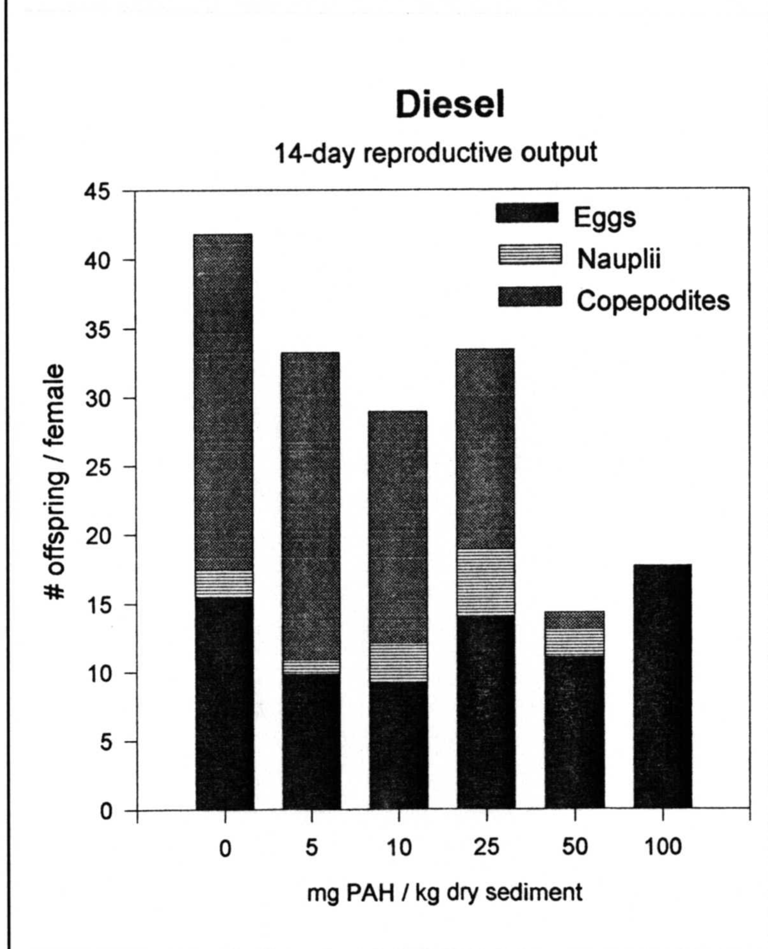

Figure 2C.9. Histogram of total reproductive output in terms of mean number of offspring produced by one mating pair in the **diesel fuel** 14-day reproductive output experiment with *Schizopera knabeni*. Total is fractioned into number of eggs, nauplii and copepodites. 0ac = acetone Control.

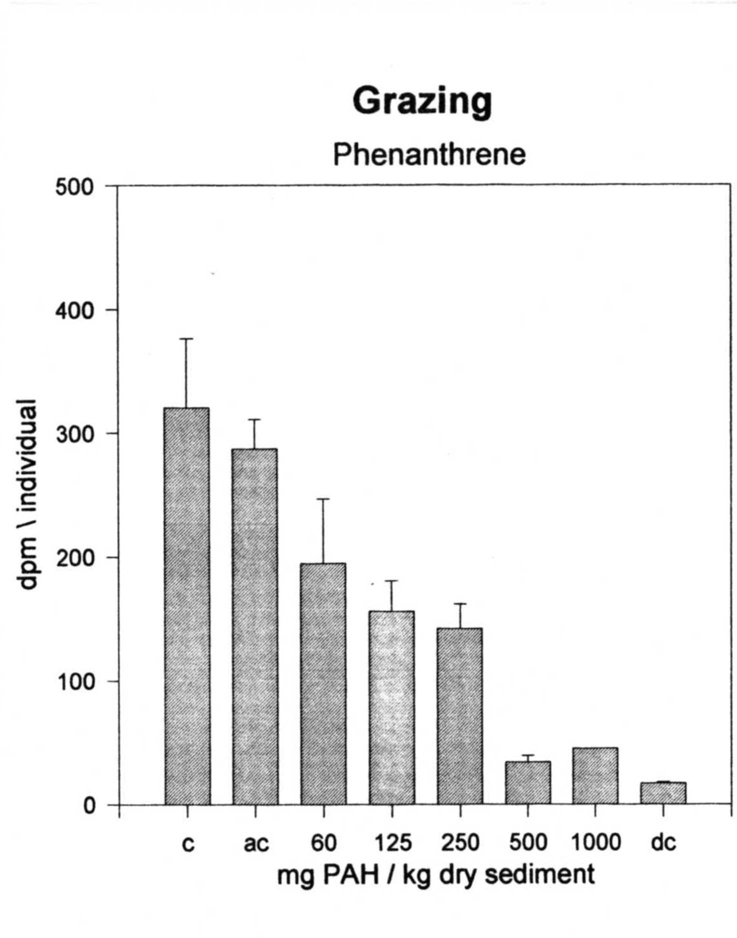

Figure 2C.10. Histogram of the radioactivity incorporated in *Schizopera knabeni* after grazing for 3 hrs on ^{14}C Radiolabeled *Schizopera galbana*. c = control; ac = acetone control; dc = dead control; dpm = disintegration per minute.

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MODELING THE BEHAVIOR OF INTEGRATED PRODUCERS AND INDEPENDENT PRODUCERS: IMPLICATIONS FOR OFFSHORE OIL AND GAS DEVELOPMENT AND POLICY

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Major oil and gas companies are shifting their exploration and production (E&P) investment from the United States to foreign countries. As they do so, smaller companies, "independents," are expected to play a more prominent role in domestic E&P. Within both industry and government circles the apprehension is widespread that such a shift from the majors to the independents will cause domestic oil and gas resources to be developed less aggressively and less efficiently.

This project addresses such concerns by attempting to discern and quantify differences in behavior and success among firms of different sizes (majors, large and small independents) operating on the Gulf of Mexico OCS. Indicators such as 1) exploration and development effort, 2) wildcat success ratio, 3) drilling productivity and 4) wildcat drilling as percent of total drilling effort are derived and used to compare performances of majors and independents.

An economic model of the process of hydrocarbon reserve additions also has been developed and used to test the hypothesis that majors have explored for and developed petroleum resources more efficiently or aggressively on the Gulf OCS than have independents. The model is used to study differences between majors and independents in the responsiveness of their drilling to changes in: 1) economic factors, 2) resource depletion, and 3) taxation.

Our findings to-date are as follows:

1. Over the past ten-years, independent operators accounted for 57% of cumulative wildcat permits issued to search for new hydrocarbon reservoirs/fields on the OCS and 70% of total exploratory wells drilled on the OCS. Moreover, small independents accounted for more than 40% of all exploratory wells drilled by independents and 28% of total exploratory wells.
2. Independents have been more willing to assume the higher risk inherent in exploration than the majors. More than 55% of independents' total drilling effort was exploratory drilling in comparison to the 21% wildcat ratio for the majors. And while only one in every four wildcat wells drilled by the majors was successful during the period 1983-1992, one in every three wildcat wells drilled by independents was successful at finding new reserves during the same period.
3. Contrary to conventional thinking, the upstream oil and gas industry indicators we have developed indicate that independents have been both more aggressive and more successful than the majors in exploration, while the majors have only been moderately more successful than independents in development drilling on the OCS.
4. In the aggregate, large, medium-sized, and small independents have all been more effective than the majors in adding hydrocarbon resources per successful foot drilled. If success is measured by barrels-of-oil-equivalent(BOE)-added-per-foot-of-successful-wells-drilled, on average, independents were more successful than the majors--adding 267 BOE per successful foot drilled over the 1983 to 1993 period compared to 226 BOE per successful foot drilled for the majors. If total footage drilled, rather than successful footage, is used, the difference narrows. Majors added 108 BOE per foot drilled while independents as a group added 110 BOE. Within the independent classification, large independents added 117 BOE per foot, middle-sized independents 114 BOE per foot and small independents 103 BOE per foot drilled.

To investigate these differences more carefully, we developed a hydrocarbon model of reserve additions on the Gulf of Mexico OCS. The hydrocarbon model views drilling as the primary means of generating new reserve additions; subject to resource availability, economic and policy incentives, cumulative geological knowledge and technical progress. The model structure is a combination of econometric descriptions of drilling behavior and geologic-engineering specifications of the effectiveness of drilling at adding new hydrocarbon reserves. The model is estimated using pooled, cross-section (majors, large and other independents) and time series data (for the period 1978 through 1992).

Empirical estimates made with our hydrocarbon model confirm the inferences drawn from descriptive analysis.

We found no statistical evidence of significant differences in the responsiveness of gross find-rate of hydrocarbon-reserves to technical progress among firms of different sizes operating on the OCS. We did find that resource depletion (or the growing maturity of the Gulf of Mexico OCS) more negatively affects majors' ability to add new reserves (per foot of successful wells completed) than it affects independents. Responsiveness of gross find-rate to cumulative drilling (a proxy measure for resource depletion) on the Gulf of Mexico OCS is estimated, on average as -0.81, -0.64 and -0.61, respectively, for majors, large independents and other independents.

Further, we found no differences among firms of different sizes in the responsiveness of drilling effort on the OCS to before-tax net cash flow (economic incentives) or the effective tax rate. Estimates of the hydrocarbon drilling equation suggest a highly negatively elastic response of drilling to the effective tax rate and a positively inelastic response of drilling effort to economic benefits. Drilling response to resource depletion is also more negatively elastic for majors than it is for independents.

This report covers the first six months of project activity. During the remainder of the project we will

1. Assemble and organize data from the Louisiana Department of Natural Resources (LDNR) files necessary to replicate the analysis summarized here for the Louisiana state jurisdiction. The principal problem in doing this is estimating reserves and reserve additions because the LDNR data does not provide such data.

2. Compare the results for the OCS we have described in this report with the results for the Louisiana jurisdiction.

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ROLE OF BOTTOM SEDIMENT REDOX-CHEMISTRY NEAR OIL PRODUCTION FACILITIES IN THE SEQUESTER/RELEASE AND/OR DEGRADATION OF METALS, RADIONUCLIDES AND ORGANICS

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SUMMARY

Bottom sediment was collected from a brackish site in coastal Louisiana. The sediment had been exposed to produced water discharge from several wells for a number of years (St. Pe, 1990). The sediment contained radium and elevated levels of selected metals and petroleum hydrocarbons. The influence of sediment redox chemistry on the partitioning of metals and radium and the degradation of petroleum hydrocarbons at the site was examined.

Adsorption isotherms for selected metal including barium was determined in sediment incubated in microcosms (Patrick *et al.* 1973) under various sediment redox conditions ranging from +450 mV to -170 mV. Freudlich isotherms were used to determine metal/elemental adsorption at the various redox levels. Results obtained have shown the importance of sediment geochemistry on metal adsorption. We determined the adsorption capacity for Cu, Zn, Cd, As, Pb, Cr, Ni and Ba. We were particularly interested in Barium because of its presence in drilling muds. Under oxidized condition, Fe^{3+} and Mn^{4+} hydroxides were the main components responsible for sediment adsorption capacity at the study site. Under reduced condition, sediment humic, fulvic materials, and Fe(II), Mn(II) sulfides controlled metal adsorption.

Shown in Figures 2C.11 and 2C.12 are results of cadmium and barium adsorption at various sediment redox conditions (-Eh) which depict the importance of sediment redox chemistry on the adsorption or release of metals in bottom sediment at the site.

When sediment redox condition (Eh) was +430 mV (highly oxidized) the adsorption capacity of the sediment for Cd was high due to high adsorption capacity by oxidized Fe(III) and Mn(IV) oxyhydroxides. As the sediment became moderately anaerobic (-80 mV) the adsorption capacity decreased. This decrease was attributed to the dissolution of Fe(III) and Mn(IV) oxyhydroxides.

As more anaerobic condition developed (-130 mV) the adsorption capacity of the sediment for Cd increased. At this redox level, sulfate was reduced to sulfide (S^{2-}) which precipitated Mn^{2+} and Fe^{2+} to form insoluble sulfides. At the initial stage of sulfide formation, the degree of supersaturation was low. The attraction between S^{2-} and Fe^{2+} or Mn^{2+} was only sufficient to cause these ions to bind together forming amorphous precipitates. These newly formed amorphous precipitates (FeS and MnS) have high surface areas. Therefore the sediment under these conditions had a high adsorption capacity for Cd.

When intense reducing conditions were reached (Eh=-160 mV) the adsorption capacity of the sediment for Cd decreased. At this range, the sulfide ion (S^{2-}) concentration increased and the degree of supersaturation was great. The formation of FeS and MnS precipitates on the surface of amorphous FeS and MnS particles formed larger crystal lattice particles. These large FeS and MnS particles contained less surface area and were less active. Therefore the sediment at these redox levels containing such particles have less adsorption capacity for Cd.

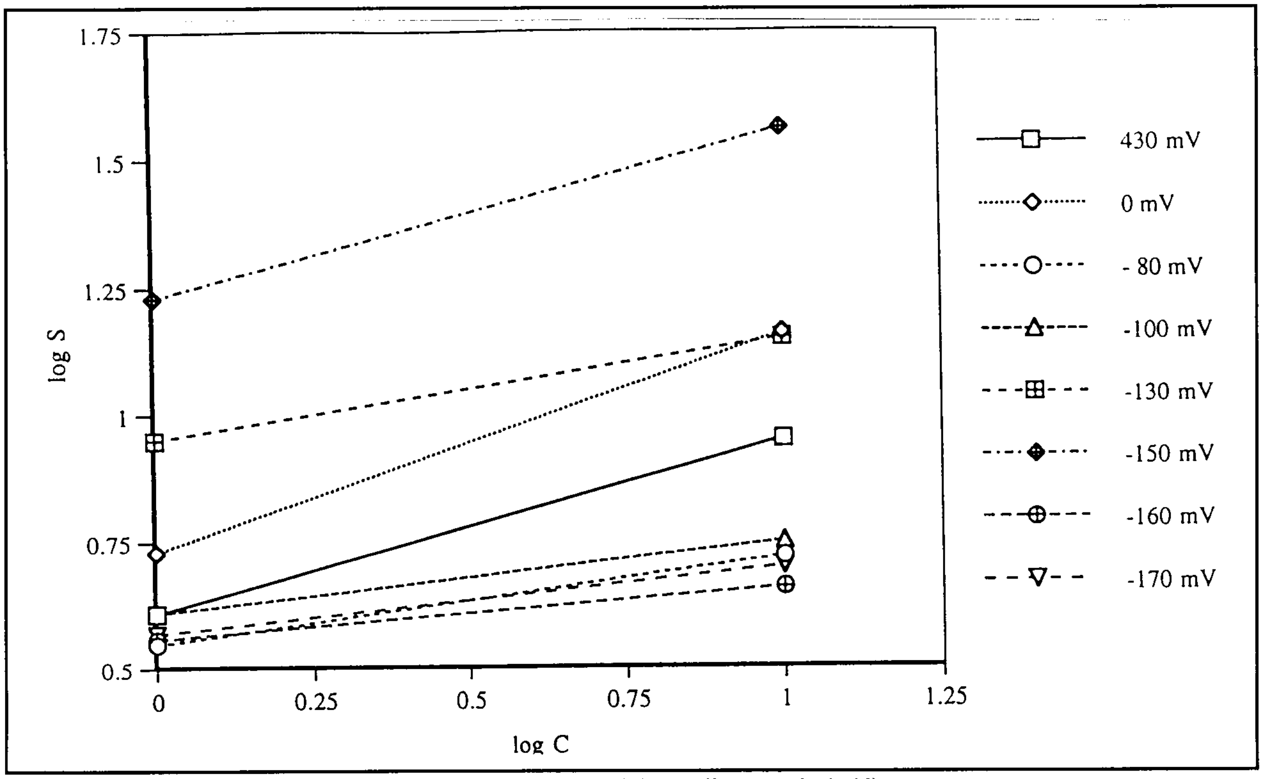

Figure 2C.11. Adsorption of Cadmium as influenced by sediment Eh (mV)
S = Concentration of adsorption Cd, C = Concentration in solution

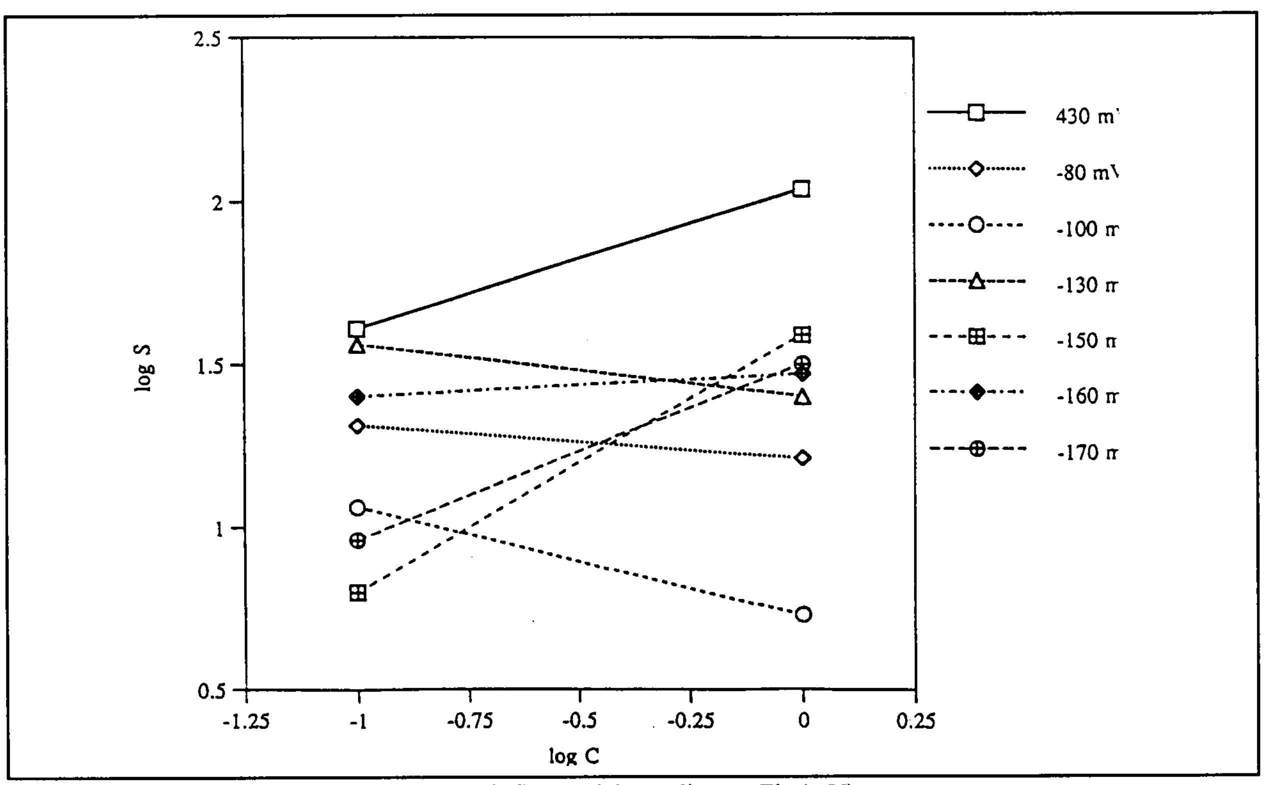

Figure 2C.12. Adsorption of Barium as influenced by sediment Eh (mV).
S = Concentration of adsorption Ba, C = Concentration in solution.

Barium adsorption rate was also influenced by sediment redox condition. At highly oxidized conditions (Eh=430 mV) the sediment had a high adsorption capacity for Ba due to the greater adsorption capacity by Fe(IV) and Mn(IV) oxyhydroxides contained in the sediment. When sediment became anaerobic, the adsorption capacity decreased due to the dissolution of Fe(IV) and Mn(IV) oxyhydroxides.

Factors affecting the solubility and mobility of ^{226}Ra in the sediment at the site was also evaluated using sequential extraction procedure adopted from Shannon *et al.* (1991). The sediment collected contained significantly high ^{226}Ra activity was incubated in microcosms under controlled conditions. Results indicate that ^{226}Ra solubility was controlled by co-precipitation of radium within sulfate minerals (e.g. barite and gypsum). Very little was in available or potentially available forms. In biologically-active, contaminated bottom sediments, conversion of sulfate to sulfide results in the dissolution of some barite releasing small amounts of radium to other available forms. Key results include:

1. Selective extractions of the sediment indicated that very low activities of radium are present in "available" or "potentially available" forms. Nearly all of the radium activity (>95%) can only be extracted using strong acids.
2. The modified MINTEQ geochemical speciation model indicated that sediment porewater is unsaturated with respect to pure radium minerals but supersaturated with respect to other sulfate minerals such as barite ($BaSO_4$) and gypsum ($CaSO_4$. $2H_2O$). Radium can co-precipitate within these minerals.
3. In the biologically-active bottom sediment under anaerobic conditions, conversion of sulfate to sulfide results in the dissolution of some barite, redistributing small amounts of radium (approximately 5% of the total activity) to available and potentially available forms.

Degradation of petroleum hydrocarbon as influenced by sediment redox condition at the site was also determined. It is apparent from our initial analyses that the sediment at this discharge site were not enriched with lighter petroleum hydrocarbon fractions particularly aromatics. This suggested that there was either rapid degradation of these fractions or the solubility of these components was conducive to mobility. The rate of degradation in the sediment was determined by the use of an internal marker (Hopane). Historically the ratio of heptadecane: pristane and octadecane: phytane have been used as a reference of degradation (Bertrand *et al.* 1983). A problem is that pristane and phytane are somewhat biodegradable; therefore, the ratio are useful only in the early stages of biodegradation. Hopanes are very resistant to biodegradation (Peters and Moldowan 1993) and serve as an excellent internal marker for this degradation. Hopanes are the molecular fossils of bacterial hopanoids and may be the most abundant chemically defined organic species on earth (Ourisson and Albrecht 1992; Prince *et al.* 1987). Hopane has been shown to be neither generated no degraded in the time frames of laboratory experiments on biodegradation (Prince *et al.* 1994).

Sediment obtained from the discharge site was incubated in microcosm at various redox levels (Eh). The initial sediment added to the microcosm was found to contain primarily long chained branched fractions (e.g., isoprenoids). This suggests that the lighter molecular weight fractions are rapidly degraded or leached from the sediment. To estimate the time or capacity for degradation of lower molecular weight fractions (aromatic etc.) at various redox levels south Louisiana crude oil was added to the microcosm. Hopane was shown to be an excellent internal standard for determining petroleum hydrocarbon degradation rate. Samples were periodically removed and then analyzed on a HP MS-GC to determine degradation. Results using hopane internal standards shows that sediment redox conditions were also important in petroleum hydrocarbon degradation.

In conclusion, sediment redox chemistry at the produced water discharge site was shown to be very important in determining release, mobility of metals and radium and in the degradation of hydrocarbons.

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SESSION 2D

AIR QUALITY ISSUES ON THE OUTER CONTINENTAL SHELF

Session: 2D - Air Quality Issues on the Outer Continental Shelf

Co-Chairs: Mr. William S. Steorts and Dr. Mark Yocke

Date: November 16, 1994

Presentation	Author/Affiliation
Photochemical, Meteorological, and Emissions Modeling Results of the Gulf of Mexico Air Quality Study	Dr. Mark A. Yocke Gary Z. Whitten Nina K. Lolk Marianne C. Causley Systems Applications International ICF Kaiser Engineers Mr. William S. Steorts U.S. Minerals Management Service Gulf of Mexico OCS Region
A Study of SO_2 Concentration and Dispersion Meteorology in a Class I Area	Dr. S. A. Hsu Coastal Studies Institute Louisiana State University
Measurements of SO_2 and NO_x Concentrations and Related Meteorological and Limnological Parameters in a Class I Area in Summer 1994	Dr. S. A. Hsu Coastal Studies Institute Louisiana State University

PHOTOCHEMICAL, METEOROLOGICAL, AND EMISSIONS MODELING RESULTS OF THE GULF OF MEXICO AIR QUALITY STUDY

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The Clean Air Act Amendments of 1990 (CAAA) specifically mandate that the U.S. Department of the Interior's Minerals Management Service (MMS) conduct a research study to assess the potential for certain types of onshore impacts of air pollutant emissions from offshore oil and gas exploration, development and production in the Outer Continental Shelf (OCS) regions of the Gulf of Mexico. Furthermore, the study was to assess the need for further control of offshore air pollution emissions. This mandate grew out of widely expressed concerns regarding the cumulative impacts onshore of air pollutant emissions from more than 3,000 offshore oil and gas production and development facilities in the central and western Gulf of Mexico. The impacts of greatest concern are ozone concentrations in onshore areas not attaining the National Ambient Air Quality Standard (NAAQS) for one-hour average ozone (120 parts per billion [ppb]). These nonattainment areas include the region from Baton Rouge to the Gulf of Mexico, two parishes around Lake Charles in Louisiana, the Houston–Galveston–Beaumont–Port Arthur area, and Victoria County in Texas.

Accordingly, MMS undertook sponsorship of the Gulf of Mexico Air Quality Study (GMAQS), which is intended to evaluate the effects of the development of Outer Continental Shelf (OCS) petroleum resources on onshore ozone concentrations. The first stages of this three-year project began in May 1992.

GOALS AND OBJECTIVES OF THE STUDY

The overall goal of this study was quantitatively to determine through modeling (emissions, meteorological, and photochemical) the effects of current and future OCS development in the Gulf of Mexico on the nonattainment areas for ozone in Texas and Louisiana delineated above.

PROJECT ELEMENTS AND CHRONOLOGY

The project was divided into eight major tasks conducted in the following sequence:

1. identification of representative historical ozone episodes;
2. development of appropriate emissions inventories for these historical episodes (including OCS and onshore emissions, and growth/control in calendar years of interest);
3. preliminary emission, meteorological and photochemical modeling of selected historical episodes;
4. design and conduct of a field study to collect appropriate meteorological and air quality data during the summer of 1993;
5. development of emission inventories for the 1993 ozone episodes and projection of future year emission inventories.
6. meteorological and photochemical modeling of ozone episodes selected from the 1993 field study; assessment of the ozone impacts of alternative OCS future development scenarios in the Gulf Coast area on the on shore ozone nonattainment areas;
7. characterization of the uncertainty in the model estimations;
8. evaluation of the needs for future research or data collection efforts to improve understanding of the OCS effects on ambient ozone onshore.

The principal elements of the study were the field study, data analyses, emissions inventory development, meteorological modeling, and photochemical modeling. This paper describes the emission, meteorological, and photochemical modeling procedures and interim results of the GMAQS for a high ozone episode that occurred throughout the study region on 17-21 August 1993.

OVERVIEW OF EMISSION INVENTORY MODELING

Comprehensive gridded, hourly emissions inventories were prepared for the entire study area, for the 1993 ozone episodes. These inventories cover an area of nearly one million square kilometers, encompassing the OCS and onshore ozone nonattainment areas (Houston, Beaumont, Lake Charles, and Baton Rouge).

Air pollutants inventoried include NO, NO_2, speciated VOC, and CO. These inventories were converted to formats suitable for input to the photochemical model using the Emissions Processing System (EPS2.0). Quality assurance guidelines and procedures were developed, applied, and documented throughout the emissions inventory process to assure traceable emissions processing with minimal errors.

The emission inventories prepared included both onshore and offshore emissions and OCS related emissions. All relevant emissions from anthropogenic and natural (i.e., biogenic and geogenic) sources were considered, with special attention focused on offshore anthropogenic sources. Emissions from onshore anthropogenic sources were estimated based on information obtained from the USEPA 1990 Interim State Implementation Plan (SIP), the Louisiana Department of Environmental Quality (LADEQ), and the Texas Natural Resources Conservation Commission (TNRCC).

A special survey was conducted to inventory offshore emissions sources. In conjunction with MMS, three survey forms were designed to solicit the information needed to estimate emissions from OCS production platforms, crew/supply boats and crew/supply helicopters. A software package was designed and developed for this study to estimate platform emissions by accessing the survey database, assigning quality assurance tracking codes, making quality control checks and data corrections, calculating emissions, and preparing the emissions data files in the format required by EPS 2.0. The emission calculations performed by the software reflect recent updates to the methodology given in EPA's Compilation of Air Pollutant Emission Factors (AP-42, Supplement E). Fugitive emissions were estimated using factors from a recent MMS Pacific OCS Study (MMS 92-0043,44). Estimates of emissions were also prepared for other OCS sources, including pipeline and military vessels, and helicopters, using available information from a variety of sources.

OVERVIEW OF METEOROLOGICAL MODELING

Following preparation of the geographical and meteorological input data files required by the SAIMM, several test applications of the model were performed to establish the most appropriate set of input parameters and modeling procedures. For coarse grid resolution simulations, the SAIMM was exercised for the 17-21 August episode day using episode-specific temperature and moisture profiles and Four Dimensional Data Assimilation (FDDA) and variable surface characteristics.

A procedure for extracting information from the coarse-grid SAIMM simulations to provide time- and space-varying boundary conditions for fine-grid resolution simulations was developed and tested for the Houston domain using the coarse-grid simulation results. The SAIMM was exercised for the fine-grid domain using domain-wide initial temperature and moisture profiles, FDDA, and variable surface characteristics. Information from the coarse-grid simulation was transferred to the fine-grid simulation using the FDDA procedure; the FDDA analyses were prepared by incorporating observations into a coarse-grid-simulation-derived first-guess field. Several fine-grid simulations were run to determine how to best achieve the one-way nesting (i.e., which of the prognostic variables to nudge and the optimum strength of the nudging coefficients) in the fine-grid simulations. The one-way nesting procedure was successfully applied to the generation of representative meteorological fields for episodes on 17-21 August 1993.

OVERVIEW OF PHOTOCHEMICAL MODELING

An advanced photochemical air quality model, the Urban Airshed Model (UAM-V), was set up and tested for the 17-21 August 1993 ozone episode. The episode was selected on the basis of extensive analysis of 1993 field study data. The gridded model inputs were developed under the emissions inventory and meteorological modeling procedures described above. A nested grid was employed with the finest grid spacing over the Houston/Beaumont industrialized/urban areas, and the coarse-grid nest covering the balance of the roughly 1,000km by 1,000km modeling domain.

Evaluation of the model's performance for this episode was completed using available air quality measurements, and the model was found to perform reasonably well, based on both quantitative statistical tests and qualitative comparisons. Sensitivity tests were carried out to examine the model's responses to uncertainties in inputs and to changes in the OCS emissions inventory.

The UAM-V modeling results for this episode suggest that the effect of transient emission likely played an important role in the formation of the highest ozone levels. In particular, a spill of gasoline in the Ship Channel area of Houston on morning of 19 August appears to have contributed to the highest ozone levels measured during the episode. The model appears to be sensitive to both NO_x and VOC emissions depending on the region and the mix of local emissions, suggesting that a mixed NO_x and VOC emissions control strategy may be required. Furthermore, sensitivity tests suggest that the existing emissions inventory in the Houston/Bay City/Beaumont areas may be inadequate for day-specific photochemical modeling, due perhaps to unresolved day-to-day variations in emissions.

Results from running UAM-V for this episode with and without the OCS emissions showed virtually no onshore impacts on ozone concentrations and only relatively small impacts (9-39 ppb ozone) in some areas well offshore.

NEXT STEPS

Since the meteorology for the 17-21 August 1993 showed little penetration of air from over the Gulf into either the Baton Rouge or greater Houston regions, the episode does not reveal significant OCS impacts in the areas of high ozone. Nevertheless, the modeling of this episode was instructive about the general meteorological, air quality, and emissions issues surrounding the ozone problems in the study region. A later summer 1993 episode, 6-11 September, was characterized by high ozone (albeit not as high as during the August episode) along the Gulf coastline. Air flow during this period also suggests that onshore emissions could have been transported well offshore overnight and returned onshore the following day. Therefore, this September period may offer greater potential for commingling of onshore and onshore emissions than did the August episode. For these reasons, it was decided that the remaining modeling efforts on this project will focus on this September episode. The final report, to be completed by 1 August 1995, will present the results of the September modeling, focusing on the potential for OCS ozone impacts onshore.

A STUDY OF SO_2 CONCENTRATION AND DISPERSION METEOROLOGY IN A CLASS I AREA

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ABSTRACT

Owing to energy productions from oil platforms in the Gulf of Mexico, it is unavoidable that sulfur compounds such as SO_2, H_2S, and H_2SO_4 are affecting nearby coastal areas. On the other hand, the most recent Clear Air Act does not allow Class I areas such as National Seashores and Wildlife Refuges to be polluted. In the offshore region east of the Mississippi River, for example, there are very active areas of energy production and therefore many potential sources for the emissions of SO_2 and other sulfur compounds. Unfortunately, downwind from these emission facilities are the Gulf Islands National Seashore (including Petit Bois, Horn, and Ship Islands) and Breton and Delta National Wildlife Refuges. In the summer of 1993, three SO_2 measurement stations were in operation on both Delta and Breton National Wildlife Refuges. Our results show that the maximum 24-hour and 1-hour SO_2 concentrations in these wilderness areas were 12 and 6 ppb, respectively, as compared to the corresponding NAAQS values of 500 and 140 ppb. Even if one adds the respective 10 and 2 ppb for the prevention of significant deterioration increments (for Class I areas) for these sampling periods, the maximum SO_2 concentration is still less than 6% of the NAAQS value. It is also found that after the passage of a weak cold front on 11 September 1993,

when the wind blew from the land to the Gulf, the SO_2 concentration was at least twice as high as when the Bermuda High Pressure System resumed its normal influence, i.e., when the wind blew from the Gulf toward the land. Therefore, the SO_2 concentration in our area may be due to sources from both the land and the offshore region.

INTRODUCTION

The most recent Clean Air Act requires that Class I areas such as national parks and wildlife refuges are subject to the Prevention of Significant Deterioration (PSD) doctrine. For PSD areas, maximum "increments" of SO_2 and total suspended particles have been established. Sulfur compounds are a necessary by-product of offshore oil and natural gas production. The region east of the Mississippi Delta contains not only large amounts of offshore petroleum production, but also the Gulf Islands National Seashore and the Breton and Delta Wildlife Refuges. Therefore, a study of the SO_2 concentration and its impact in these wilderness areas has been initiated by the U.S. Minerals Management Service since 1993. Some results of our SO_2 measurements are presented in this paper.

FIELD EXPERIMENTS AND RESULTS

The concentration of atmospheric pollutants is inversely proportional to the wind speed. Generally speaking, the wind speeds are lower in the summer than in other seasons. With this in mind, we have been funded by the Minerals Management Service since 1993 to measure the SO_2 concentration in the summer of 1993 and again in the upcoming summer of 1994 in the Breton Wilderness area. Some results from 1993 are shown in Figure 2D.1. Note that the highest SO_2 concentrations in the summer of 1993 are incorporated in the figure so that they can be compared to the National Ambient Air Quality Standards (NAAQS). Since the maximum 24-hour NAAQS for SO_2 is 140 ppb for both primary and secondary standards, we use this value for our brief discussion here. In the summer of 1993 the averaged maximum 24-hour was 3 ppb, which is approximately 2% of the 140 ppb allowable once a year. Figure 1 also delineates the PSD increments of the SO_2 for 24-hour maximums, which is approximately 2 ppb. The Breton Wilderness area is also a Class I area, so the PSD values must be applied. Therefore, we have about 5 ppb for the 24-hour maximum, which is below 5% of the maximum 24-hour value of 140 ppb allowable once per year.

In our area, atmospheric frontal systems become active in September. An example of the SO_2 measurements in the fall is provided in Table 2D.1. It shows that after the passage of a weak cold front on 11 September 1993, when the wind blew from the land to the Gulf, the SO_2 concentration was at least twice as high as when the Bermuda High Pressure System resumed its normal influence, i.e., when the wind blew from the Gulf toward land. Therefore, the

Table 2D.1. A comparison among calibrated measurements of SO_2 concentrations (in ppb) in the Breton Wilderness Area when the wind blew from land to Gulf on 11 September and vice versa on 13 September 1993 (in parentheses).

Location	Maximum 3-hour average	Maximum 24-hour average
Gosier Island	8.5 (3.2)	5.8 (2.3)
Breton Island	11.9 (2.0)	6.3 (1.7)
Pass-A-Loutre	2.3 (1.0)	2.0 (1.0)
EPA Standards*	500	140

* Not to be exceeded more than once per year.

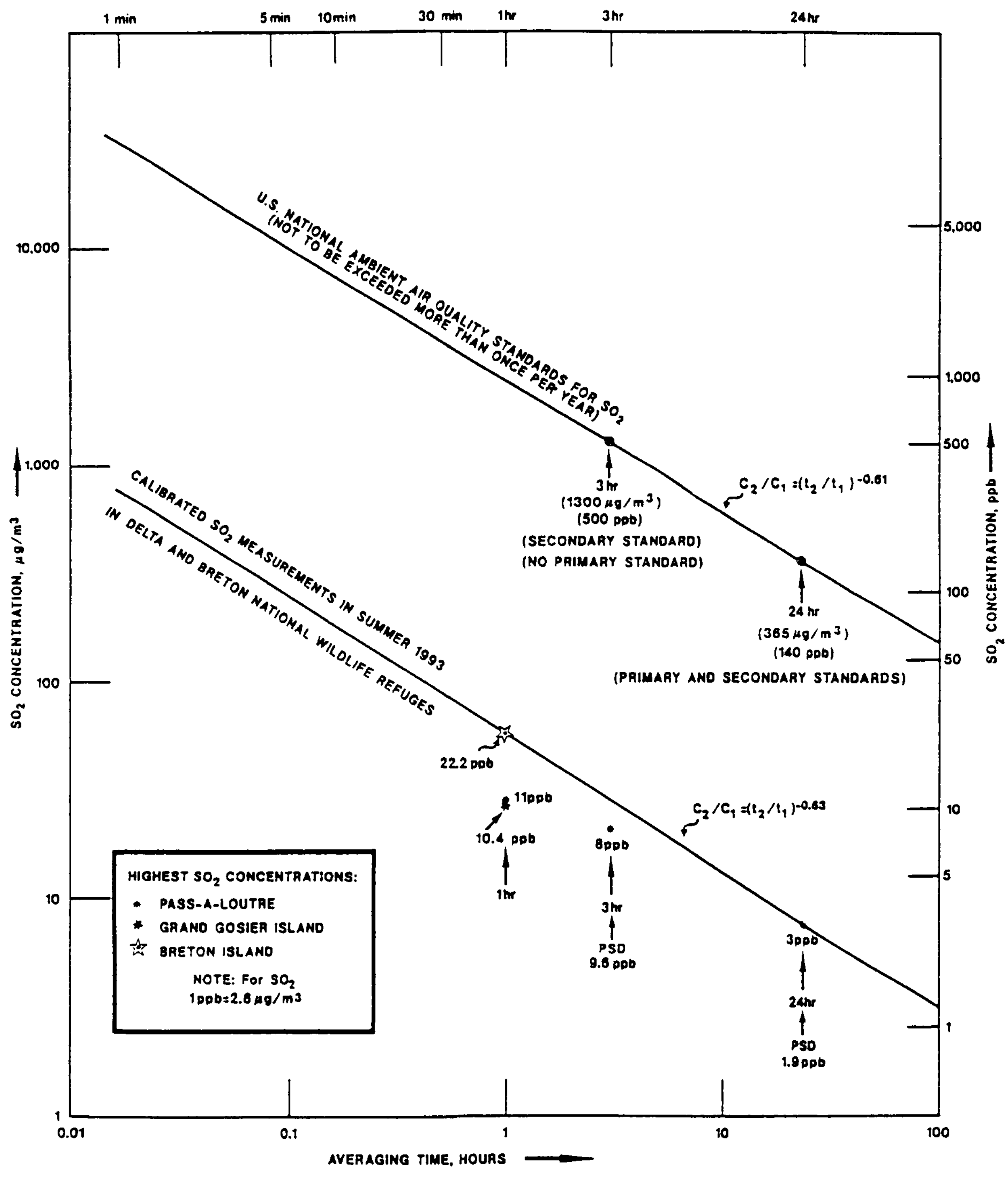

Figure 2D.1. Measurements of the SO_2 concentration in the Breton Wilderness Area in the summer of 1993 and their pollution levels relative to the NAAQS and PSD.

SO_2 concentration in our area may be due to sources from both the land and the offshore region.

CONCLUSIONS

On the basis of our SO_2 measurements in the summer of 1993 in the Breton and Delta Wildlife Refuges, the SO_2 concentration in these Class I areas was only 2% of the national maximum allowable once per year. However, we also found that when the wind blew from the land to our Class I area offshore, the SO_2 concentration was more than twice as compared to the meteorological condition when the wind blew from the Gulf toward the land. Therefore, it is recommended that detailed (hourly) measurements of the SO_2 concentration for an entire one-year period be made in order to separate the contributions from the offshore region vs. land sources. In addition, an SO_2 transport trajectory climatology should be thoroughly investigated for the Gulf Coast region.

ACKNOWLEDGEMENTS

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MEASUREMENTS OF SO_2 AND NO_x CONCENTRATIONS AND RELATED METEOROLOGICAL AND LIMNOLOGICAL PARAMETERS IN A CLASS I AREA IN SUMMER 1994

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In the summer of 1994 both SO_2 and NO_x concentrations were measured at Pass-A-Loutre in the Delta Wildlife Refuge and at both Gosier and Breton Islands in the Breton Wilderness area. Related limnological and surface meteorological parameters were also measured. In addition, upper-air radiosoundings were made to determine the mixing height in these Class I areas. Some preliminary results are summarized as follows (see example figures as attached):

1. When the wind direction shifted from south to west (mainly from the Gulf of Mexico) to the north (mainly from coastal regions of LA/MS/AL), both SO_2 and NO_x concentrations increased at least by a factor of two. For SO_2, the concentration at Gosier increased from 1 to 2 ppb, at Breton from 4 to 16 ppb, and at Pass-A-Loutre from 2 to 13 ppb. For NO_x, it increased from less than 25 to 75 ppb with a maximum of 175 ppb at Breton and from less than 5 to 25 ppb at Pass-A-Loutre. These results are very similar to those obtained in the summer of 1993 after the passage of a cold front.

2. The mixing height ranged approximately from 300 to 400 m in the morning and from 400 to 700 m in the afternoon. The climatological summer mean of approximately 1,200 m for both morning and afternoon over our study area as compiled by Holzworth (in EPA-AP-101) is thus overestimated by a factor of two to three. It is shown that, based on the free-convective theory, the mixing height over our study area in the afternoon should be around 600 m rather than 1,200 m. The results of our radiosoundings over the deep Gulf in the summer of 1993 also showed that the mean mixing height was approximately 600 m with a standard deviation of 100 m.

3. The salinity in the pond adjacent to our air quality measurement site on Gosier Island in the summer of 1994 ranged from 8 to 14 ppt. The pH values were from 8 to 8.5. Diurnal variations in salinity, water temperature, and pH were pronounced. The diurnal range of salinity was about 3 ppt, pH 0.5, and water temperature 5°C.

Dr. Hsu received his B.S. degree in meteorology from the National Taiwan University, Taipei, in 1961, his M.S. in environmental health engineering, and his Ph.D. in meteorology from the University of Texas at Austin, in 1967 and 1969, respectively. Since 1969, he has been a professor at the Coastal Studies Institute, Louisiana State University. Dr. Hsu

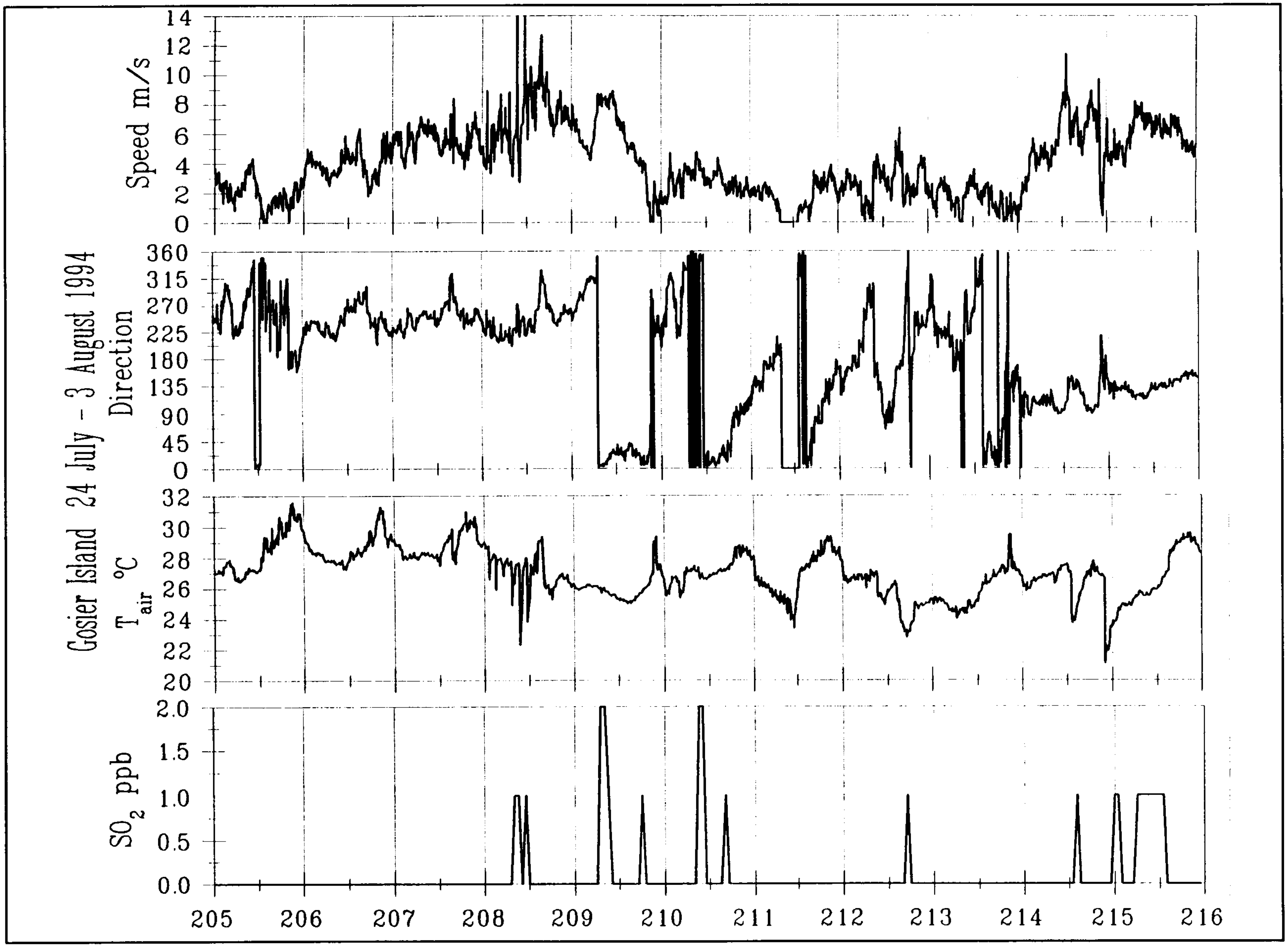

Figure 2D.2. Gosier Island, 24 July - 3 August 1994.

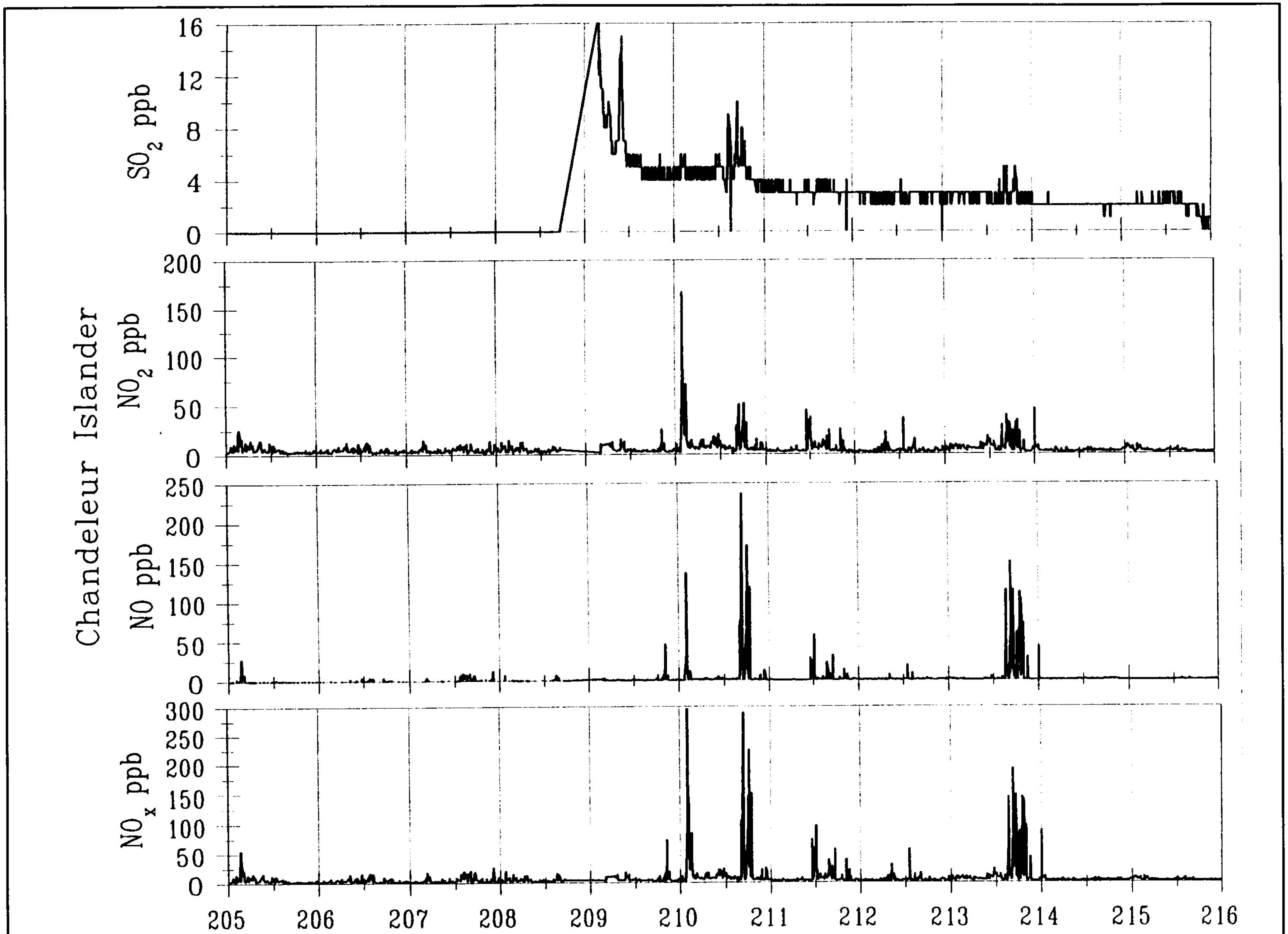

Figure 2D.3. Chandeleur Island.

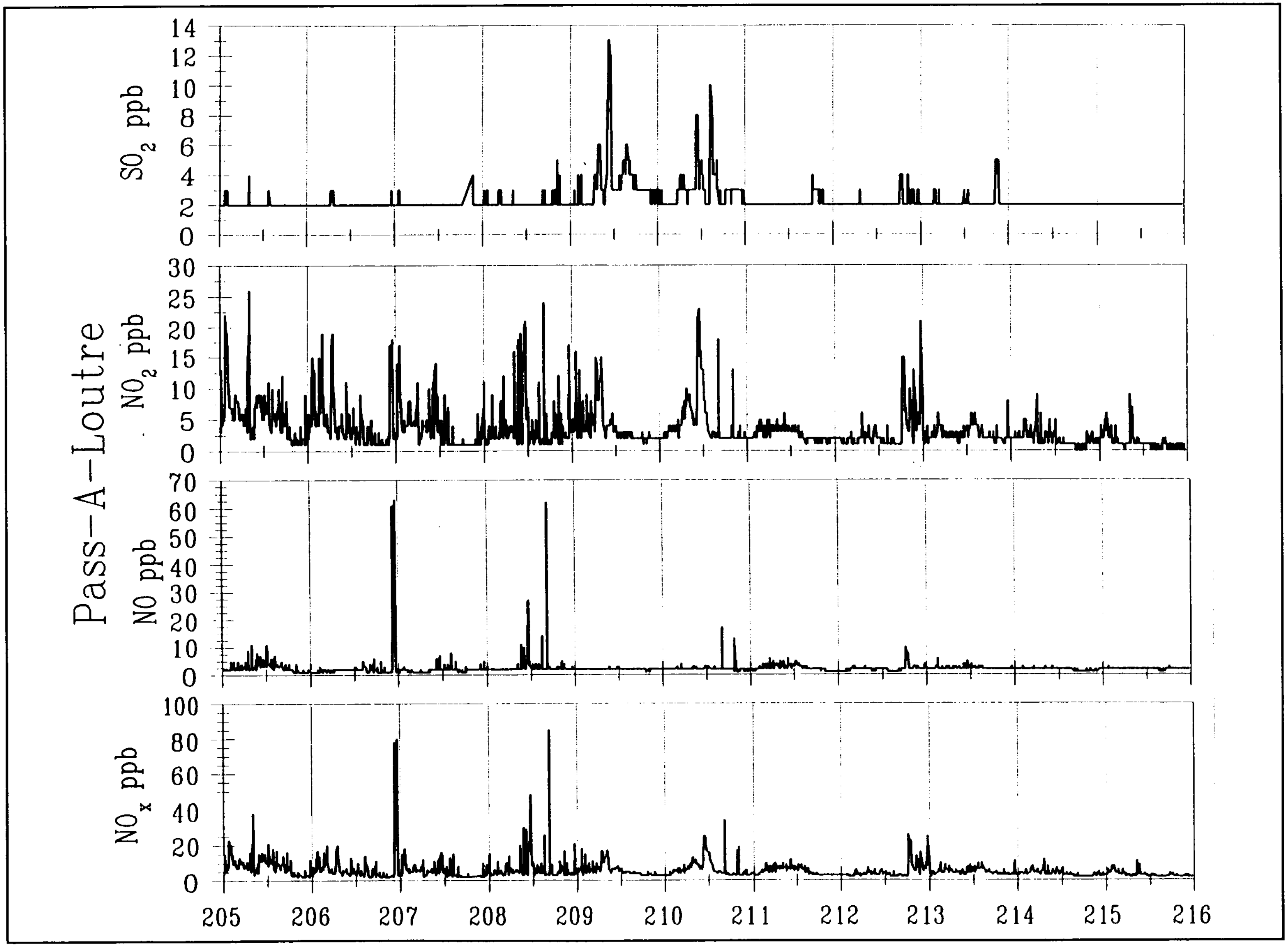

Figure 2D.4. Pass-A-Loutre.

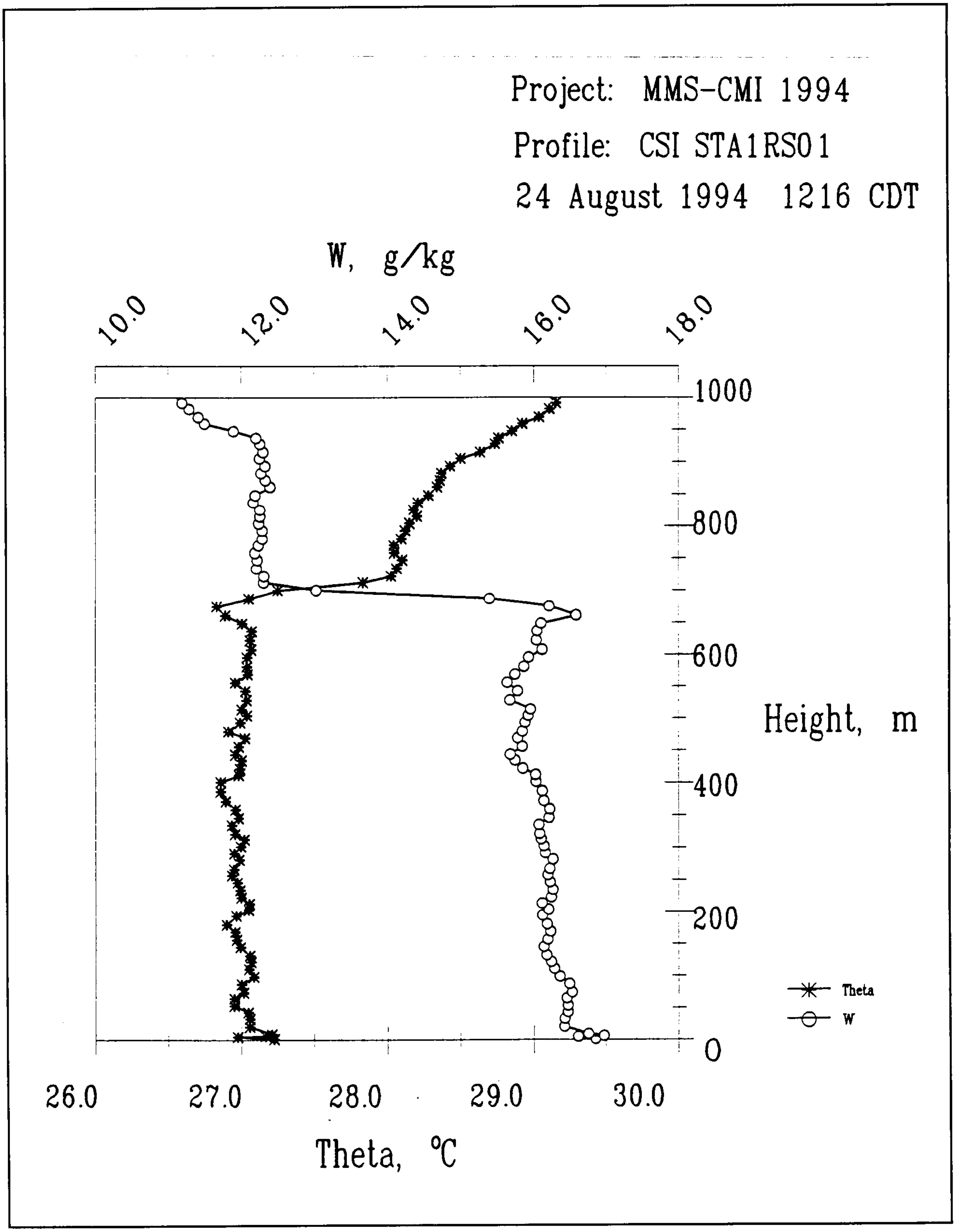

Figure 2D.5. 24 August 1994.

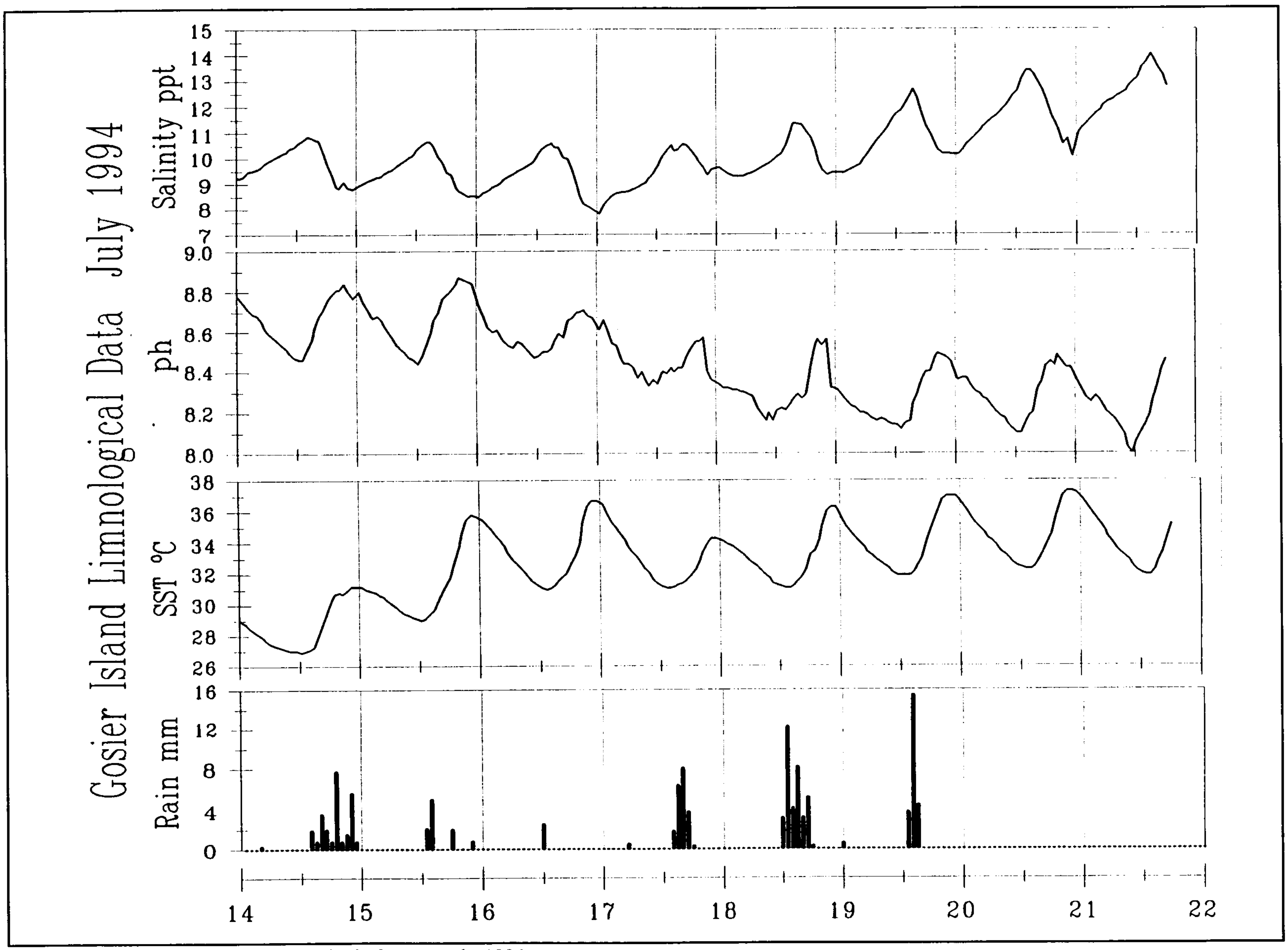

Figure 2D.6. Gosier Island Limnological Data, July 1994.

has published over 100 technical articles including a textbook entitled Coastal Meteorology (published in 1988 by Academic Press, London). His major research interests are boundary-layer and air-pollution meteorology.

SESSION 3A

GOOMEX PROGRESS REPORTS, PART II

Session: 3A - GOOMEX PROGRESS REPORTS, PART II

Co-Chairs: Dr. Pasquale Roscigno and Dr. Mahlon C. Kennicutt II

Date: November 16, 1994

Presentation	Author/Affiliation
Size Structure and Health of Macroinvertebrate Populations at GOOMEX Sites	Dr. Eric N. Powell Dr. Elizabeth Wilson-Ormond Mr. Matthew S. Ellis Department of Oceanography Texas A&M University
Aromatic Hydrocarbon Exposure at GOOMEX Study Sites - Toxicological Indicators	Dr. S. H. Safe[1] Dr. S. J. McDonald[2] Ms. K. L. Willett[1] Ms. K. Beatty[2] [1]Department of Veterinary Physiology and Pharmacology Texas A&M University [2]Geochemical and Environmental Research Group Texas A&M University
GOOMEX Porewater Toxicity Testing	Dr. R. Scott Carr Mr. Duane C. Chapman Mr. James M. Biedenbach National Biological Survey
Histopathology of Demersal Fishes at GOOMEX Study Sites	Dr. John W. Fournie Mr. Lee A. Courtney U.S. Environmental Protection Agency Gulf Breeze, Florida
Meiofauna Genetic Variability	Mr. Greg Street Marine Science Institute University of Texas at Austin
Status of Macroinvertebrate Reproduction and Histopathology at GOOMEX Sites	Dr. Eric N. Powell Dr. Elizabeth A. Wilson-Ormond Mr. Matthew S. Ellis Ms. Shue Li Mr. Yung-Kul Kim Department of Oceanography Texas A&M University

Advanced Toxicological Techniques Applied to the GOOMEX Study

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SIZE STRUCTURE AND HEALTH OF MACROINVERTEBRATE POPULATIONS AT GOOMEX SITES

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One component of the Gulf of Mexico Offshore Operations Monitoring Experiment (GOOMEX) project involves the assessment of macroinvertebrate population structure and health. Little information is available concerning how population structure and health is affected in these species by oil and gas field development. We have utilized several different methods to assess differences in macroinvertebrate population structure in species living near by and far from gas-producing platforms. Differences in catch per unit effort (CPUE), size-frequency distribution and health (determined by the presence of parasites and pathologies), were used as indicators of possible sublethal effects of exposure to chemical contaminants or other gas field-associated factors in target species.

Animals were collected by trawling from locations close to (near-field) and far from (far-field) three platforms, MAI-686, MU-A85, and HI-A389, to assess the effect of oil and gas field development on macroinvertebrate population structure and health. After collection, all individuals of target species were measured to determine size-frequency distribution and CPUE. Specimens of target species were preserved and returned to the laboratory for complete histological analysis. Each tissue section was analyzed for the presence and intensity of parasites and pathologies. Intensity of parasitism was determined by counting every occurrence of specific parasites or pathologies in each individual tissue section. Target species were: the shrimp *Trachypenaeus similis, Penaeus aztecus,* and *Solonocera atlantidis*, the crabs *Callinectes similis, Portunus gibbesii,* and *Portunus spinicarpus*, the starfish *Astropecten duplicatus,* and *Astropecten cingulatus*, the stomatopods *Squilla empusa, Squilla chydaea,* and *Squilla edentata*, and the scallop *Amusium papyraceum*.

CPUE was calculated by dividing the number of individuals of a specific species collected in a trawl by the length of that trawl as determined by shipboard navigation. CPUE can be used as an indicator of species abundance; for example, high values of CPUE indicate that more individuals were collected per trawl, hence the species is probably present in higher abundance. Although few species had significantly different CPUE between the near and far-field stations, starfish, scallops and penaeid shrimps were all more abundant at some far-field stations. Only species of mantis shrimp had significantly higher abundance at near-field stations.

Differences in patterns of size-frequency distribution of target species between the near and far-field stations were frequently observed and were platform specific. Analysis by sex showed that size differences were not simply produced by site discrimination according to sex. For example, size-frequency distributions at MAI-686 show that nearly as many species are larger near the platform as far from the platform. Female *P. aztecus* and most crabs were larger in the far-field. Both sexes of *T. similis* and all starfish were larger in the near-field. At MU-A85, species were only significantly larger far from the platform. These included shrimps, crabs, stomatopods and scallops. Starfish were unaffected. In contrast, species at HI-A389 were larger only near the platform. These included female (but not male) crabs and female stomatopods. Size-frequency distribution varied by cruise. Some species were consistently larger on the spring cruises than on the winter cruises. Combining the results of CPUE analysis and the size-frequency distributions show that not only are some species larger far from the platform, but they are also present in higher abundance. For others, abundances do not change, but size-frequencies do.

Common parasites and pathologies in shrimp were nematodes, cestodes, gut inflammations, cf. *Baculovirus*, and cysts in connective and muscle tissue. Crabs had nematodes and several gill pathologies. Starfish were frequently parasitized by nematodes. Shrimp were heavily parasitized and larger individuals had higher intensities of most parasites and pathologies. Infection intensity was often related to sex. At least one viral epizootic (cf. *Baculovirus*) was sampled at MU-A85, and viral infections were also observed at MAI-686. In contrast to shrimp, crabs were relatively free of parasites and pathologies, but starfish were heavily parasitized by nematodes. Stomatopods, scallops and hermit crabs had very few parasites, always at low prevalences.

Some parasites and pathologies varied according to position from the platforms. At MAI-686, some parasites were more intense in the near-field (e.g. nematodes in crabs), and some were more intense in the far-field (e.g. *Baculovirus* in shrimp, and nematodes in starfish). However, at MU-A85, essentially all significant differences included higher incidences in the near-field. This included cestodes and cysts in shrimp, gill maladies in crabs, and nematodes in starfish.

Proximity to the platforms influences the catch per unit effort and size-frequency distributions of some species. Abundance, as determined by CPUE is higher at the far-field stations when differences exist. Changes in size structure were frequently observed. At MAI-686, these changes were complex. Some species were larger in the near-field, others larger in the far-field. At MU-A85 and HI-A389, size structure changes were consistent. Affected species were larger in the far-field at MU-A85 and larger in the near-field at HI-A389. Accordingly, each platform exhibited a uniquely different pattern.

The platform-specific pattern in differences in size-frequency distribution could be related to differences in the chemical environment at those platforms. For example, MAI-686 has a recurring summer increase in SiO_2 and decrease in oxygen in the near-field. Possibly increased productivity at that platform allows larger individuals of some species to be common near the platform while decreased O_2 drives other species away. Unlike, MAI-686, MU-A85 has a contamination gradient (heavy metals and hydrocarbons). Like MAI-686, sedimentary TOC declines in the near-field. For one or both of these two reasons, nearly all species are larger in the far-field. HI-A389 had the strongest contaminant gradient but no TOC gradient. Several species are larger at the near-field station. Differences in sediment type or local food availability may control population structure there.

In general, differences in species abundance and size-frequency distributions, with small individuals typically found near the platform and higher abundances at the far-field station, might be explained by (1) decreased growth in near-field individuals; (2) higher mortality of adults nearer the platform; or (3) migration with age. The relative importance of each cannot evaluated. Causative factors might include differences in food resources near the platforms, increased exposure to contaminants that detrimentally affect growth and health, or differences in the predator abundance near the platform. Forcing factors might be water column chemical anomalies, contamination gradients, and naturally-occurring sedimentary chemical gradients. Evidence exists suggesting the importance of each of these in selected cases.

In most populations of invertebrates, prevalence and intensity of parasites and pathologies is usually higher in older individuals. Older individuals should have a greater possibility of being parasitized or diseased by virtue of their longer life. Size can be used as a surrogate for age in most invertebrate species. Therefore, since we analyzed the largest individuals we collected, we should have analyzed the oldest, and because the individuals at the far-field station are typically larger, they should also be older. Higher prevalence and intensity of parasitism then, may result from individuals being older at the near or far-field stations. However significant gradients existed, even taking size into account. In this study, species collected from the far-field typically had higher prevalence and intensity of parasites and pathologies. This suggests a difference in population health on scales of three kilometers. At MAI-686, the distribution of infection was complex. Some parasites were present in higher intensities near the platforms, while others were present in high intensities in the far-field. This complexity was also seen in the size structure of the populations. At MU-A85, parasitism was much heavier in the near-field despite the fact that larger individuals were consistently more abundant in the far-field. Histopathology shows strong evidence for a near-field decrease in population health at MU-A85 where a contamination gradient exists. At MAI-686, the presence of TOC and water column chemical gradients produces a complex relationship between location and parasitism/pathology.

The results obtained identify physiological impacts on populations living in close proximity to gas platforms in some developed fields. In general, individuals tend to be smaller, tend to be found in lower abundance, and tend to have higher intensity and prevalence of specific parasites at near-field sites. Each platform exhibits a different pattern of differences in size-frequency distributions and parasitism, probably due to its own unique chemical and physical environment. Further statistical analyses, particularly correlations between the body burdens of chemical contaminants and differences in size and intensity of parasitism, may help to clarify the effect of offshore gas production on these species.

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AROMATIC HYDROCARBON EXPOSURE AT GOOMEX STUDY SITES - TOXICOLOGICAL INDICATORS

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The detoxification work element was designed to the meet the primary objective of the GOOMEX project, namely, to assess the sublethal effects of potential chronic exposure of marine organisms to organic contaminants derived from offshore oil/gas exploration and development activities.

Polynuclear aromatic hydrocarbon (PAHs) mixtures are a major class of organic contaminant in the marine environment. PAHs released as the result of drilling activities are considered to be a likely contaminant in the Gulf of Mexico. PAHs are typically derived from spills of crude oil and refined petroleum, runoff, and combustion sources (Boucart *et al.* 1961; Hites *et al.* 1977; Suess 1970; and Huggett *et al.* 1987). PAHs are susceptible to biodegradation and their presence in water, sediment, and organisms is usually due to relatively recent petroleum spills and/or chronic exposure from non-point sources. Numerous studies have demonstrated that organic contaminants, such as PAHs, are probable etiologic agents (Tanabe 1989; Tanabe *et al.* 1989; Kannan *et al.* 1989; and Tillitt *et al.* 1992). Historically, hydrocarbon contaminant studies measured ambient concentrations in water, sediments, and tissues using highly sensitive analytical methods to quantify these chemicals. However, these mixtures are invariably complex, and it is difficult to identify and quantitate all components. Even if the concentrations of all components of these mixtures are obtained, the extrapolation of this data in terms of potential adverse effects is difficult. Thus, the use of biomarkers and bioassays for evaluating environmental contamination are potentially powerful alternatives to historical analytical (chemical) approaches.

The biomarkers utilized in this study include P450IA-dependent catalytic enzyme activities [ethoxyresorufin O-deethylase (EROD) and aryl hydrocarbon hydroxylase (AHH)], P450IA mRNA levels, *in vitro* cell bioassay responses (rat hepatoma H4IIE), and the production of biliary PAH metabolites. This report presents data from all four cruises conducted as part of the GOOMEX project at three platforms (MAI-686, MU-A85, and HI-A389).

Both fish and invertebrates were collected by trawling. All specimens were maintained alive until dissection. After dissection, fish livers were immediately frozen in liquid nitrogen until analysis. Invertebrate tissues were frozen at -20°C until extraction. Bile was frozen at -20°C until analysis.

Microsomes were prepared from fish livers by homogenization followed by differential centrifugation. EROD and AHH activities were determined fluorometrically from hepatic microsomal preparations. Total RNA was isolated from hepatic samples by subcellular fractionation and extraction. P450IA mRNA was determined by Northern Blot analysis using a cDNA probe for rainbow trout P450IA. Naphthalene, phenanthrene, and benzo[a]pyrene (BaP) equivalent metabolites were measured in bile by high performance liquid chromatography (HPLC) and fluorescence detection.

Invertebrate tissues were extracted with methylene chloride and purified by column chromatography and HPLC. The methylene chloride extracts were transferred into DMSO. Subsequently, rat hepatoma H4IIE cells were treated with aliquots of tissue extracts, and the induction of EROD activity was measured and used to determine 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) toxic equivalents (TEQs; Safe 1990).

Study results are based on those species of fish captured at both the near and far stations. Table 3A.1 lists the 14 species collected at both near and far stations for at least one platform.

Table 3A.1. Species of fish collected at both near and far stations for at least one platform.

Scientific Name	Common Name	Scientific Name	Common Name
Ancyclopsetta dilecta	3-eyed founder	*Caulolatilus intermedius*	tile fish
Centropristis philadelphica	rock sea bass	*Cynoscion arenarius*	sand sea trout
Cyclopsetta chittendeni	mexican flounder	*Lagodon rhomboides*	pin fish
Ogcocephalus declivirostris	bat fish	*Paralichthys lethostigma*	southern flounder
Pontinus longispinis	scorpion fish	*Pristipomoides aquilonaris*	wenchman
Syacium gunteri	shoal flounder	*Synodus foetens*	lizard fish
Trichopsetta ventralis	sash flounder	*Urophycis spp.*	hake

Five hundred and ninety fish were analyzed for the detoxification element of the GOOMEX project. Of these, biliary PAH metabolite concentrations were determined on 376 samples and EROD and AHH activities were determined for 543 and 268 fish livers, respectively. Additionally, approximately 150 P450IA mRNA analyses were completed on hepatic samples. Eighty-one AHH assays were conducted on invertebrate digestive tissues from Cruise 1. Although *in vitro* assay were conducted using samples collected on Cruise 1, the data was not used for final analyses because of analytical problems associated with small sample size. For subsequent cruises *in vitro* assays were conducted using extracts of 99 invertebrates to assess potential contaminant exposure.

The levels of biliary BaP equivalent metabolites were typically low and no significant differences in near/far station comparisons were observed. The presence of BaP metabolites indicates exposure to pyrogenic PAH and the low levels of BaP metabolites observed in this study are consistent with analytical data in which pyrogenic PAH levels were typically below method detection limits. The presence of naphthalene and phenanthrene equivalent metabolites in bile indicates exposure to low molecular weight PAHs. Although naphthalene and phenanthrene metabolites were detected no consistent significant near/far station comparisons were observed. However, species differences were observed in biliary PAH metabolite concentrations which indicates intrinsic species variations. However, nearly 40% of the biliary metabolite data were excluded from data analyses because chromatograms from these samples indicated that the data was compromised. Bile collected from fish captured at HI-A389 and MU-A85 were particularly prone to degradation presumably due to the length of trawl recovery and water depth related stresses.

AHH activity was only measured in fish hepatic samples collected on cruises I and II; whereas, EROD activity was measured in all hepatic fish samples. AHH activity was not measured in fish collected on subsequent cruises because generally a good correlation between the two assays had been established and the EROD assay was found to be more sensitive. However, a few species of fish (i.e., *Lagodon rhomboides* and *Synodus foetens)* did not exhibit a coordinated induction of bith AHH and EROD activities which suggests that these species may express an altered CYPIA protein compared to most other fish species. No significant cruise, platform, or near/far station differences in EROD and AHH activities were observed for any species of fish. However, significant species differences were detected. The highest mean EROD activity was measured in pin fish (145 pmol/min/mg). Elevated EROD activities were also measured in tile fish (51 pmol/min/mg), bat fish (28 pmol/min/mg), and shoal flounder (26 pmol/min/mg).

Extracts of invertebrate tissues collected on Cruises 2, 3, and 4 (Table 3A.2) were analyzed using an *in vitro* cell bioassay (i.e., rat hepatoma H4IIE cells) to determine their CYPIAI induction potency as measured by EROD activity and to derive TEQs.

Table 3A.2. Invertebrate species collected on Cruises 2, 3, and 4.

Scientific name	Common name
Trachypenaeus similis	shrimp
Squilla empusa	mantis shrimp
Penaeus aztecus	brown shrimp
Callinectes similis	crab
Amusium papyraceum	scallop
Solencera atlantidis	shrimp
Portunus spinicarpus	crab

The bioassay-derived TEQ values for brown shrimp captured at MAI-686 near were significantly higher than the TEQ values for brown shrimp collected at MAI-686 far. No other significant near/far station differences were noted; however, species differences were observed. The TEQs for scallops (1.36 ng/g) were significantly higher than those for any other species (<0.37 ng/g). This is consistent with the expected higher levels of contaminant bioaccumulation in bivalves.

In summary, the biomarker data showed few significant differences in near/far station comparisons and indicate that fish and invertebrates are only minimally exposed to PAHs, which is consistent with the chemical data.

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GOOMEX POREWATER TOXICITY TESTING

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As part of the multidisciplinary GOOMEX program to assess the impacts associated with offshore oil and gas exploration and production activities, a series of toxicity tests with sediment pore water was conducted. During the first cruise, five platforms were sampled using a radial array design with 25 stations per platform arranged on five radii. Three of the original five platforms were sampled during the second cruise using the same sampling design. A total of 200 stations, therefore, were sampled concurrently for sediment chemistry and toxicity during the first two cruises.The samples were kept refrigerated until they were delivered to the laboratory, and the pore water was extracted immediately using a pneumatic extraction device. The toxicity of the sediment pore waters was determined using two different tests with the sea urchin *Arbacia punctulata*; the fertilization test and the embryological development test. Both tests were performed on samples from the first cruise. Only the embryological development test was performed on samples from the second cruise, as this proved to be the more sensitive of the two assays for these samples.Significant toxicity was observed at four of the five platforms sampled during the first cruise. No toxicity was observed at Mustang Island-A85 and the six most toxic stations were observed at High Island-A389. Significant toxicity was observed at 14 stations overall with the sea urchin embryological development assay but at only three stations with the sea urchin fertilization test. The stations showing reduced fertilization also exhibited impaired development in the embryological development assay. All but three of the toxic stations were within 150 meters of a platform. Significant toxicity was observed in the vicinity of two of the three platforms in the second cruise. Three of the five stations closest to the platform were observed to be toxic at Matagorda Island-686. Three stations near the platform exhibited significant toxicity at High Island-A389 and corresponded with four of the six stations observed to be toxic from the first cruise. Significant toxicity was observed at eight stations overall with the sea urchin embryological development assay for the 75 samples from the second cruise. All of the toxic stations (except one station at Mustang Island-A85) were within ~75 meters of a platform. Highly significant statistical associations have been observed between porewater toxicity and the bulk sediment concentrations of several metals (e.g., zinc, lead, mercury and silver) at the High Island site. MacDonald (1993) determined a "probable effects level" (PEL) for zinc in whole sediments to be 300 mg/Kg. All of the toxic High Island stations were near or exceeded this concentration. The PELs for lead (160 mg/Kg), cadmium (7.5 mg/Kg), mercury (1 mg/Kg), and silver (2.5 mg/Kg) were also exceeded at some stations. However, since the PEL of zinc is far exceeded at all of the sites where the PEL of other elements are exceeded, it is possible that the toxicity of the High Island sediments is largely controlled by zinc alone or in combination with other metals.In order to assess the relative sensitivity of the sea urchin assays as compared with meiobenthic organisms, the response of two meiobenthic invertebrates to selected pore waters from High Island A-389 was also evaluated. One species, *Dinophilus gyrociliatus,* a small polychaete, has been previously used in toxicity testing. The techniques for culture and testing with this organism are well established. The other species, *Longipedia americana*, a benthic harpacticoid copepod, has notbeen cultured previously or used in toxicity testing. There was excellent agreement among the results of three tests (i.e., copepod vs. polychaete vs. sea urchin development). All stations which were toxic in the meiobenthic animal tests were also toxic in the sea urchin embryological development test.The sea urchin embryological development test appears to be similar in sensitivity, or slightly more sensitive, than the two meiobenthic tests and is considerably more reliable, cost efficient, and simpler to conduct. There was a high degree of agreement between the two meiobenthic tests and the sea urchin embryological development test. For these reasons we would recommend that the urchin assay be used as a surrogate for assessment of the potential impacts of contaminated pore water on meiobenthic invertebrates from the Gulf of Mexico.

HISTOPATHOLOGY OF DEMERSAL FISHES AT GOOMEX STUDY SITES

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While gross fish pathology is a potential response indicator of environmental status that is easy and economical to measure, it will not allow the identification of important contaminant-associated pathological abnormalities. Histopathological examination of select tissues is widely recognized as a reliable method for assessing the adverse effects of exposure to anthropogenic contaminants in marine fishes. For example, certain pathological conditions in the liver of wild fishes morphologically resemble lesions induced in fishes by experimental exposure to a variety of toxicants, including carcinogens. Furthermore, some of these lesions have also been shown to be positively associated with exposure to xenobiotic chemical contaminants in field studies.

Macrophage aggregates (MAs), particularly those in the spleen, also appear to be a good histopathological indicator of contaminant exposure. MAs are focal accumulations of macrophages found in the spleen, liver and kidney of fishes and they contain the pigments hemosiderin, ceroid/lipofuscin, and melanin (Wolke 1992). Occurrence of MAs may vary depending on the size, nutritional status, or health of a particular fish species (Agius 1980; Wolke *et al.* 1985). In addition, the number and size of MAs increase with age in some species (Brown and George 1985; Blazer *et al.* 1987). Suggested functions for these aggregates include the centralization of foreign material and cellular debris for destruction, detoxification or reuse.

Changes in splenic MA parameters (e.g., number, size) in relation to environmental contamination have been noted by several investigators (Kranz and Peters 1984; Wolke *et al.* 1985; Spazier *et al.* 1992). Hence, it has been suggested that these structures may be sensitive but non-specific indicators of stress. Preliminary studies from the Environmental Monitoring and Assessment Program in the Gulf of Mexico demonstrated an increase in splenic MA number and percent of tissue replaced in most species from contaminated sites. Some species were good indicators of elevated tissue contaminants while others were good indicators of sediment contaminants (Blazer *et al.* 1993).

Samples of liver and spleen were taken from all specimens and processed for histopathological analysis. Tissue samples were processed for routine paraffin histology. Sections were cut at 6 µm, stained with Harris' hematoxylin and eosin and examined microscopically by experienced fish pathologists.

Splenic MA analysis was performed on tissue sections of spleen prepared for histological evaluation as described above. Data are generated using a true color (HSI imaging) Particle Analysis package (Microcomp® Image Analysis System with Sony 3CCD color video camera input). (Mention of commercial tradenames does not imply endorsement by the U.S. Environmental Protection Agency.) The system is calibrated and data collected at 10x magnification. Three fields of view (screens) are randomly selected and analyzed from each spleen sample. Analysis is performed on images generated by computer produced masks of the MAs in each screen with the number of MAs per screen and the area in μm^2 of each MA recorded and stored. A size discriminator is used to eliminate objects $< 50\ \mu m^2$ (~size of 3 aggregated macrophages). Total screen area counted is also determined for calculation of percent area occupied by MAs.

Histopathological evaluations were performed on liver and spleen samples taken from 543 fish specimens examined from GOOMEX Phase 1 collections. This reflected 189, 126, 122 and 106 fishes from cruise 1, 2, 3 and 4, respectively. Species collected for histopathological examination were *Syacium gunteri* (site MAI-686 all cruises), *Trichopsetta ventralis* (site HI-A389 cruises 2-4 and site MU-A85 all cruises) and *Pontinus longispinis* (site HI-A389 cruise 1).

No contaminant related liver lesions (e.g., hydropic vacuolation, hepatic megalocytosis, hepatocellular neoplasms) were observed in any of the tissues examined. However, a number of other pathological findings were noted (Table 3A.3). Parasitic infections were the most common abnormalities, with microsporidians being the most prevalent. Two other prevalent lesions included inflammatory foci and granulomatous inflammation. These lesions were usually associated with parasitic infections (e.g., nematodes) and were not related to the study sites.

Splenic MA analysis was performed on 416 flatfishes collected from sites MAI-686, HI-A389 and MU-A85 during Phase 1 sampling. The number of MAs per mm^2 and percent area occupied by MAs for each site/station and cruise are summarized in Figure 3A.1. Analysis of the data indicates four main points: (1) fish from site MAI-686 had a statistically greater number of MAs per mm^2 during all cruises except the third cruise, (2) MAs from fish at site MAI-686 were generally smaller than those from the other two sites (3) when analyzed by near/far station grouping, no significant difference was noted among samples, and (4) the MA size and percent area occupied by MAs at site HI-A389 were significantly greater than the MAs at either site MAI-686 or MU-A85.

Table 3A.3. Pathological abnormalities in liver and spleen.

				% Prevalence for Cruise			
Site	Station	Species	Lesion	1	2	3	4
MAI-686	N	*Syacium gunteri*	Granulomas	5.0	0.0	0.0	0.0
			Inflammatory foci	35.0	0.0	0.0	0.0
			Microsporidians	35.0	64.7	21.1	40.0
			Nematodes	5.0	17.6	10.5	6.7
			Sporozoan (?)	10.0	0.0	5.3	6.7
	F	*Syacium gunteri*	Granulomas	0.0	0.0	10.5	0.0
			Inflammatory foci	15.0	0.0	10.5	0.0
			Microsporidians	0.0	54.2	52.6	25.0
			Nematodes	0.0	4.2	5.3	10.0
			Sporozoan (?)	0.0	12.5	10.5	10.0
HI-A389	N	*Trichopsetta ventralis*	Granulomas	—	15.0	25.0	10.0
			Inflammatory foci	—	10.0	15.0	40.0
			Microsporidians	—	10.0	0.0	0.0
			Nematodes	—	0.0	5.0	5.0
			Sporozoan (?)	—	0.0	10.0	0.0
	F	*Trichopsetta ventralis*	Granulomas	—	5.0	27.3	10.0
			Inflammatory foci	—	5.0	18.2	0.0
			Microsporidians	—	25.0	13.6	0.0
			Nematodes	—	15.0	9.1	5.0
MU-A85	N	*Trichopsetta ventralis*	Granulomas	30.0	31.8	30.0	10.0
			Inflammatory foci	0.0	13.6	5.0	20.0
			Microsporidians	20.0	27.3	60.0	0.0
			Nematodes	25.0	5.5	10.0	0.0
			Sporozoan (?)	10.5	10.0	20.0	0.0
	F	*Trichopsetta ventralis*	Granulomas	31.6	21.7	34.8	38.1
			Inflammatory foci	47.4	34.8	26.1	19.0
			Microsporidians	10.5	26.1	26.1	19.0
			Nematodes	5.3	8.7	4.3	0.0
			Sporozoan (?)	0.0	4.3	13.0	0.0

N = near station; F = far station

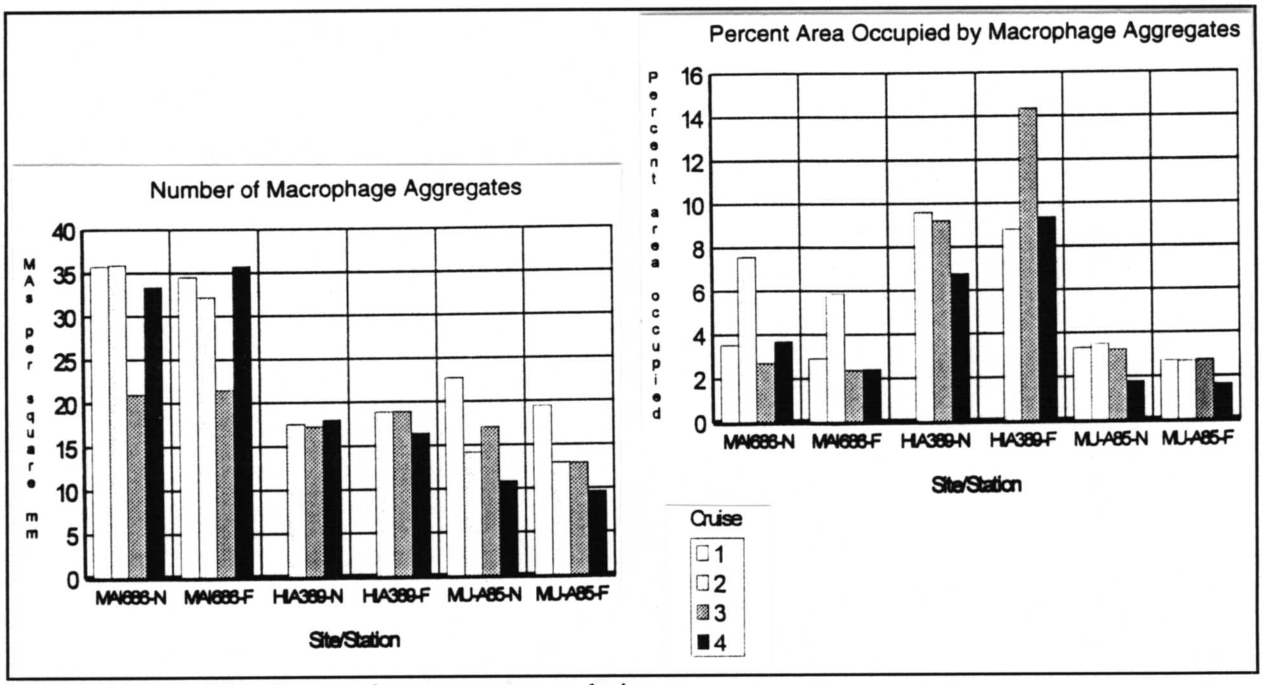

Figure 3A.1. Splenic macrophage aggregate analysis.

Histopathological evaluation of tissues sampled from GOOMEX study site fishes revealed no lesions attributable to contaminant exposure. Parasitic infections, predominantly microsporidians and nematodes, were commonly found in fishes at all sites/stations. All pathological findings from these fishes (i.e., granulomas and inflammatory foci) were associated with parasitic infections.

The reason fish from MAI-686 had a greater number of MAs per mm^2 during three of the four cruises and that MAs in those fish were generally smaller was probably due to species differences. *Syacium gunteri* was the only species collected at site MAI-686, whereas *T. ventralis* was the only species collected at the other 2 sites. Since no other data on MAs from *S. gunteri* are available for comparison, no difference between near and far sites at site MAI-686 was seen, and no apparent correlations were noted with contaminant data and the MA parameters at site MAI-686, little can be said regarding these findings. The lack of near/far differences may be related to the relative proximity of these sites. The far site is only 3,000 meters from the platform (near site), while this may be sufficient separation when looking at sediment contaminants, it may be likely that the fish sampled range over an area greater than the site separation and are actually members of the same population.

Point four above should be viewed as two separate observations, a statistical difference in MA size and percent area occupied by MAs between sites HI-A389 and MAI-686 and between sites HI-A389 and MU-A85. Examination of the data then indicates that the HI-A389 and MAI-686 site differences reflect the cross-species comparison discussed earlier and therefore cannot be compared. The differences between the samplings at sites HI-A389 and MU-A85 however, are statistically significant site differences within a single species (*T. ventralis*). These differences were also consistent in observations from three cruises (no comparisons were possible between these two sites during cruise 1 because no flatfish were collected from HI-A389). The observations did not correlate with organics or metals sediment contaminant data and therefore, did not indicate any obvious contaminant effects relative to the GOOMEX study sites and are presently unexplained.

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MEIOFAUNA GENETIC VARIABILITY

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One possible sublethal response to contaminant exposure is a loss of population genetic variability. Such a loss might occur if certain phenotypes were selected against during the onset of the contamination. If some phenotypes were selected against, there would be a tendency for the entire population to shift towards a more adaptive phenotype under the new selection regime imposed by the contaminants. This situation is described as a "bottleneck" where selection creates a narrow space through which only certain genotypes may pass (Barton and Charlesworth 1984). In order to assess whether such a bottleneck occurred at the stations in the program, the population genetic variability in harpacticoid copepods was compared "near" a platform (at ring two, approximately 30-50 m from the platform) to populations of the same species "far" from a platform (at ring five, ≥3 km from the platform). The hypothesis that there are stronger selective pressures at near field stations than at far field stations due to the identified contamination gradients around each platform. If these pressures exist, they should cause near-field populations to show a loss of genetic variability relative to far-field populations, which are under less rigorous stress.

Five species of harpacticoid copepods were chosen for this study. Harpacticoids are ideal organisms for a genetic study. They are ubiquitous in marine systems, and therefore easy to sample. They have short generation times, which suggests a rapid response to changing conditions (Hicks and Coull 1983). They also have low dispersal capabilities due in part to small size, the characteristic of brooding their eggs, and possessing larvae with direct benthic development (Hicks and Coull 1983). Furthermore, harpacticoid abundance, diversity, life history and toxicology are all being studied for Phase I of the GOOMEX project. The five species chosen were selected because they were abundant at all platforms and because they were easy to identify. The latter prevents confounding population effects with differences between cryptic species. The species included *Normanella* sp.15, *Enhydrosoma pericoense*, *Cletodes* sp.17, *Robertsonia* sp.1 and *Tachidiella* sp. 86. Of these, only *E. pericoense* has been previously described, and therefore assigned a species name.

The basic procedure involved extracting the DNA from individual copepods, amplifying the 16S rRNA region of the mitochondrial (mtDNA) by the polymerase chain reaction (PCR; Bucklin *et al.* 1992), comparing restriction fragment length polymorphisms (RFLPs), and calculating an index for haplotype diversity. Mitochondrial DNA was used because it evolves at a rapid rate, has been well characterized by decades of research on population genetics, and is directly maternally inherited, thereby prohibiting any confounding effects of recombination events (Avise *et al.* 1987). PCR was necessary in order to generate enough DNA from single copepods for analysis using RFLPs. Four restriction enzymes were used for the RFLPs, Rsa I, Hae III, Msp I, and Taq I. After the restriction fragments were run on electrophoresis gels, an index of genetic variability was calculated from each station:

$$h = 1 - \sum x_i^2$$

where h = haplotype diversity, x_i = the frequency of the ith haplotype, and i = the number of haplotypes (Avise 1994). A haplotype is a particular configuration of restriction fragments.

A MANOVA was performed on h for each species, using distance (near vs. far), platform (HI-A389, MAI-686 and MU-A85), and cruise (two vs. three) as covariates. There were no differences between any platforms or cruises. However, three of the species had mean h values which were significantly less near a platform than they were far ($p = 0.0001$ for *Normanella*, $p = 0.025$ for *Enhydrosoma*, and $p = 0.014$ for *Cletodes*). While the other two species (*Robertsonia* and *Tachidiella*) showed the same general trends, they were not significantly different from near to far. This is thought to be a function of the sample size, which was greater than 300 individuals for the three species which showed significance, and less than 300 for the two species which were not significant ($n = 206$ and 103 for *Robertsonia* and *Tachidiella*, respectively). The fact that there were no differences in h values at the far station for any species or platform suggests that it is the platforms themselves which are having an effect and not merely local geographic variation

This supposition was supported by using a logistic, linear regression to attempt to explain variance in genetic variability based on platform effects. In nearly all cases, a population was dominated by a single, nearly ubiquitous haplotype, and a series of unique haplotypes. Therefore, the dependent side of the logistic model took the form of number of individuals not conforming to the dominant haplotype, divided by the total number of individuals measured equal to the three. This value was set equal to the results of a principal components analysis performed on all the physical and chemical variables measured for the GOOMEX program. The first three principal components account for 57.8% of variability in the data set.

PC1 accounted for a significant amount of variation, and therefore was included in the model for *Normanella* ($p = 0.006$), while PC2 was significant in the regression models for both *Cletodes* ($p = 0.009$) and *Enhydrosoma* ($p = 0.0002$). There was no linear relationship between any factors and the species *Robertsonia* and *Tachidiella* since sample size was lower than the 300 individuals per species needed to see near vs. far differences. One possible explanation why genetic variability in *Cletodes* and *Enhydrosoma* showed a linear relationship to PC2, has to do with the lifestyles of these two species. Both are members of the family Cletotidae, and are long and vermicular in shape. These are burrowing, infaunal harpacticoids that would be expected to be sensitive to such factors as grain size (Hicks and Coull 1983). Grain size has a heavy loading value for PC2. *Normanella* is a larger, epifaunal harpacticoid, that might be expected to show less of a response to sediment characteristics.

In conclusion, comparison of population haplotype diversity suggests that offshore oil and gas production can cause a sublethal response in populations of harpacticoid copepods. In at least some species, there is linear relationship between variability and concentrations of potentially toxic contaminants (heavily loaded for PC1). For this reason, measuring population genetic variability does seem to be a useful management tool. However, it is unlikely that significant results will be found unless a sample size of at least 300 individuals is used per treatment.

Estimating genetic variability has several advantages over more traditional means of sampling populations, such as comparisons of estimates of abundance, diversity and life history characteristics. Measuring genetic variability does not require as much skill in taxonomy, so long as target species can successfully be delineated. Furthermore, because comparing RFLPs is a measure of genotypic variation, it is superior to measurements of phenotypic variation, which can be confounded with a number of other factors. Finally, because molecular biological techniques are currently being refined, improved and automated, the technology will become increasingly rapid, less expensive, and user-friendly.

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STATUS OF MACROINVERTEBRATE REPRODUCTION AND HISTOPATHOLOGY AT GOOMEX SITES

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One component of the Gulf of Mexico Offshore Operations Monitoring Experiment (GOOMEX) project involves the assessment of macroinvertebrate reproduction. Very little is known about the reproductive effort of most continental shelf invertebrates. Accordingly, whether reproductive effort is affected in these species by oil and gas field development is also largely unknown. We have utilized several different methods to assess differences in the reproductive effort of invertebrate species living near by and far from oil and gas producing rigs. Differences in male-to-female ratios, percent gravid females (in crabs), and stage of reproductive development determined visually, histologically and by immunological probe were used as indicators of possible sublethal effects of exposure to chemical contaminants or other oil and gas field-associated factors on reproductive effort. The relationship between health (as described by the prevalence and intensity of parasitism and pathologies) and reproductive stage was also examined.

Animals were collected by trawling from locations close to (near-field) and far from (far-field) the platforms, to assess the effect of oil and gas field development on macroinvertebrate reproduction. Animals used were the shrimp *Trachypenaeus similis, Penaeus aztecus,* and *Solonocera atlantidis*, the crabs *Callinectes similis, Portunus gibbesii,* and *Portunus spinicarpus*, the starfish *Astropecten duplicatus,* and *Astropecten cingulatus*, the stomatopods *Squilla empusa, Squilla chydaea,* and *Squilla edentata*, and the scallop *Amusium papyraceum*. After collection, individuals of target species were measured. Reproductive development for most species was evaluated by two methods; visual inspection and histological analysis. In crabs, an immunological probe was also used. Visual inspection provides immediate results and a large n, but stage identification is less precise and fewer stages can be discriminated. Histological examination provides more detail and a relationship with parasitism and pathology, but quantification is still difficult and only a few individuals can be assayed. The immunological probe provides quantification and a higher n and can also be used on samples homogenized for chemical analyses, but histopathology cannot be assessed. Hence, all three approaches provide useful, and different, views of reproductive status.

Immediately after collection, individuals were sexed, and a visual determination of the reproductive stage of females was made based on the development and color of the ovary. Whole specimens were preserved and returned to the laboratory for complete histological analyses. Tissue sections were analyzed for sex, stage of reproductive development, and presence and intensity of parasites and pathologies. The reproductive cycle of most of the species involved in this study has not heretofore been studied; therefore a semi-quantitative reproductive scale was developed for each species based on the appearance of the gonads and the quantity of gametes present for both methods. The immunological probe was developed using eggs obtained from egg masses. A New Zealand white rabbit was selected as a host animal for antibody production. Mancini's radial immunodiffusion method was used for the quantification of egg or sperm protein (the more sensitive ELISA assay is not normally needed). A gonadal-somatic index was calculated as the ratio of the total dry weight of gametic tissue to total biomass. Comparison of gonadal weight in animals ready to spawn, measured by the probe, to the weight of egg masses in gravid females yielded equivalent results, indicating that the probe satisfactorily measured total egg concentration in gonadal tissue.

At both the near and far-field sites individuals collected were overwhelmingly female, with male:female ratios as high as 17:1 (*Trachypenaeus similis*, MAI-686, far). That the majority of individuals collected were female may result from the fact that females are larger for many of the species (particularly shrimp species) and may be retained more easily by the net. Percent gravid females was determined for each species of crab collected at both the near and far-field stations. A gravid crab was a female collected 'in sponge'; that is, with a visible egg sac. If differences existed in the percent gravid females between the near and far-field station, more gravid females were typically collected at the far-field station; however, no significant trends were observed.

Stage of reproductive development was determined through visual inspection for all females of shrimp and crab species. Reproductive development may be delayed by exposure to contaminants and may be related to the size (age) of the individual. Few relationships between distance from the platform and size or stage of reproductive development were found. However, in three of the four significant cases, females were more reproductively advanced in the far-field. Three species of shrimp showed a relationship between location and stage of reproductive development. *Solonocera atlantidis* and

Parapenaeus similis at HI-A389 both had higher stages of reproductive development at the far-field station, where the larger females were collected. *Solonocera atlantidis* also had a higher stage of reproductive development at the near-field station even though the larger individuals were collected at the far-field station at MU-A85 and *Trachypenaeus similis* had a higher stage reproductive development at the far-field station at MAI-686 even though the larger individuals were collected at the near-field station. These results suggest that the largest individuals are not always the farthest along in reproductive development.

Stage of reproductive development was determined through histological examination for both males and females of target species. If differences in reproductive development existed between the near and far-field stations, those individuals collected from the far-field station were typically farther along in their reproductive development. This was true in four of the five cases showing significant results.

No significant trends were observed when reproductive status was quantified by weighing egg masses or by immunological probe not explained by size differences. Wherever size structure was significantly altered, a significant effect in fecundity could be expected by this result alone, however. Preliminary results also indicate significant differences in egg quality. Protein and percent water analysis conducted on the egg sacs of gravid crabs show differences related to the proximity to the platform at MAI-686. Differences in egg quality may indicate differences in egg viability at this site. Results are not yet available for MU-A85 AND HI-A389.

Evidence for an impact of proximity to the rig on reproductive development is not as strong as trends noted in population size structure. Environmental stresses such as exposure to contaminants can affect reproductive activity by delaying reproductive development or by decreasing the quantity of gametes produced. In some cases the far-field station had a higher proportion of gravid female crabs than the near-field. Histological analysis follows the trend in gravid females, with more reproductively advanced individuals found far from the platforms. For these stations, it is possible that exposure to contaminants has slowed reproductive development in those organisms near the platform, so that the population at the far-field station was more advanced. Alternatively, near-field individuals may have spawned earlier. Differences in egg quality are not as ambiguous to interpret. Egg quality may be affected by proximity to the platform. At MAI-686, crab eggs had different proportions of water and protein at the near and far-field stations. Therefore, differences in both reproductive effort and quality of spawn produced may be affected by the chemical or physical characteristics at the platforms sites.

Sampling frequency may be inadequate to differentiate these two possibilities. The stress of parasitism and diseases also affects reproductive development in many species of invertebrates by slowing reproduction or decreasing the quantity of spawn produced. At MU-A85, levels of parasitism and disease were related to stage of reproductive development. At this platform, the stage of reproductive development was significantly higher in the far-field station for starfish, scallops and all shrimp species; and parasitism was higher in near-field individuals. These results suggest that reproductive development was higher in individuals with less intensity of parasitism at this site. The individuals at the far-field station were all significantly larger suggesting that they were also older than those collected at the near-field station, but size did not explain either the trend in reproduction or parasitism/pathology. MU-A85 has a chemical contamination and TOC gradient such that contaminants are higher and TOC lower near the platform. Either gradient could affect reproductive stage, but it is unlikely that lower TOC would impact the intensity of parasitism/pathology. No such trend was observed at MAI-686 where a TOC gradient exists, but where a contaminant gradient was not observed, lending support to the possible role of the contamination gradient in explaining the trends at MU-A85. Insufficient data are available to test this hypothesis at HI-A389 where a contaminant gradient also exists.

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A toxicological assessment of demersal fish and invertebrate exposure to contaminants associated with offshore oil and gas production was pursued as an objective of the GOOMEX project. Assays developed to serve as biomarkers for detecting the presence of polynuclear aromatic hydrocarbons (PAHs) were measured at the GOOMEX study sites. A multi-pronged approach to assessing exposure was taken. High molecular PAH (four or more rings) can act as aryl hydrocarbon (Ah) receptor agonists much like2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) and related halogenated aromatic hydrocarbons (Safe, 1990). PAHs bind to the intracellular Ah receptor and form a ligand-induced nuclear transcription factor which binds to specific regions of the genomic DNA thereby initiating transcription. Induction of the CYP1A gene is one of the most sensitive indicators of exposure to PAHs and is characterized by increased P4501A mRNA levels and P4501A dependent catalytic enzyme activities. Biomarkers related to the CYP1A induction response utilized in the GOOMEX study include: P4501A-dependent enzyme activities [ethoxyresorufin-O-deethylase (EROD) and aryl hydrocarbon hydroxylase (AHH)], P4501A mRNA levels, and the nuclear Ah receptor complex. Benzo[a]pyrene and ethoxyresorufin are used as substrates in the AHH and EROD enzyme assays, respectively. They are generally accepted as equivalent substrates for P4501A in most organisms. A good correlation (r^2=0.64) was observed in EROD and AHH activities for most fish species sampled for the GOOMEX project. However, pin fish, *Lagodon rhomboides*, and lizard fish, *Synodus foetens*, exhibited high EROD:AHH (5 and 17, respectively). The lack of microsomal enzyme activities could be due to the expression of CYP1A (P4501A) gene products which exhibit different catalytic activities or the induction of multiple forms of CYP1A. To investigate these differences other parameters associated with the induction response including identification of the nuclear Ah receptor complex and CYP1A mRNA levels were determined in these fish.

The Ah receptor is a soluble protein for which the endogenous ligand and normal physiologic function are unknown. The Ah receptor has been previously identified in the cytosolic fraction of two fish hepatoma cell lines (RTH-149 and PLHC-1). The photoaffinity labeled Ah receptor was also identified in the hepatic cytosol of seven species of teleost and elasmobranch fish including scup, winter flounder, killifish, rainbow and brown trout, and dogfish (Hahn and Stegeman 1992). To date there is no reported evidence for the nuclear Ah receptor necessary for transcriptional activation in fish. In order to characterize the receptor in pin fish and lizard fish, ten individuals of each species were treated with 2.5 μg/kg [^{3}H]TCDD, a compound known to have the high affinity for the Ah receptor. Ten fish were also dosed with [^{3}H]TCDD in the presence of a 100-fold excess of unlabeled TCDD to determine the specificity of ligand binding. After four hours, the fish were sacrificed, their livers removed, homogenized, and the nuclear extract was isolated. Samples were layered onto sucrose density gradients and centrifuged. Thirty fractions were collected from each gradient and the radioactivity was determined by liquid scintillation counting. [^{14}C] labeled bovine serum albumin (4.4S) and catalase (11.3S) were used as external standards. The Ah receptor profiles for both pin fish and lizard fish showed a specifically bound Ah receptor complex which sedimented at 5.4S. Similar Ah receptor profiles were found in laboratory experiments using the killifish *Fundulus grandis*. Although cartilaginous fish diverged evolutionarily 450-550 million years ago (Carroll 1988), the sedimentation characteristics of the nuclear Ah receptor in these fish were similar to the mammalian Ah receptor from several different species including humans.

Quantitation of P4501A mRNA levels was also utilized to characterize Ah receptor-mediated responses in fish. Total RNA was isolated from homogenized liver samples by subcellular fractionation and extraction by a modification of the method of Chomczynski and Sacchi (1987). P4501A mRNA levels were determined by Northern Blot analysis using a cDNA probe developed in rainbow trout (courtesy of Dr. John Lech). CYP1A levels were standardized relative to B-tubulin mRNA. CYP1A mRNA were identified in GOOMEX fish and the gel electrophoretic transcripts were similar for the different species. No significant differences were observed for species (i.e. lizard fish and hake) that were sampled at near and far stations. Because no significant near/far station differences were observed, the CYP1A levels in fish are believed to be constitutive or background responses. A dose response induction of CYP1A mRNA was observed in laboratory studies in which killifish were dosed with increasing concentrations of BaP.

In contrast to data from teleost and elasmobranch fish, no cytosolic or nuclear Ah receptor has been identified in agnathan fish or marine invertebrates (Hahn and Stegeman 1992). This is consistent with the findings that there was low to non-detectable AHH activities in invertebrates. In order to assess the CYP1A induction potency of PAHs which may accumulate in invertebrates, extracts of invertebrate tissues were obtained and bioassayed in cultured rat hepatoma H4IIE cells. This cell line is highly P4501A responsive. Using this technique, PAH induction equivalents (TEQs) can be derived in relation to TCDD, a toxic reference standard. Extracts from GOOMEX invertebrates yielded very low TEQs. Significantly higher TEQs were calculated for scallops compared to the other GOOMEX invertebrates.

The results of these studies indicate that the exposure of marine fish and invertebrate species to PAHs at selected offshore oil and gas production platforms is low. This was evidenced by the low TEQs observed for invertebrate extracts in *in vitro* assay and the low P4501A dependent activities in fish sampled at near and far stations at each GOOMEX platform.

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Dr. S. H. Safe joined the faculty of Texas A&M University in 1981 and is a Distinguished Professor in the Department of Veterinary Physiology and Pharmacology. His areas of research interest include environmental and biochemical toxicology. Dr. Safe received a B.S. and M.S. in Chemistry from Queens College, Canada and his Ph.D. in Bioorganic Chemistry from Oxford University, United Kingdom.

Dr. S. J. McDonald has worked at the Geochemical and Environmental Research Group for 9 years. She is an Assistant Research Scientist and is involved with several research projects. Her areas of research interest include biomarkers of organic xenobiotic exposure in marine fauna. Dr. McDonald received her B.S. and M.S. in Biology from Old Dominion University and her Ph.D. in Oceanography from Texas A&M University.

Ms. K. Willett is a second year graduate student in the Toxicology Program at Texas A&M University. Her area of research interest are environmental toxicology. Ms. Willett received her B.A. in Chemistry from the University of North Carolina.

Ms. K. Beatty is a Research Assistant at the Geochemical and Environmental Research Group. Ms. Beatty's research interest include fisheries biology and environmental toxicology. She received her B.S. in Biology from Southwest Oklahoma State University and her M.Ag. in Fisheries Sciences from Texas A&M University.

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Dr. Mahlon C. Kennicutt II, Senior Research Scientist, is Chief Chemist of the Geochemical and Environmental Research Group with the College of Geosciences and Maritime Studies at Texas A&M University. Dr. Kennicutt has expertise and research interests in marine chemistry, environmental chemistry, and organic geochemistry. He received a B.S. in chemistry in 1974 from Union College and a Ph.D. in oceanography from Texas A&M University in 1980. Dr. Kennicutt has published over 100 peer-reviewed papers, numerous book chapters, and has made scientific presentations world-wide.

SESSION 3C

COASTAL MARINE INSTITUTE PROGRESS REPORTS, PART II

Session: 3C - Coastal Marine Institute Progress Reports, Part II

Co-Chairs: Dr. James J. Kendall and Dr. Robert S. Carney

Date: November 16, 1994

Presentation	Author/Affiliation
Introduction	Dr. James J. Kendall U.S. Minerals Management Service Gulf of Mexico OCS Region Dr. Robert S. Carney Director, Coastal Marine Institute Louisiana State University
Development of Bioremediation for Oil Spill Cleanup in Coastal Wetlands	Dr. I. Mendelssohn[1] N. Atilla[1] Ms. K. Debusschere[3] Mr. C. Henry[1] Dr. Q. Lin[1] Dr. E. Overton[1] Mr. R. Portier[1] Dr. N. Rabalais[2] Ms. P. Roberts[1] Ms. M. Walsh[1] [1]Louisiana State University [2]Louisiana Universities Marine Consortium, Cocodrie [3]Coastal Environments, Inc., Baton Rouge
Coastal Marine Environmental Modeling	Dr. Masamichi Inoue Coastal Studies Institute Dr. William J. Wiseman, Jr. Department of Oceanography & Coastal Studies Louisiana State University
Socioeconomic Baseline Study for the Gulf of Mexico, Phase I	Dr. Joachim Singlemann Dr. Forrest A. Desearan Dr. Charles M. Tolbert Dr. Natsumi Aratame Department of Sociology and Rural Sociology Louisiana State University
Are Coastal Fauna Chronically Exposed to Petroleum Hydrocarbons and Hypoxia Better Adapted to These Factors?	Dr. William B. Stickle, Jr. Dr. Tapash Das Department of Zoology and Physiology Louisiana State University

Seasonal and Spatial Variation in Density and Size Distribution of Fishes Associated with a Petroleum Platform in the Northern Gulf of Mexico	Dr. David R. Stanley Dr. Charles A. Wilson Coastal Fisheries Institute Center for Coastal, Energy and Environmental Resources Louisiana State University
Characterization of Sea Anemones as Bioindicators of Offshore Resource Exploitation	Dr. Gary W. Winston Ms. Linda Heffernan Mr. Robin Ertl Department of Biochemistry Louisiana State University Dr. William B. Stickle, Jr. Department of Zoology and Physiology Louisiana State University

INTRODUCTION

Dr. James J. Kendall
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Dr. Robert S. Carney
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This is a continuation of Session 2C, CMI Progress Reports, Part I. As noted previously, the CMI, a cooperative agreement between the MMS and the State of Louisiana, was established to address the parallel OCS information needs of both parties in a timely, cost effective manner, while taking full advantage of the academic talents in the immediate OCS planning area.

Under the terms of this agreement, the MMS and the State of Louisiana provide matching funds to conduct environmental research of joint interest. The state, through Louisiana State University (LSU), provides matching funds of at lest one dollar for each dollar provided by the MMS (up to $10 million over a five-year period). All funds obligated are used to support studies that fall within a general framework.

The CMI framework, which provides broad boundaries for guidance in the development of specific research projects, was designed to include the following: technologies for extracting and transporting non-energy resources; environmental responses to changing energy extraction and transport technologies and spills; analyses and synthesis of existing data/information from previous studies; modeling of environmental, social, and economic processes and systems; new information about the structure/ function of affected systems via application of descriptive and experimental means; and projects that improve the application and distribution of multisource information.

Projects proposed for support under the CMI are reviewed by the CMI Technical Steering Committee, on which MMS and LSU are equally represented. The daily activities of the program are administered from LSU's Baton Rouge campus by the CMI Director, Dr. Robert Carney. Dr. James J. Kendall, Chief of the Environmental Studies Program for the MMS Gulf of Mexico Region, provides the MMS an additional means of meeting its own information needs, as well as those of one of its most important regional customers.

The session includes topics ranging from the development of bioremediation techniques for oil spill cleanup to physical oceanography.

Dr. James J. Kendall is the Chief of the Environmental Studies Section, MMS, Gulf of Mexico Regional Office. His research interests include the effects of contaminants on the physiology of corals, the behavior of reef animals, and procedures for aquatic toxicity testing. Dr. Kendall has conducted research and monitoring programs in the Gulf of Mexico, Galveston Bay, the Florida Keys, and the Gulf of Eilat, Red Sea. He received his B.S. in biology from Old Dominion University and his Ph.D. in oceanography from Texas A&M University.

Dr. Robert Carney, an associate professor in LSU's Department of Oceanography and Coastal Studies, has served as director of LSU's Coastal Ecology Institute since 1986 and has been director of the LSU-MMS CMI program since its inception. He received his M.S. from Texas A&M University and his Ph.D. from Oregon State University. Prior to LSU, Dr. Carney was employed at Moss Landing Marine Labs, the National Science Foundation, and the Smithsonian Institution.

DEVELOPMENT OF BIOREMEDIATION FOR OIL SPILL CLEANUP IN COASTAL WETLANDS

Dr. I. Mendelssohn[1], N. Atilla[1], Ms. K. Debusschere[3], Mr. C. Henry[1], Dr. Q. Lin[1]
Dr. E. Overton[1], Mr. R. Portier[1], Dr. N. Rabalais[2], Ms. P. Roberts[1], Ms. M. Walsh[1]

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Bioremediation, the act of adding materials to contaminated environments to cause an acceleration of natural biodegradation processes, is a promising means by which oil released into salts marshes can be removed with little impact to the habitat. However, neither the ecological effect nor the efficacy of introducing oil-degrading bacteria or fertilizers into the salt marsh has been determined. The objectives of the first year of our multi-disciplinary study are (1) to determine the ecological effects of the microbial and fertilizer products on wetland plant, infaunal and microbial communities and (2) to determine whether these bioremediation agents enhance oil biodegradation in intact salt marsh mesocosms. The experiment designed to meet the first objective has been completed; the experiment examining the second question is nearing completion.

Sods of marsh soil and vegetation approximately 30 cm in diameter and 25 cm deep were collected from a salt marsh in south Louisiana and used in a greenhouse mesocosm study. Half of the mesocosms received a dose of oil typical of an offshore spill that has moved ashore. Five oiled and five unoiled mesocosms were sprayed with a commercial bacterial inoculum; another set of five each received the manufacturer's recommended dose of slow-release fertilizer designed to stimulate natural oil biodegradation; a third set of each was left without treatment to serve as controls.

The effect of various treatments on the plants was monitored during the course of the three-month experiment using three variables: leaf elongation, photosynthesis, and aboveground biomass. Soil response was determined by measuring respiration, Eh, pH, salinity, micronutrient and macronutrients. The effect of the biromediation treatments on meiofauna was monitored by enumeration of nematodes, copepods, copepod nauplii and oligochaetes at day 0, 1 week, 2 weeks, 4 weeks and 12 weeks. General microbial biomass and several key microbial components, including yeast, filamentous fungi, chitin-utilizing bacteria, actinomycetes, chitin-degrading bacteria, and petroleum-utilizing microbes, were also tracked by sampling at day 3, 2 weeks, 4 weeks and 12 weeks.

Results from plant and soil response monitoring indicate that fertilization significantly increased plant growth and soil respiration, that oil had no significant effect on plant growth and significantly increased soil respiration, and that microbial inoculum had no significant effect on either plant growth or soil respiration. Examination of three of the five meiofauna sample replicates indicates that there is no evidence of depressed fauna due to application of either bioremediation product. Nematodes positively responded to both bioremediation products and oil. Among the various microbial populations there is no statistically significant difference among treatments for either day 3 or week 4, indicating that microbial communities are not adversely affected by any of the bioremediation products.

The greenhouse experiment designed to meet the second objective, the determination of whether bioremediation products enhance oil biodegradation in salt marshes, is ongoing. The mesocosms are being sampled for (1) petroleum hydrocarbon chemistry to identify and quantify the degree of oil biodegradation, (2) oil morphology, which will be related to oil chemistry, as an inexpensive means of evaluating oil biodegradation, (3) soil microbial response to determine the effect of the bioremediation products on the microbial communities that are performing the oil biodegradation, (4) soil chemistry to determine the effect of the bioremediation products on those factors that limit the growth of microbe and plants, and (5) plant response to evaluate the combined effect of the oil and products on plant vigor and growth.

Dr. Irving Mendelssohn is a professor of oceanography and coastal ccology at LSU conducting research through the Wetland Biogeochemisty Institute. Educated at Wilkes College, VIMS, and North Carolina State University, he came to LSU in 1979. His primary research interests are: the influence of environmental constraints on plant distribution and productivity and ecophysiological adaptation. His research experience includes natural perturbations as well as those associated with oil spills in marsh habitats.

A native of Belgium, Dr. Karolien Debusschere received her undergraduate training at Rijksuniversiteit in Ghent and her doctoral training at LSU in geography with a minor in agronomy. As a research associate with the Louisiana Geological Survey and the LSU Center for Coastal Energy and Environmental Resources, she has participated in oil spill and coastal morphology research.

Charles Henry has been a research associate in the Institute for Environmental Sciences at LSU since 1985 specializing in analytical chemistry. He is a graduate student at LSU, having received a B.S. in environmental science. He is highly experienced in oil spill studies ranging from the Persian Gulf to the Exxon Valdez and the Mega Borg.

Dr. Edward Overton is director of the Institute for Environmental Sciences at LSU. Educated at Spring Hill College and the University of Alabama, he came to LSU in 1984. His area of expertise is trace organic analyses using high resolution separation techniques. He is principal architect and chief chemist for NOAA's Hazardous Materials Response Branch Chemical Hazard Assesment Team. His research activities include oil spill related work around the world.

Dr. Ralph J. Portier is professor in the Institute for Environmental Sciences at LSU and director of the Aquatic/Industrial Toxicology Lab. Educated at Nichols State and LSU, he joined the faculty in 1983. His parimary area of expertise is microbial physiology of ectreme marine environments and the application of this information to bioremediation.

Dr. Nancy Rabalais is an associate professor at the Louisiana Universities Marine Consortium, LUMCON. Educated at Texas A&I and the University of Texas, she began participation in the founding of LUMCON in 1983. Her professional expertise includes continental shelf ecosystems and the effects of oil and gas operations. She has extensive experience along the Gulf Coast and in China.

Dr. Maud Walsh is a research scientist in the Institute for Environmental Sciences at LSU. Educated at Bryn Mar and LSU, she began environmental research in 1989. She works in the laboratory of Dr. Ralph Portier on a wide variety of microbial and bioremediation topics.

COASTAL MARINE ENVIRONMENTAL MODELING

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INTRODUCTION

This program builds on the results of a recent study of physical processes responsible for land-loss in coastal Louisiana. The first year of the present study has dealt extensively with exercising and learning from a two-dimensional depth-integrated model initially developed during this previous study.

METHODS

The two-dimensional depth-integrated hydrodynamic model was developed and applied to study circulation in the Terrebonne/Timbalier and the Four League Bay systems (Figure 3C.1). The fully-nonlinear model equations include horizontal eddy viscosity and the bottom friction represented by a Manning's coefficient. At land boundaries, no normal flow and no-slip boundary conditions are applied. At open boundaries, the sea-level height is specified. The wind forcing is assumed to be spatially uniform over the model domain. The model equations are discretized on the staggered mesh grid C of Arakawa (Mesinger and Arakawa 1976). The numerical scheme adopted here is Grammeltvedt C scheme (Grammeltvedt 1969) which conserves mass and total energy. Leapfrog scheme is used for time integration with Euler scheme inserted at regular time step to eliminate the computational mode due to the central time differencing. The frictional terms are lagged in time for numerical stability. The model bottom bathymetry was taken from the Nautical Charts (Scale 1:80,000), and the coastal boundaries were approximated on the model grid as closely as possible (see Figures 3C.2 and 3C.3). The model grid spacing between like variables is taken to be 463 m, and the time step used is 10 s. The horizontal eddy viscosity used is 10 m^2/s. The Terrebonne/Timbalier Bay Model includes both Terrebonne Bay and

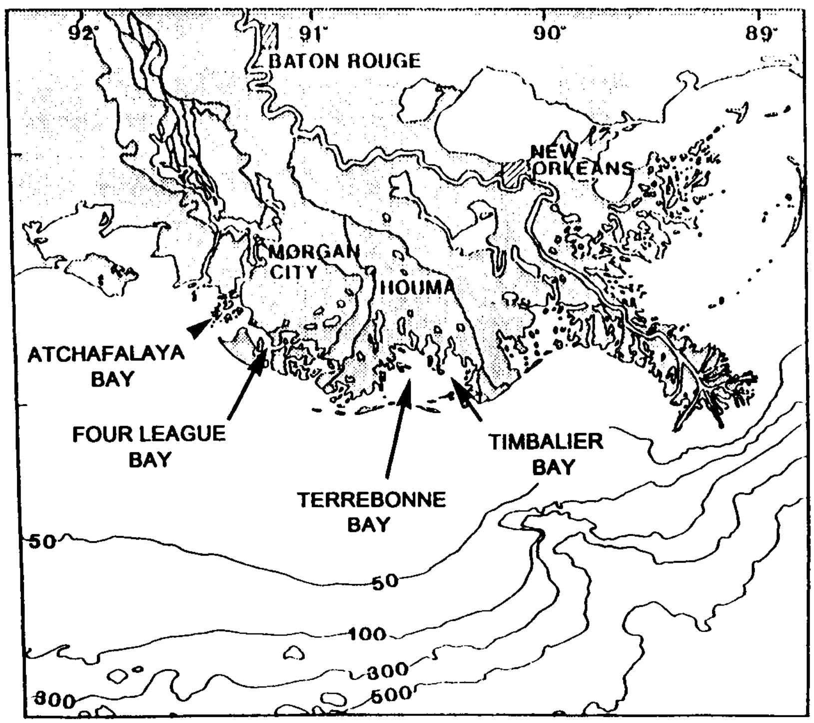

Figure 3C.1. Location map of the study sites.

Timbalier Bay (see Figure 3C.3). In addition, the southern boundary of the model domain is taken outside the bay in order to permit less restrictive model simulation of flow field near the entrances to the bay. The Four League Bay model includes not only Four League Bay but also a portion of Atchafalaya Bay and a portion of the open Gulf to the south (see Figure 3C.3).

RESULTS

Since our main objective is to simulate circulation in bays and the coastal ocean as realistically as possible, an extensive model calibration is carried out using the field data recently collected (Wiseman and Inoue 1993). The model is forced by the observed wind and the sea-level height. Wind stresses acting on the sea surface were estimated from wind measurements made at Isles Dernieres for the Terrebonne/Timbalier Bay Model and from those made in Four League Bay for the Four League Bay Model (Hsu personal communication). An empirical relationship derived for Four League Bay (Hsu personal communication 1992) is used to convert from wind speed to wind stress. Sea-level heights along the open boundaries are estimated from the observations. For the Terrebonne/Timbalier Bay Model, the bottom pressure records collected at the main entrance to the bay are used to specify sea-level height along the southern open boundary. For the Four League Bay Model, the sea-level height measurements collected by the U. S. Army Corps of Engineers at Amerada-Hess platform located just outside the northwest open boundary of the model domain are used to specify sea-level height along the northwest open boundary. The lack of sea-level height measurements near the southwest open boundary presented a major problem in defining proper open boundary conditions along this open boundary. After a series of model calibration runs, it was decided to use the same sea-level height at the Amerada-Hess platform to specify boundary conditions along the southwest open boundary without any changes in amplitude and phase.

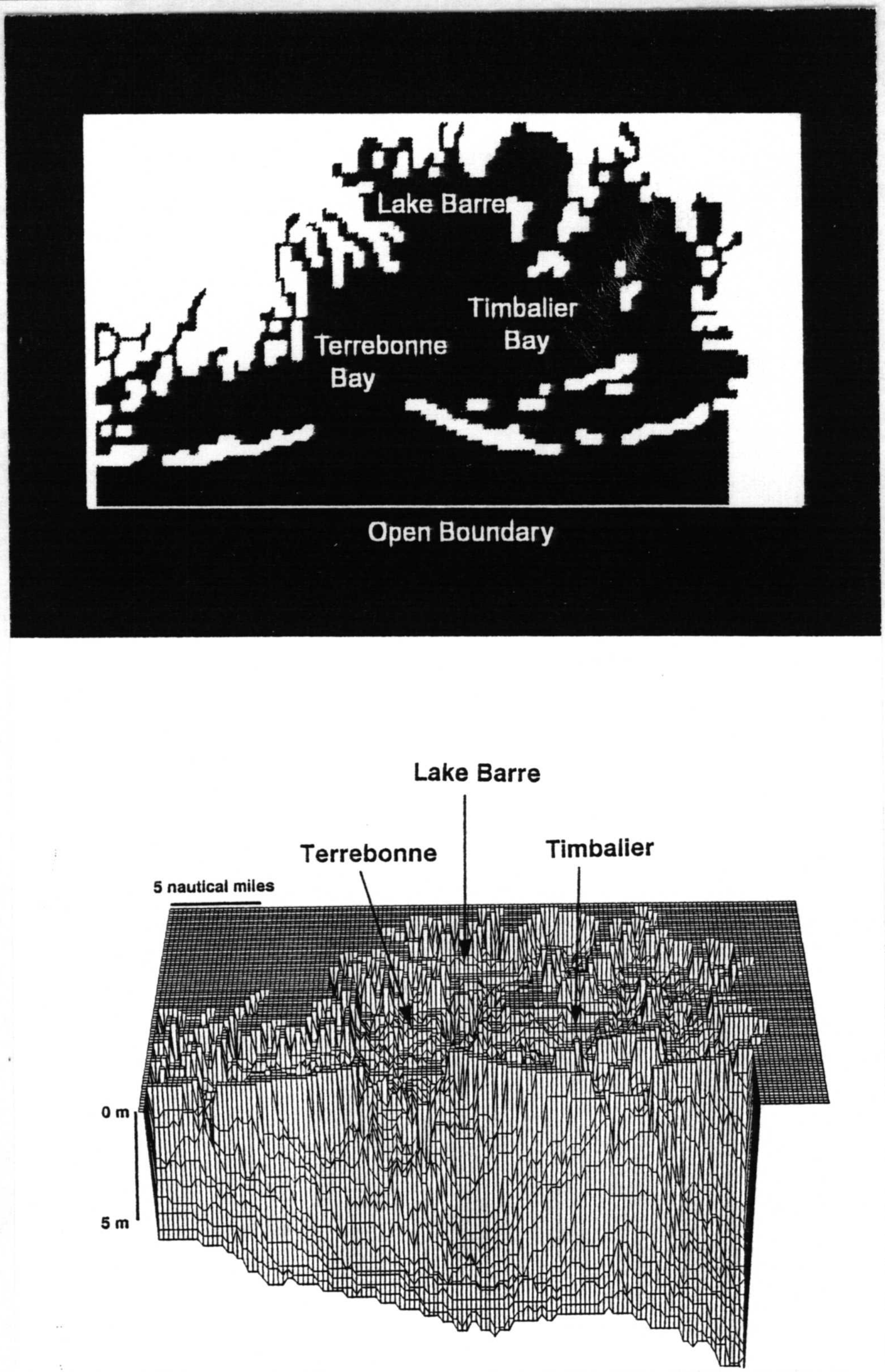

Figure 3C.2. Top: Model geometry of the Terrebonne/Timbalier Bay Model. The southern boundary is open. Bottom: Model bathymetry of the Terrebonne/Timbalier Bay Model.

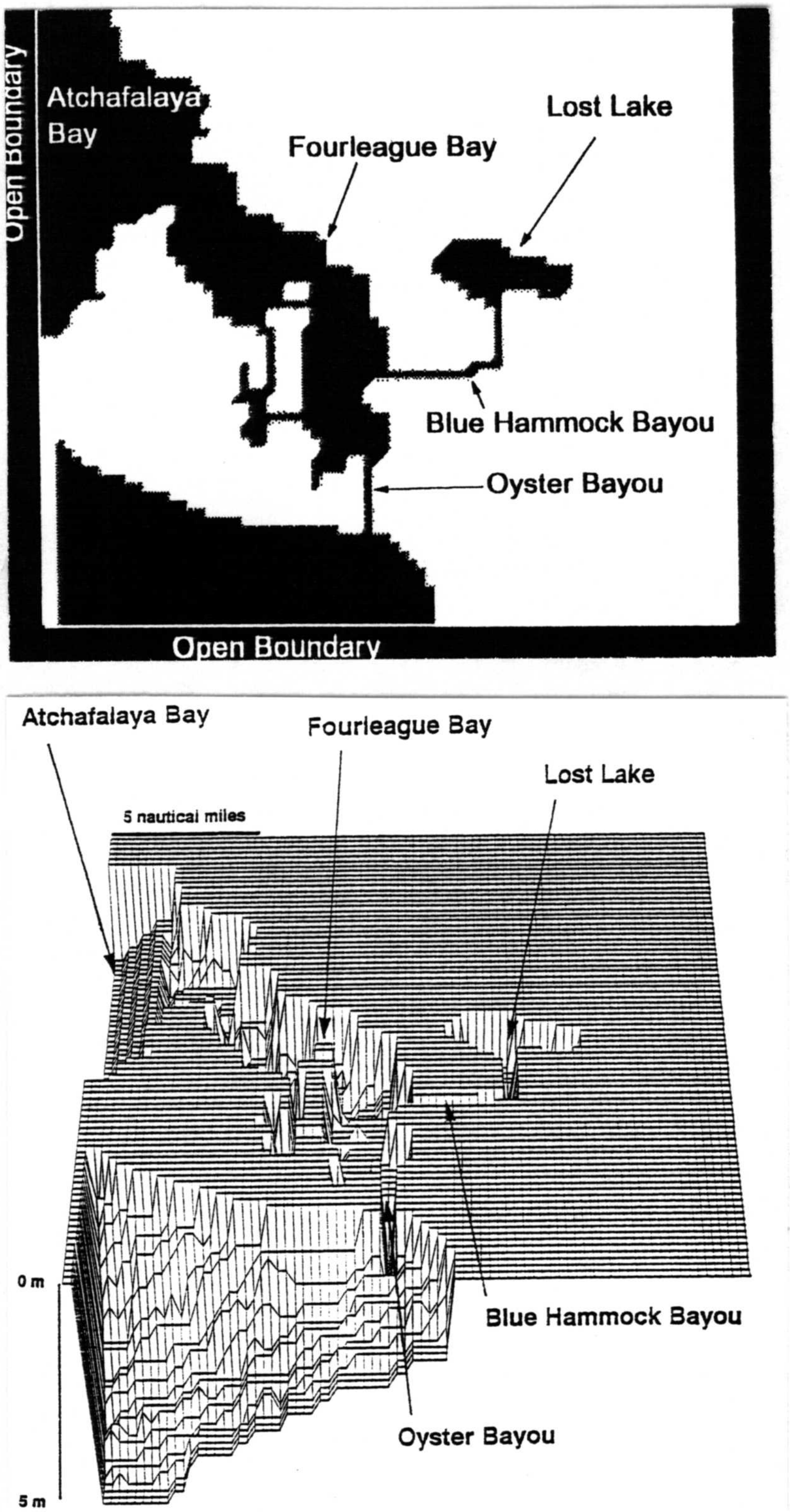

Figure 3C.3. Top: Model geometry of the Four League Bay Model. The northwestern and southwestern boundaries are open. Bottom: Model bathymetry of the Four League Bay Model.

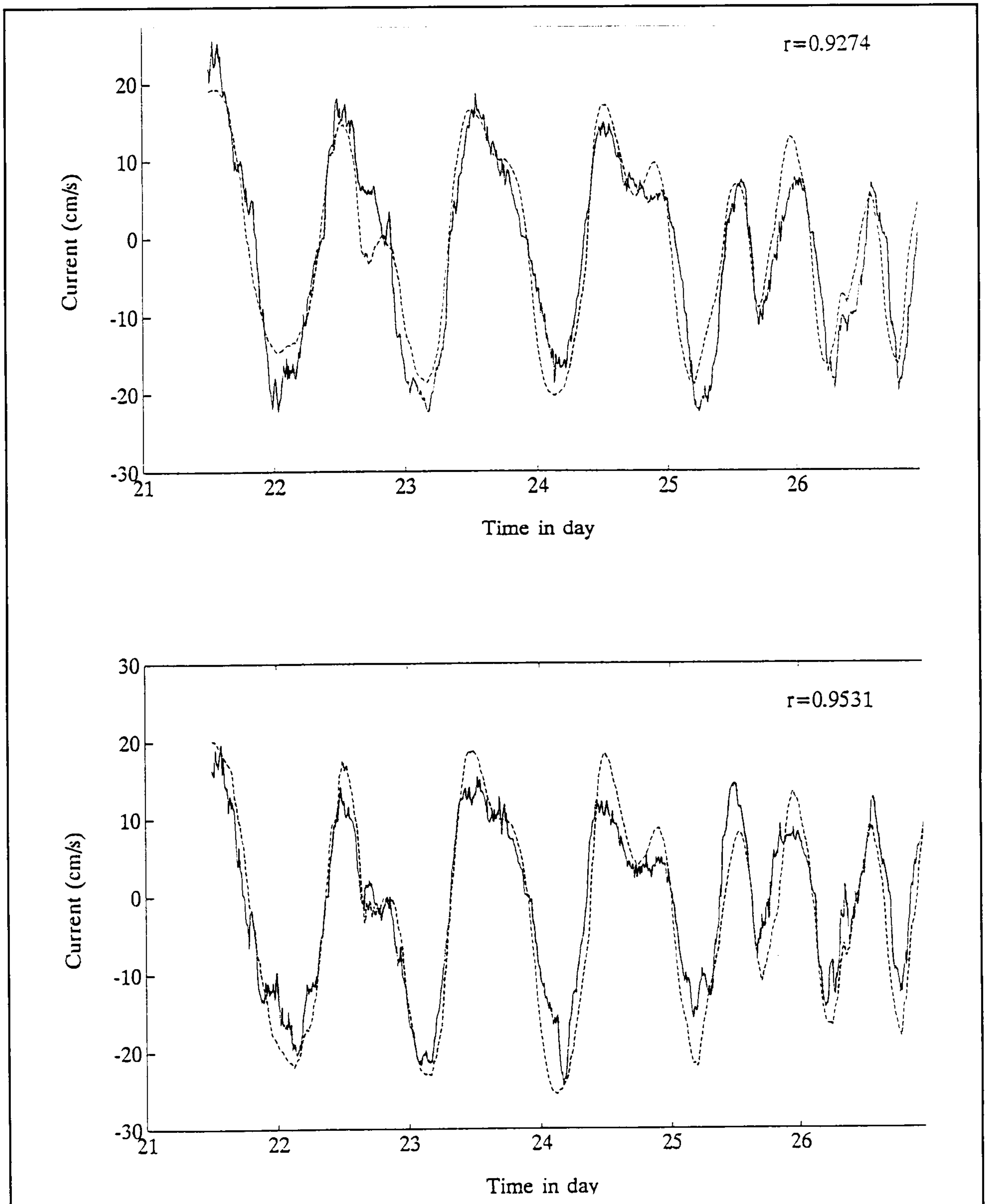

Figure 3C.4. Observed (solid line) and simulated (dashed line) currents at Station 3 located in the middle of Terrebonne Bay for the period 03/21/90-03/27/90. East-west component (top), and north-south component (bottom). r is correlation coefficient between the observed and modeled currents.

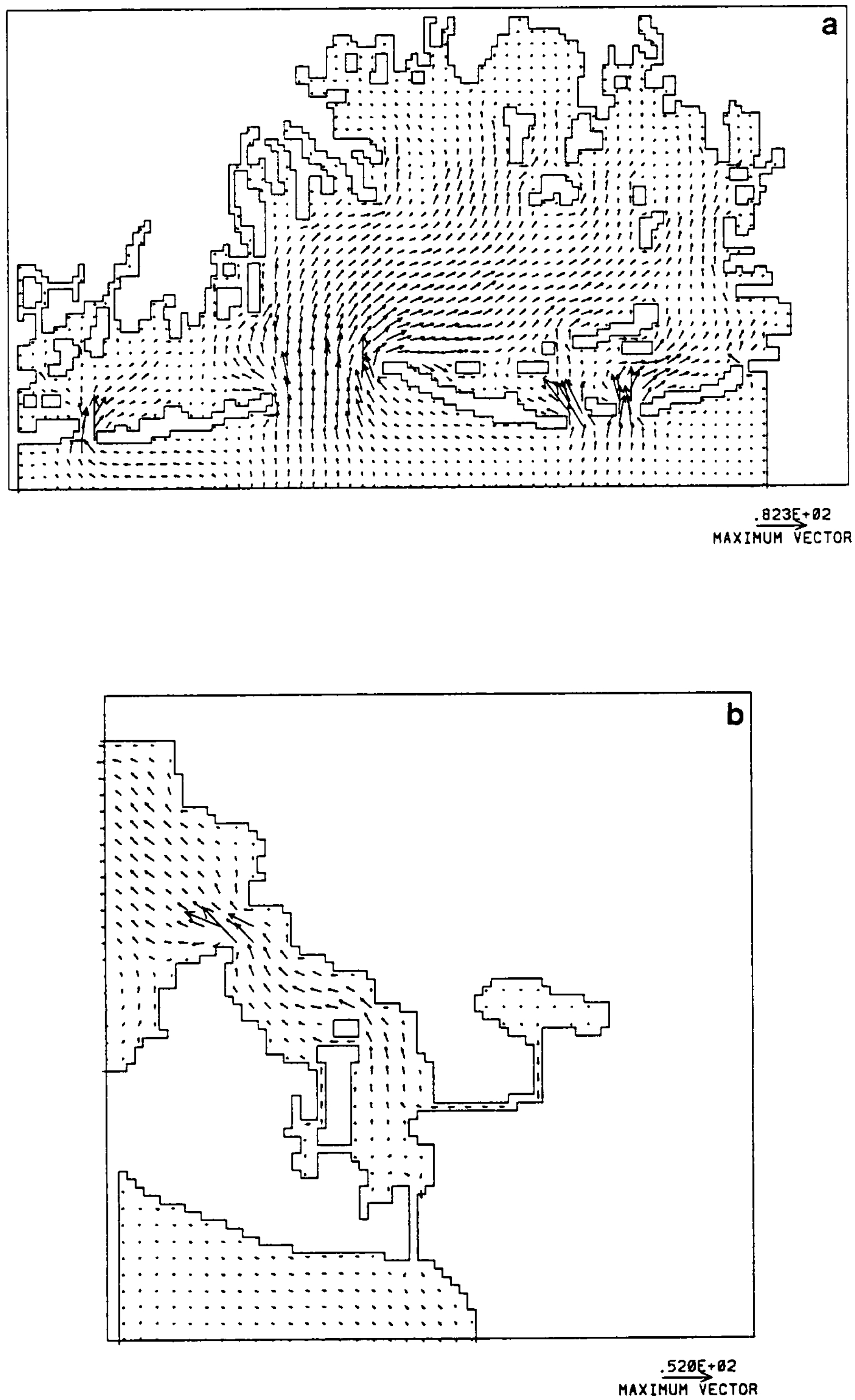

Figure 3C.5. A: Simulated currents within Terrebonne/Timbalier Bay at 6 hr on 05/02/90. Maximum reference vector shown is 82 cm/s. B: Simulated currents within Four League Bay at 16 hr on 08/05/92. Maximum current vector shown is 52 cm/s. Numbered dots indicate mooring locations.

A series of calibration experiments was carried out to identify realistic bottom friction parameters. Manning's values of 0.07 for the Terrebonne/Timbalier Bay Model and of 0.10 for the Four League Bay Model were found to produce currents in close agreement with the those observed. These values are two or three times larger than those typical of other estuaries. This may result from the shallowness of the bays giving rise to enhanced bottom friction due to the combined effect of currents and the surface wave field, which is not accounted for in the model formulation. Large bottom friction identified for Four League Bay could be due to the high concentrations of suspended sediments observed inside the bay that could reach as high as 1600 mg/l (Day, personal communication). Mean correlation coefficients between observed and simulated currents computed for east-west and north-south components at each of the five mooring sites in Terrebonne/Timbalier range from 0.70 to 0.95. An example is shown in Figure 3C.4. The higher correlations found in the Terrebonne/Timbalier Bay Model highlight the well-posedness of this bay system, i. e., outside influence coming from the Gulf of Mexico is well accounted for by the specification of sea-level height along the open boundary that was actually measured at the nearby main entrance. In contrast, correlations between the observed and simulated currents in the Four League Bay Model are not as good. This is mainly due to the artificial specification of the open boundary conditions used along the southwest open boundary. Various previous measurements of sea-level height in this region suggest that sea-level heights south of the Four League Bay are different from those coming from the north (Rouse personal communication 1994). Despite this deficiency in the model setup, various model simulation runs using the Four League Bay Model produced reasonable currents in comparison to the observations. Only exception is in and near the Oyster Bayou that is strongly affected by the sea-level signal coming from the south (Rouse, personal communication, 1994). Currents in and near Oyster Bayou are significantly underestimated in the model.

Using the observed sea-level height and wind, the model was used to simulate circulation in those bays. Examples of current field simulated are presented in Figure 3C.5. It is evident that in those both bays, stronger currents are always found in deeper parts of the bay system. Due to the general shallowness of those bays, relatively small tidal range in Louisiana forces strong tidal currents in those bays. Significant currents could develop in narrow entrances to those bays. In terms of relative dominance of each pass into Terrebonne/Timbalier, Wine Island Pass-Cat Island Pass dominates, accounting for nearly 60% of the total inflow into the bay, while the remaining inflow is equally split between Whisky Pass and Little Pass Timbalier, each accounting for 20% of the total. For Four League Bay, the northern entrance connecting the Four League Bay to the Atchafalaya Bay appears to dominate over Oyster Bayou. However, the role of the northern entrance is probably overestimated in the model due to the artificial specification of the southwestern open boundary condition.

In contrast to Terrebonne/Timbalier, that is open to the Gulf of Mexico only to the south, circulation in Four League Bay is primarily along the orientation of the bay due to the configuration of Four League Bay, which is connected to the Gulf of Mexico at both northern and southern ends. Significant throughflow circulation could develop through Four League Bay due to occasional passages of cold fronts, associated with strong wind stresses in the direction of the orientation of the bay.

A significant progress has been made in visualizing and analyzing the model output. We have been using Data Viz, a computer animation/visualization software, on our Silicon Graphics Indigo workstation to animate the sea-level height field generated by the model. This animation/visualization software was developed in collaboration with Mr. Lingsong Bi. The most unique feature of Data Viz is its 3-D display capability with a light source in 3-D space, allowing detailed texture of the 3-D surfaces to be visible. This added capability allows us to examine not only the general gross features of the model output but also its details.

Our future efforts will include applications of a three-dimensional model, the Princeton model, to the Terrebonne/Timbalier and the Four League Bay systems. Testing of the Princeton model code has been initiated using simplified model configurations.

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Dr. Masamichi Inoue had worked at the Florida State University and at Australian Institute of Marine Science. He has been at Louisiana State University for the past eight years and is Associate Professor at the Coastal Studies Institute and in the Department of Oceanography & Coastal Sciences. His research interests include modeling ocean circulation and transport processes. Dr. Inoue received his B.E. in naval architecture from Tokai University in Japan, his M.S. in ocean engineering from the University of Rhode island, his M.E. in civil engineering and his Ph.D. in oceanography from Texas A&M University.

Dr. William J. Wiseman, Jr., has worked at Louisiana State University for the past 23 years and serves as Assistant Director of the Coastal Studies Institute and as Professor at the Coastal Studies Institute and in the Department of Oceanography & Coastal Sciences. His areas of research interest are shelf and estuarine dynamics, sediment transport processes, and biological/physical interactions in coastal waters. Dr. Wiseman received his B.E.S. and M.S. in electrical engineering, his M. A. in oceanography, and his Ph.D. from Johns Hopkins University.

SOCIOECONOMIC BASELINE STUDY FOR THE GULF OF MEXICO: PHASE I

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PURPOSE

The purpose of this project is to build a data base for analyzing the socioeconomic impact of OCS development for the period 1930-1990 in the five coastal states of Alabama, Mississippi, Louisiana, Texas, and Florida (1970-1990 only). Although offshore drilling in the Gulf of Mexico has a history exceeding fifty years, the socioeconomic impact of that activity has not been examined systematically. The present project has the following objectives: (1) to identify counties/parishes that have been directly impacted by offshore activities, and to examine changes in this impact over the period 1930-1990; (2) to build a data base for indicators of socioeconomic impact of offshore activities, focusing on the following broad areas: demographic, economic, public services, and fiscal; and (3) to analyze the effects of offshore activities on these socioeconomic factors separately for directly impacted and non-impacted counties/parishes.

We give special attention to the spatial linkages of counties/parishes by identifying the labor-market boundaries of the coastal counties/parishes in the five states. The coastal counties/parishes have many ties with communities further inland through extensive commuting flows. These flows are patterned by the work schedule in the OCS, which often requires alternating periods of seven days on/off the job. This schedule permits longer commutes than would be the case with daily commuting patterns. Changes in OCS activity thus have repercussions beyond the coastal parishes.

DIRECT ECONOMIC IMPACT OF OCS ACTIVITY ON COASTAL COUNTIES

Offshore activities have affected many coastal counties/parishes during the past 60 years. However, the extensive coast of the Gulf of Mexico, the differential infrastructure of coastal parishes, and the differences in human capital and industrial specialization make it unlikely that all coastal counties/parishes are equally impacted by offshore activities. Centaur (1986) conducted a survey in the 1980s among the largest producers in the Gulf of Mexico to measure the direct economic impact of offshore activities on counties/parishes which showed substantial variation among counties/parishes. While the methodology used in that study is not applicable to the historical baseline study, there are several alternative ways to assess direct economic impacts. For reasons of comparability over time, we will analyze industry-occupation matrices for each county/parish, making use of the most detailed industry and occupation categories (about 400 industries and 450 occupations) supplied by the U.S. Bureau of the Census. These matrices, which require special tabulations, are available for the period 1980-1990. We will analyze these industry-occupation matrices to develop a classification of counties by degree of direct economic impact from OCS activity.

THE SOCIOECONOMIC IMPACT OF OCS ACTIVITY ON COASTAL COUNTIES

Once the database has been created and those counties/parishes identified that have been directly impacted by offshore activities, the project will analyze the socioeconomic impact by offshore activities in coastal areas by comparing directly impacted and non-impacted counties/parishes. The socioeconomic impact of OCS activity will be conceptualized in terms of four broad areas: demographic, economic, public services, and fiscal.

1. Demographic: Economic development has a number of demographic consequences, and we expect them to occur in response to OCS activity as well. The demographic consequences affect population growth as well as population structure. Regions that experience economic growth typically experience above-average population growth resulting from net in-migration. Age selectivity is a universal characteristic of migration; migrants tend to be concentrated in the age group 15-34 years of age. Migration can also affect the sex ratio of the population. In the case of OCS activities, it is likely that net in-migration into the Gulf Coast region is dominated by males, which would increase the sex ratio. While the linkage between development and race/ethnicity is not clear, we will include information about the racial/ethnic composition in the database.

2. Economic: Economic development tends to increase the demand for labor, although this demand can vary substantially, depending on the capital-output ratio of the industries providing the economic stimuli. Although OCS activity is very capital intensive, we nevertheless expect it to create a demand for labor that should be reflected in above-average rates of growth in civilian employment and nonfarm payroll. The increased labor demand should also raise the per-capita income in areas affected by OCS activity.

3. Public Services: Economic development usually creates a demand for labor and net in-migration, resulting in population growth. Growing areas often face the need to provide for additional police and fire protection, utilities services, education, and health services. Where population growth coincides with an increase in the tax base, such services can usually be offered with few problems. Where economic growth does not lead to increased income and a larger tax base, however, the provision of these services can strain the fiscal capacity of many municipalities and counties.

4. Fiscal: Development and population growth directly affect the structure of revenues and expenditures, as noted above in the context of public services. It is thus essential for any baseline study to include information on municipal/county revenues and expenditures by fiscal category. It is likely that there is a time lag between the infrastructure needs of an area and its ability to provide resources for these needs, since a growing area often requires services before the tax base has developed to meet them. The more important question, however, is the magnitude of this time lag, i.e., the length of time during which the gap between service needs and fiscal capacity exists.

The project will assemble a database for the period 1930-90 that contains county/parish-specific and labor-market-area-specific information about the indicators (defined below) of direct economic impact and of the four broad areas of socioeconomic impact (Table 3C.1). That database will permit us to identify those counties/parishes and labor markets areas that are directly impacted in economic terms by OCS activity. The impact/non-impact distinction will then be used to assess the socioeconomic impact of OCS activity on the levels of counties/parishes and labor market areas. The results of our analyses will not change the content of the database, since other researchers might want to focus on issues not addressed by our anticipated analyses. Moreover, the content of the database has to remain unchanged in

Table 3C.1. Data sources for socioeconomic baseline study for the Gulf of Mexico, Phase I (as of November 1994).

	FISCAL	GOVT EMPLOYMENT	CIVIL EMPLOYMENT	DEMOGRAPHY
Items	Revenue by source Expenditures by purpose	Health, public welfare, police, fire, etc.	Industry, occupation Income, establishments (including farming)	Age, sex, race, migration, marital status, education
1930	Financial statistics 1932 Tax commission Annual report	NA	Census (M)	Census (0003)
1940	1942 CG (M)	NA	Census (M) or Industry (7) < --CCDB (7736) Occupation (12) < --Census (0003)	Census (0003)
1950	1957 CG (M)	1957 CG (M)	Census (M) or Industry (9) < --CCDB-52 (0003) or CCDB (7736) Occupation (12) < --Census (0003)	Census (0003)
1960	1962, 67 CG (0017)	1962, 67 CG (0017)	Census (M) or CCDB-62, 67 (0003) or CCDB 7736	Census (0003) CCDB-62,67 (0003) or CCDB (7736)
1970	1972, 77 CG (8117, 8118)	1972, 77 CG (8117, 8118)	Census (M) or Industry (11), Occupation (13) < --Census (9694)	Census (9694)
1980	1982 CG (8395, 8394) 1988 CG (6069, 9484)	1982 CG (8395, 8394) 1988 CG (6069, 9484)	Census (M) or Industry (11), Occupation (13) < --Census (9693)	Census (9693)
1990	NA	NA	Census (M) or Industry (17), Occupation (13) < --Census (6054)	Census (6054)

Note:
NA: Not available as of November 1994
(M): Need to key-in manually
CG: Census of Government
CCDB: City and County Data Base
(xxx): ICPSR Data Tape number

order to give other researchers the opportunity to replicate our analyses.

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Dr. Charles M. Tolbert is professor of sociology and rural sociology at Louisiana State University. He recently co-authored *Work in the Fast Lane: Flexibility, Division of Labor, and Inequality in High-Tech Industries* (1992). His ongoing research interests include labor markets, industrial organization, and labor force issues. He just completed a new analysis of 1990 labor market areas in the United States. Dr. Tolbert received his B.A. in sociology from Baylor University and his Ph.D. in sociology from the University of Georgia.

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ARE COASTAL FAUNA CHRONICALLY EXPOSED TO PETROLEUM HYDROCARBONS AND HYPOXIA BETTER ADAPTED TO THESE FACTORS?

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INTRODUCTION

Marine and estuarine fish are sensitive to short term exposure to the water soluble fraction of crude oil, but their tolerance does not change much after 12-24 h because of the presence of an inducible cytochrome P-450 enzyme system for metabolizing aromatic hydrocarbons. In contrast to this pattern, invertebrates tolerate high concentrations (ppm range) in 96 hour bioassays; however, their tolerance declines during a 28-day exposure period (Stickle *et al.* 1987; Wang and Stickle 1987).

Water column concentrations of 20-1,000 ppb aromatic hydrocarbons have been monitored in the Barataria Bay to the Louisiana Offshore Oil Platform (LOOP) transect. Oil spills and discharge from produced water also impact fauna of the continental shelf and coastal embayments along the Louisiana coastline. Animals from this area may be adapted to chronic exposure to aromatic hydrocarbons. We know that the 21-day LC_{50} of a population of the blue crab *Callinectes sapidus* collected from a locale near Ocean Springs, Mississippi was 3,927 ppb aromatic hydrocarbons in the WSF of South Louisiana crude oil (Wang and Stickle 1987, 1988). This concentration is considerably higher than found for the pink shrimp, *Pandalus borealis* from southeastern Alaska (Stickle *et al.* 1987) with a 28-day LC_{50} of 28 ppb aromatic hydrocarbons.

Several sublethal stress indices have been shown to be sensitive indicators of physiological stress in marine fauna exposed to the Water-soluble fraction (WSF) of petroleum hydrocarbons including the determination of induction of a form of the cytochrome P-450 enzyme system, scope for growth (energy budget) and RNA:DNA ratios. Induction of several families of cytochrome P-450 enzymes have been documented in fish, but their functional significance in enhancing physiological fitness of the fish has not been demonstrated. Induction, as determined by enhanced cytochrome P-450 activity and estimated from induction of 7-ethoxyresorufin O-deethylation (EROD) activity, is a useful biomarker of environmental contamination. Parallel experiments on the activity of this system in killifish exposed to petroleum hydrocarbons and those from a pristine habitat will allow us better to assess the relationship of this detoxification/toxication system to tolerance and sublethal responses.

The most sensitive biomarkers used with various species of invertebrates are the determination of scope for growth (an energy budget) and the determination of the RNA:DNA ratio. Scope for growth has been shown to decline in a concentration related manner with the WSF of petroleum hydrocarbons in the molluscs *Mytilus edulis* (Widdows *et al.* 1982; Stickle *et al.* 1985) and *Thais lima* (Stickle *et al.* 1984) as well as in the crustaceans *Pandalus borealis* (Stickle *et al.* 1987) and juvenile *Callinectes sapidus* (Wang and Stickle, 1987). The primary component of the scope for growth to decline in a concentration related manner with WSF of petroleum hydrocarbon exposure in all of these studies was their feeding rate. Actual growth was correlated with scope for growth in the blue crab as was the protein:DNA and RNA:DNA ratio (Wang and Stickle 1988).

OBJECTIVES

One of our objectives is to test the hypothesis that populations of the Gulf killifish, *Fundulus grandis*, and the blue crabs, *Callinectes sapidus* and *C. similis*, from the oil-exposed coastal Louisiana have become more tolerant and better adapted to chronic petroleum hydrocarbon pollution than populations of this species from more pristine locations.

A second objective is to determine possible interactions between prior exposure in the Gulf killifish, and the blue crabs to the WSF of South Louisiana crude oil with simultaneous exposure to hypoxic water. How does the Gulf killifish and blue crab tolerance of the WSF of South Louisiana crude oil vary as a function of the level of hypoxia to which they are exposed? Induced cytochrome P-450 enzymes will require oxygen as a substrate in the metabolism of aromatic hydrocarbons and previous studies have indicated that the metabolic rate of fish exposed to WSF of crude oil (Thomas and Rice 1979) exhibit elevated metabolic rates at 30% of the 4 day LC_{50} and 63% of the 21 day LC_{50} respectively. Since killifish cannot tolerate depressed metabolic rates for long when exposed to hypoxia there should be competition for oxygen by the cytochrome P-450 system enzymes and the electron transport system which will result in reduced tolerance of petroleum hydrocarbons when also exposed to hypoxic seawater.

PROGRESS TO DATE

Progress to date with experiments performed and measurements done is shown in Table 3C.2.

Hypoxia Exposure System and Bioassay

Tolerance to hypoxia has been measured so far for the blue crabs, *Callinectes sapidus* and *C. similis*, and the killifish, *Fundulus grandis*, collected from the produced water site near Pass Fourchon. The hypoxia exposure system consisted of four sets of 12 flow-through aquaria. Two aquaria were assigned for each experimental oxygen tension for each species. Each experimental aquarium (38 liter) consisted of an undergravel filter overlaid with oyster chips. Water was pumped from a large filtration unit into each aquarium by a peristaltic pump at a rate sufficient to provide two exchanges per day. Target oxygen tensions of 115, 90, 50, 25 and 0 torr (74%, 58%, 32%, 16% and 0% of air saturation and 5.47, 4.17, 2.31, 1.16, and 0 ppm dissolved oxygen) were created and maintained by mixing bottled nitrogen and oxygen with Matheson gas mixers (model 7402T) along with 0.03% carbon dioxide to maintain the pH at approximately 7.8. Experimental conditions (temperature, salinity, PO_2, pH, ammonia) were checked daily. Ammonium concentration never exceeded 25μM. LC_{50} values were calculated for each day using the Spearman-Karber technique (Hamilton *et al.* 1977). Figure 3C.6 shows the LC_{50} for all three species plus the southern oyster drill from the produced water site.

Concentration of DNA, RNA and RNA:DNA ratio was measured for each species exposed to constant levels of hypoxia. DNA analysis was performed according to the procedure developed by Munro and

Table 3C.2. Experiments performed and measurements done.

Experiments Performed	Measurements Done
28 days hypoxic exposure on *Callinects sapidus,C. similis, Stramonita haemastoma* and *Fundulus grandis*	1. Survival 2. Feeding rate 3. Growth 4. RNA:DNA ratio
28 days starvation on *C. sapidus, C. similis*	1. Feeding rate for 3 days after 7, 14, 21 and 28 days of starvation 2. Metabolic rate after starvation and subsequent feeding 3. RNA:DNA ratio
28 days exposure to the water soluble fraction of South Louisiana crude oil on *C.similis* from Port Fourchon (polluted site) and *C. sapidus* from Florida (pristine site)	1. Survival 2. Feeding rate 3. Growth 4. RNA:DNA ratio

Fleck (1966). RNA content of the pellet was determined using the modified Schmidt-Thannhauser procedure recommended by Munro and Fleck (1966).

We did not observe any significant changes in the concentration of DNA and RNA or in the RNA:DNA ratio in the muscle tissue after 28 days of exposure to constant hypoxia in the killifish. A slight increase in the RNA synthesis activity was observed in the fish exposed to the higher levels of hypoxic water. Significant increase in the RNA and DNA concentration has been noticed in the liver tissue of killifish at the more severe levels of hypoxia after 28 days of exposure (Table 3C.3).

Starvation caused a higher RNA synthesis in killifish after 7 days, which declined to the control level after 14 days. All the fish died after 14 days of starvation. Analyses of DNA and RNA concentration due to starvation in crabs and oyster drills are yet to be performed. The liver tissue of killifish showed a considerably higher concentration of DNA after 14 days of starvation. The concentration of RNA did not change significantly after starvation.

Measurement of Oxygen Consumption

Oxygen consumption rates of the two species of crabs and the oyster drills were measured using the flow-through system described by Stickle *et al.* (1985). Water was pumped via a submersible pump from the appropriate dosing compartment through a manifold, with excess water returned to a separate reservoir via a return tube. Ten side ports from the manifold were connected to separate flow-through respiration chambers (250 ml.) so that a blank (control) chamber was placed at each end. Water was pumped from the reservoir into the distribution manifold at a low flow rate (~20ml/min). Two hours were allowed between loading crabs and the initiation of the respiration determinations to allow for crab adaptation to the chambers. Oxygen consumption in each chamber was calculated using the following equation:

$\mu l\ O_2.\ hr^{-1}$ = % oxygen used by the crab * flow rate ($l.\ hr^{-1}$) * 1000 * oxygen content in water at that partial pressure.

Oil Exposure System

A flow-through oil extraction apparatus (developed by National Marine Fisheries Services, Auke Bay, Alaska) is being used to expose all the species to the water soluble fraction of South Louisiana crude oil. The apparatus (Figure 3C.7) consists of a oil generator made from a pvc pipe section (4" inside diameter, 3' length) which is filled with pea gravel. The pea gravel was sprayed with a mixture of equal volume of heated South Louisiana crude oil (Eugene Island Block) and pentane at different proportions to gener-

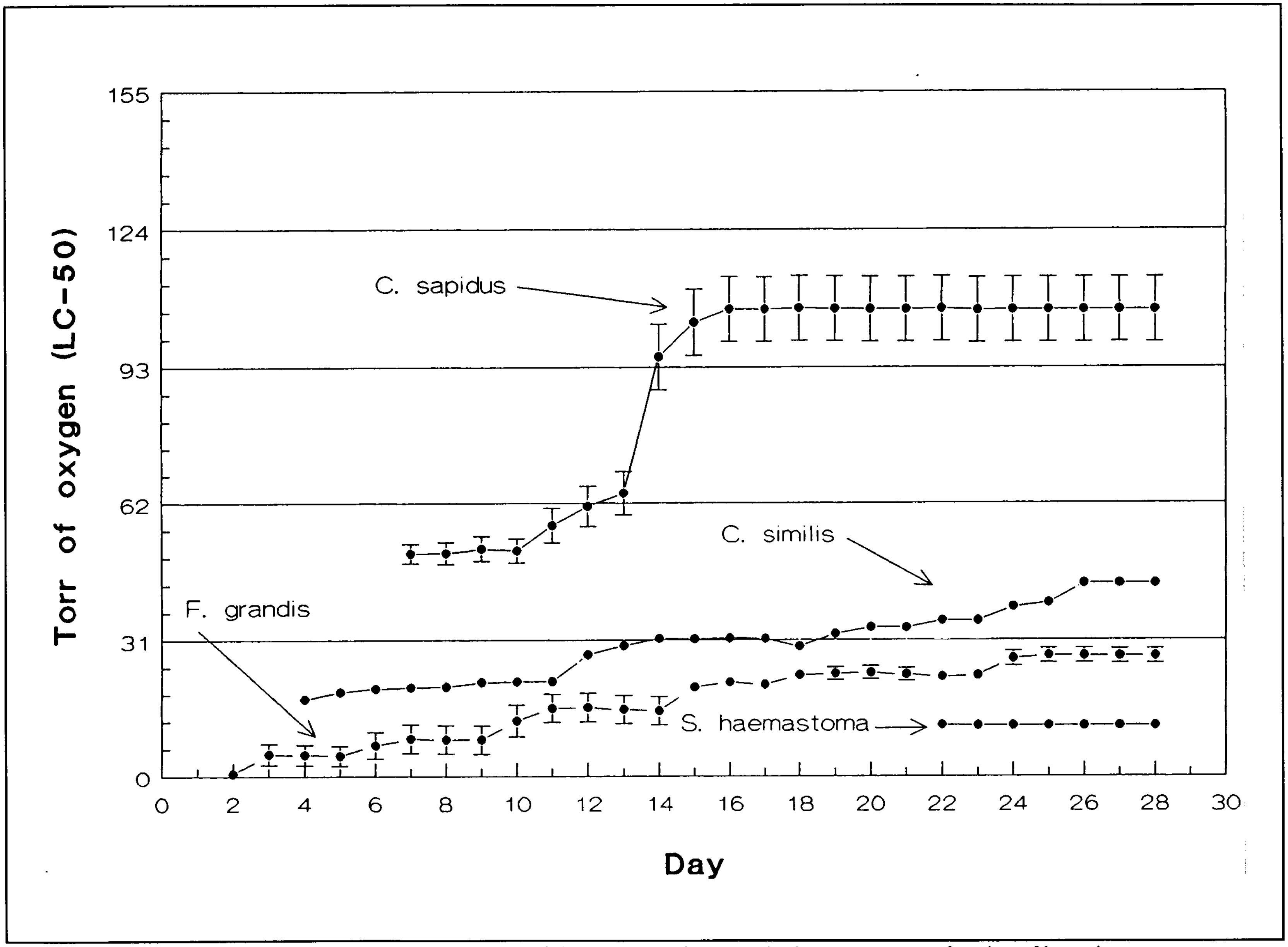

Figure 3C.6. LC50 of *Callinectes sapidus, C. similis, Fundulus grandis* and *Stramonita haemastoma* as a function of hypoxia.

ate a series of exposure concentrations. The oil was heated previously at 85°C for 48h to remove the low molecular weight fractions. After spraying the pea gravel with equal volumes of oil and pentane mixture it was air dried for 4-5 days. A reservoir located above the oil generator feeds water through gravity via an inlet located at the bottom of the oil generator. The flow of water through the line can be controlled by a needle valve. Water percolates through the gravel and exits at the top through an outlet which supplies the water into an aquarium.

In order to determine various concentrations used to measure the tolerance of all three species we used two different oil concentrations to spray the gravel. Water was flowed through the four generators at two different flow rates for 20 days. Water samples were extracted with methylene chloride for water soluble fraction of crude oil on day 4, 10 and 20 and were analyzed for the aromatic fractions of hydrocarbon by using High Performance Liquid Chromatography. Individual aliphatic and aromatic components are being analyzed at present. We have monitored the tolerance of two species of crabs from Port Fourchon, Louisiana (polluted site) and Turkey Point, Florida (pristine site) to the water soluble fraction of oil. In another experiment two species of crabs (*Callinectes sapidus* and *C. similis*) were exposed to five different concentrations of oil at a constant hypoxia (115 torr oxygen or 74% oxygen saturation). All the crabs died within the first three days of the experiment at the four higher oil dosage. About half of the crabs died in the lowest oil concentration after three days. From this experiment we can conclude that water soluble fraction of oil and hypoxia in combination can be fatal to the above two species of crabs. We are in the process of planning an experiment at hypoxic exposures representing 67% and 33% of the difference between normoxia and the 28 day LC_{50} for hypoxia at various concentrations of the water soluble fractions of South Louisiana crude oil.

PROBLEMS ENCOUNTERED

At the beginning of June there was an occurrence of asbestos release in the basement of the Life Sciences Building, at LSU, where all of our hypoxic and oil exposure facilities are located. Since then the basement was sealed off for almost three and a half months for asbestos cleanup and subsequent renovation of the air handling system. Therefore, we could not perform any of the experiments planned for those three and a half months.

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Table 3C.3. *Fundulus grandis.* Changes in the RNA and DNA concentration and RNA:DNA ration in the gulf killifish after 28 days of hypoxic exposure as compared to the control killifish from day 0. Nucleic acid concentration is given in µg/mg dry body wt.

Treatment	Day	RNA	% of day 0	DNA	% of day 0	RNA:DNA Ratio	% of day 0
155 Torr	0	64.77	100	22.89	100	2.88	100
	28	50.91	79	13.17	56	3.98	138
115 Torr	28	57.0	88	11.18	48	5.06	176
90 Torr	28	48.94	76	15.49	68	3.15	109
50 Torr	28	56.56	87	13.56	59	4.07	141
25 Torr	28	57.12	88	13.10	57	4.53	157

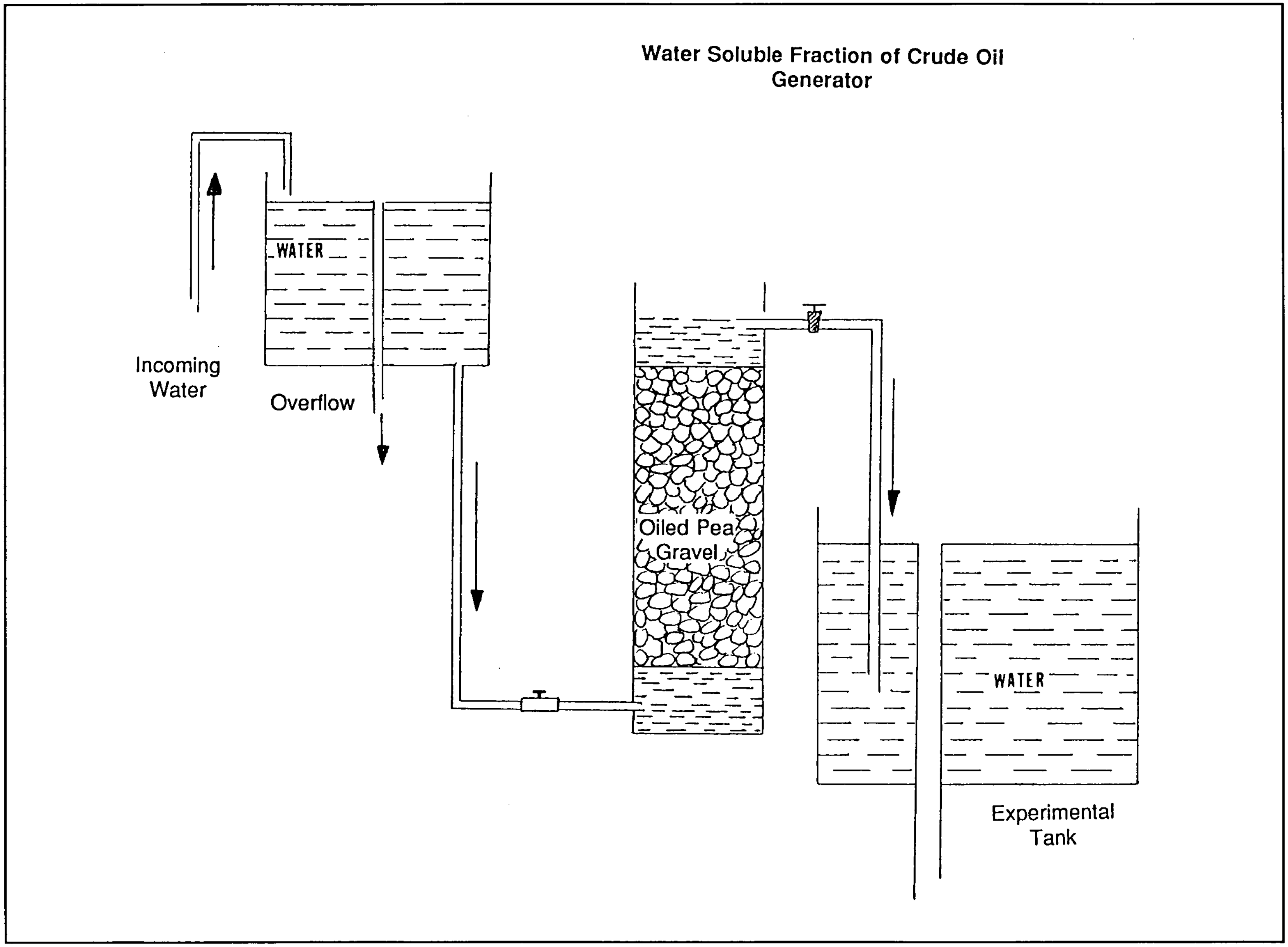

Figure 3C.7. Water Soluble fraction of the crude oil generator used to expose different species to oiled water for 28 days.

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SEASONAL AND SPATIAL VARIATION IN DENSITY AND SIZE DISTRIBUTION OF FISHES ASSOCIATED WITH A PETROLEUM PLATFORM IN THE NORTHERN GULF OF MEXICO

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INTRODUCTION

The large number and extensive nature of offshore structures in the northern Gulf of Mexico has undoubtedly influenced the marine environment and its inhabitants. Past research has emphasized environmental impacts of petroleum production, focusing on the effects of discharges such as produced waters, drilling fluids, and spills (Boesch and Rabalais 1987). The ecological significance of habitat modification provided by the petroleum platforms is, however, unknown, and much is left to speculation.

The placement of these structures has significantly increased the available hard substrate within the area (Reggio and Kasprzak 1991). Researchers have estimated that natural reefs constitute only 1.6% or 2,571 km^2 (737 to 6,385 km^2, 95% CL) of the total substrate, which is dominated by clay, silt and sand, from Pensacola, Florida, to Pass Cavallo, Texas (Parker *et al.* 1983). Hard substrate provided by petroleum structures is estimated to be 5,000 km^2, increasing available reef habitat by 78% to 195% in the northern Gulf of Mexico (Gallaway *et al.* 1981).

Fish populations are thought to be limited by recruitment, competition, available energy and habitat, and predation (Menge and Sutherland 1987, Doherty and Williams 1988, Bohnsak 1989, Bohnsak *et al.* 1991). The additional habitat provided by petroleum platforms can potentially influence all of these processes. Information on population dynamics acquired from the measurement of fish assemblages associated with offshore structures may help to determine whether these structures aggregate prey or predators, or provide critical habitat for reproduction and/or survival of fragile life history stages.

Petroleum platforms are an important component of recreational and commercial fisheries along the Gulf Coast and have long been recognized as defacto artificial reefs by fishermen. Petroleum platforms are the destination of over 70% of all recreational fishing trips in the Exclusive Economic Zone off coastal Louisiana (Reggio 1987), and it is estimated that 30% of the recreational fish caught off Louisiana and Texas coasts, approximately 15 million fish, are caught near petroleum platforms each year (Avanti 1991). Although these resources are important to fishermen, there is little information upon which fisheries scientists can base management decisions. This paucity of available information is primarily due to the difficulty of sampling these habitats with traditional fisheries sampling methods.

METHODS

Between 1990 and 1992 we conducted research in cooperation with Mobil USA Inc. to demonstrate the utility of the relatively new fisheries sampling technique, dual–beam hydroacoustics, in conjunction with standard visual reef fish assessment techniques. The purpose of this research was to document the abundance, size distribution, and species composition of fishes associated with a petroleum platform in the northern Gulf of Mexico. Monthly dual–beam hydroacoustic and visual surveys were conducted from September 1990 to June 1992 at petroleum platform West Cameron 352 (WC 352), located approximately 80 km south of Cameron, Louisiana in a water depth of 22 m (Stanley 1994).

RESULTS AND DISCUSSION

The coupling of two fisheries independent techniques, dual–beam hydroacoustics and visual point count surveys, provided the best description of the fish population associated with a petroleum platform to date. Fish size ranged from 2.5 cm to 1.1 m in length and did not change significantly ($P>0.01$) with depth or time of day, however, significant differences were detected ($P<0.01$) between platform sides and months (Figure 3C.8). Detected fish were smaller during spring and summer, increased in size through late summer and fall, and reached a maximum in the winter. This pattern suggests recruitment of smaller fish to the platform in the spring and summer, and either growth of fishes remaining around the platform or immigration of larger fish to the platform through the fall and winter. Fish were consistently larger on the south side of the platform and smallest on the north and east sides.

Fish density around the platform was highly variable with space and time. Fish density varied significantly ($P<0.01$) with side of the platform as highest densities were found on the north and east sides. Fish density also varied with depth; fish densities were significantly higher ($P<0.01$) from 2 to 12 m than from 16 to 20 m (Figure 3C.9). Perhaps the most interesting results were the large and significant changes ($P<0.01$) in fish density from month to month. Monthly densities varied by up to a factor of 5 and did not appear to follow any pattern (Figure 3C.10). No change in fish density was detected over 24 hour periods. Fish density decreased significantly ($P<0.01$) with distance from the platform. We calculated that the near–field effect of WC 352 on fishes was 16 m from the platform. Fish densities were greater from 2 to 16 m than from 16 to 72 m away from the platform (Figure 3C.11).

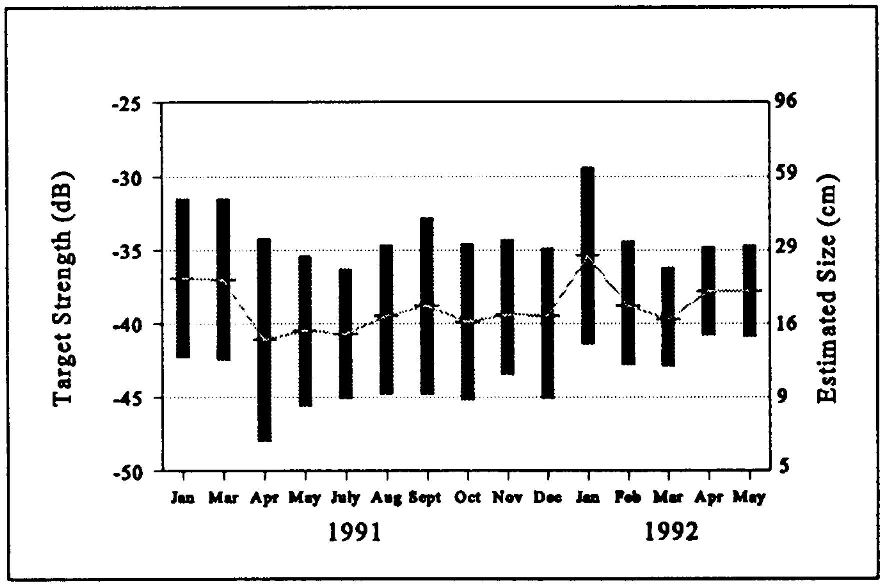

Figure 3C.8 Mean target strengths (dB) and 95% CL and estimated length (cm) of fishes associated with petroleum platform WC 352 by month for the study period of January 1991 to May 1992.

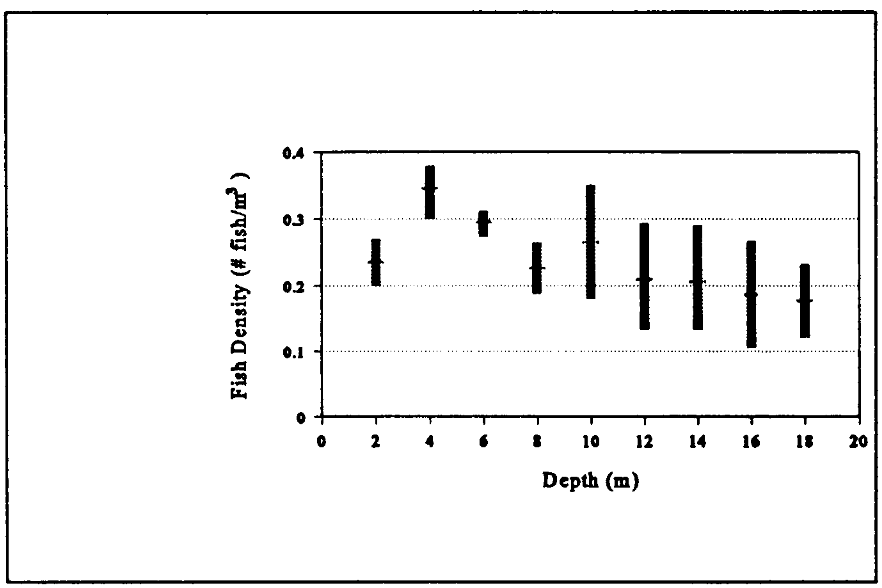

Figure 3C.9. Estimated fish density (number / m^3) and 95% CL by depth at WC 352 from January 1991 to May 1992, based on dual-beam hydroacoustics.

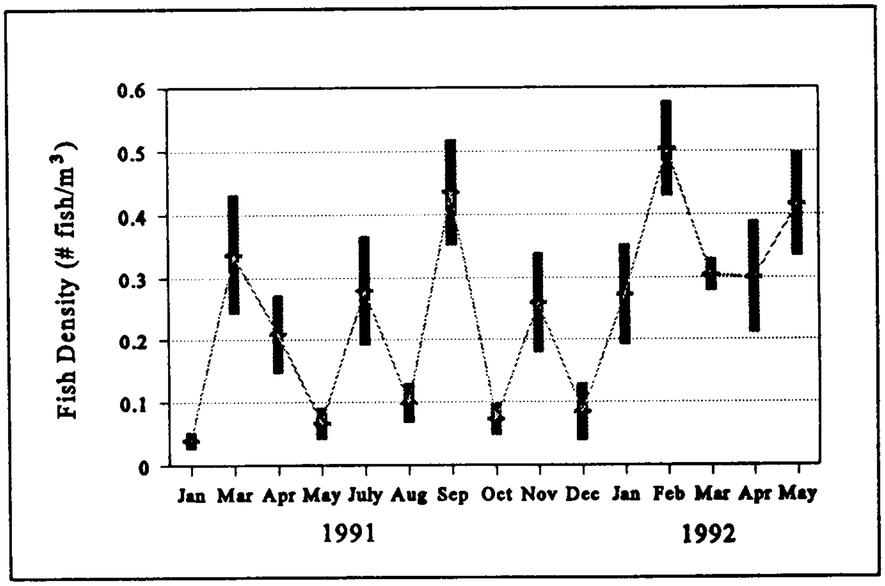

Figure 3C.10. Mean density of fish (number / m^3) and 95% CL around WC 352 from January 1991 to May 1992 based on dual-beam hydroacoustics.

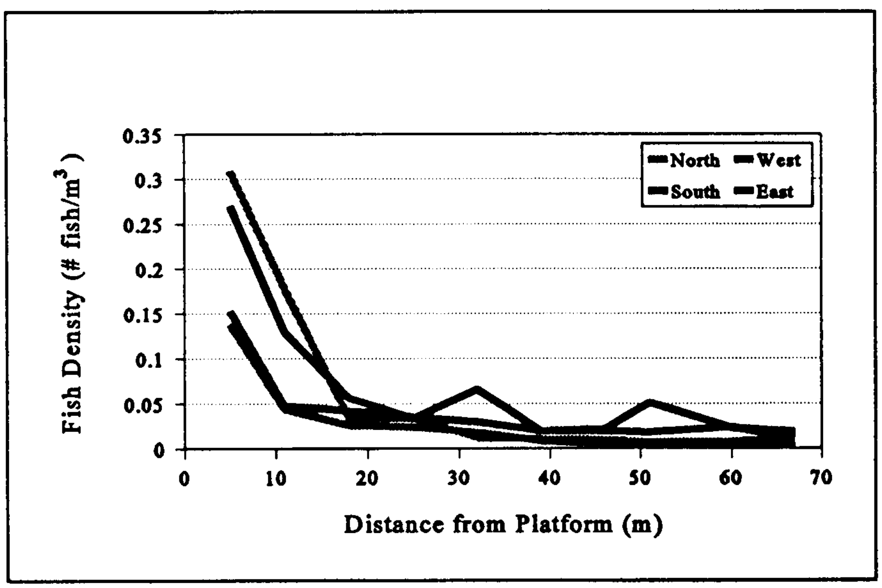

Figure 3C.11. Mean fish density (number / m^3) with distance from the WC 352 platform over the study period of January 1991 to May 1992 for each side of the platform.

The total abundance of fish at WC 352 was estimated based on the volume occupied by platform, the near–field area of influence of the platform, and densities of the associated fishes. Total abundance estimates followed the pattern of density estimates with high variation from month to month. Total abundance estimates varied from 1988 ± 413 (± 95% CL) for January 1991 to a high of 28138 ± 5532 in February of 1992. The average number of fish around WC 352 by month was approximately 12470 ± 3251.

A total of 19 species were observed during visual point count surveys with SCUBA divers or the ROV; of these, seven species made up 97% of the fish observed. The seven most common species were Atlantic spadefish (*Chaetodipterus faber*), blue runner (*Caranx crysos*), bluefish (*Pomatomus saltatrix*), gray triggerfish (*Balistes capriscus*), greater amberjack (*Seriola dumerili*), red snapper (*Lutjanus campechanus*), and sheepshead (*Archosargus probatocephalus*). The abundance of individual species changed with time, as some species (e.g. red snapper and blue fish) were most abundant in the fall and winter while others (e.g. blue runner) were more abundant during warmer months. Economically important species such as red snapper, greater amberjack and gray triggerfish constituted an average of 21.2%, 2.4% and 0.2% of the fishes around the platform. Averaged numerically there were 2,644 ± 689 red snapper, 299 ± 78 greater amberjack, and 25 ± 7 gray triggerfish around WC 352 at any one time.

Based on this first study, we concluded that fishes associated with the petroleum platform were highly transient. While the fish may be dependent on the structure for habitat, they exhibit migration to other areas. The higher abundance of fishes detected at WC 352 than described during other studies was probably due to our usage of dual–beam hydroacoustics that did not influence fish behavior, was not limited by visibility, and measured the entire area of influence of the reef.

The obvious next step in determining the effect of platforms on fish populations was to expand our research efforts to gain insight into the fish communities around other platforms. We are using the technology developed at WC 352 to study the fish population around a platform in the Grand Isle lease area (water depth 65 m) and a platform in the Green Canyon lease area (water depth 225 m). This research effort is being sponsored by the Coastal Marine Institute with MMS funding and Mobil USA Inc. Our objectives over the next several years are to:

1. measure the abundance, size distribution and species composition of fishes at these sites;
2. determine the effect of temporal, physical and environmental variables on abundance and size distribution of fishes at the platforms;
3. define the near–field area of influence of each platform.

Research began in July 1994, and preliminary results will be available during 1995. Results from this and future research will enable researchers and managers better to understand how artificial reefs function in the northern Gulf of Mexico and evaluate their effectiveness as potential management tools. Since the fisheries resources associated with petroleum platforms are not currently included in management plans, and given the current emphasis on reef fish management, information collected from this work may provide estimates of abundance and species composition of fishes near petroleum platforms and ultimately improve management of the resource.

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Dr. David Stanley is a senior research associate in the Coastal Fisheries Institute of Louisiana State University. Dr. Stanley has investigated the dynamics of petroleum platforms as artificial reefs and has adapted acoustics to assess the fisheries resources associated with these structures.

Dr. Charles Wilson is a professor in the Coastal Fisheries Institute at Louisiana State University. He was a co-author of the Louisiana "Rigs to Reefs" Program. His research interests include the use of artificial reefs by fishes, age and growth techniques for fishes and the reproductive biology of fishes.

CHARACTERIZATION OF SEA ANEMONES AS BIOINDICATORS OF OFFSHORE RESOURCE EXPLOITATION

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The overall objective of this work is to characterize the biochemical reponsiveness of sea anemones for use in environmental monitoring programs. To this end we have examined specific known stress-related parameters that can provide environmental managers, researchers and regulatory agencies with: (1) sub-lethal, early warning detection signals of environ-mental stress; (2) a means of demonstrating, assign-ing and delineating zones of ecological impact from point- and nonpoint-source pollution; and (3) quanti-fiable biomarkers of integrative stress load and ecological health through characterization of bio-chemical responses with high potential for assessing the limits of natural and inadvertant stress.

A biomarker is a change in a biological response that can be related to an exposure to, or toxic effect of, an environmental chemical or chemicals (McCarthy and Shugart 1990). Detection and evaluation of biological changes caused by exposures to various chemicals are of the utmost importance with respect to the significance of contaminant exposure. In this regard, certain biological changes can indicate exposure to specific chemicals or adverse effects of exposures. A biological response can range from molecular (biochemical) reponses, through behavioral responses, to changes in species composition affecting populations and ecosystems (Table 3C.4).

Thus biomarker research at the biochemical, organism, population or communitiy levels is equally valid. The use of biomarkers to assess the impact of contaminants or natural perturbations, e.g. anoxia associated with an increase in chemical or biological oxygen demand, that are potentially hazardous to biological organisms is under intensive investigation throughout the world.

Biomarkers have potential for a number of applications that could benefit regulatory agencies. The use of biomarkers might be envisaged on several levels: (1) establishing cause associated with an observed malady in organisms, populations or communities; (2) documenting exposure to organisms including the range and zones of delineation of that exposure; (3) documenting the effects (reversible or irreversible) caused by contamination to organisms, populations or communities.

The basis of biomarker research may have its roots in the biochemistry, physiology, behavior, systematics and population dynamics of organisms. These integrated relationships are illustrated in Table 3C.4 in the context of the limits of understanding that biomarker research can provide. Thus, for any given set of response parameters under any level of organization (biochemical, organismic, population or community), there is an inverse heirarchy of the sensitivity of the response and the ecological relevance of the response. Thus, information on the ecological relevance of a response may be at the sacrifice of sensitivity and *vise versa*.

There are two major advantages of using biochemical level changes as biomarkers of environmental contamination 1) they are generally the first responses to contamination that can be detected and quantified, and 2) biochemical changes can reflect both exposure and effect, i.e. a change in the biochemistry of an organism upon exposure to a chemical *is an effect.* In this presentation we examine the responsiveness of two classes of proteins to organic and metal exposures. The first class of proteins are those of the *cytochrome P450-dependent microsomal monooxygenases,* a complex membrane-associated, multienzyme family that is of critical importance in both the detoxification and activation of xenobiotic chemicals. A classical feature of cytochromes P450 in many organisms is their induction by xenobiotic chemicals. Induction of P450 by chemicals involves *de novo* synthesis of mRNA and its translation to P450 protein. This ability to be induced by chemicals has prompted great interest in the characterization of cytochromes P450 as potential biomarkers for environmental pollutants (Stegeman *et al.* 1992). The other class is the *stress proteins* or *heat shock proteins,* which are also induced by various chemical agents and as well by other stress factors such as heat or oxidative stress. There is growing evidence that these proteins protect other proteins and nucleic acids from environmental damage. Their usefulness as biomarkers, therefore, are as determinants of the degree to which the organism is trying to protetct itself from environmental stress (Sanders 1990).

The present summary is of preliminary studies of the cytochrome P450 and heat shock protein response in certain species of sea anemones to the model polycyclic aromatic hydrocarbon, 3-methylcholanthrene and to Cd. All biomarkers of exposure and effect ultimately have to meet two important criteria. First, the response must be of sufficient sensitivity to be detectable and quantifiable at environmentally relevant exposure levels. Second, the biomarker response must be sustained over time. Before such criteria are met in field studies it is necessary first to identify whether certain chemicals can indeed elicit a biochemical response. To that end, initial studies used acute exposures to concentrations of toxicant that may be higher than in specific environmental situations but are well below that which causes noticeable stress at the organismic level.

Sea anemones have several advantages as sentinels for pollution exposure; they actually inhabit oil platforms, are stationary (sessile), are ubiquitous and perhaps most importantly, can be easily cloned in the laboratory to generate genetically homogeneous populations thus, eliminating genetic variability in biomonitoring responses. Furthermore, because anemones have evolved to only the tissue level of development, biochemical responses in this organism reflect that of only a few cell types. By analogy, the response would be similar to an organism with one basic organ type. Thus, the whole organism is used

Table 3C.4. Integrated relationships of biomarkers and levels of biological organization.

	Biochemical	Organismic	Population	Community
Response Parameter	MFO	behavior	energy flow	abundance
	hsp	growth	interspecific interactions	diversity
	SOD	reproduction	abundance	
	DNA	survivorship		
Response Time	hrs	hrs/days	weeks/mos/yrs	mos/yrs

for biochemical assays rather than having to dissect specific organs and characterize each within several species. Sea anemones in particular, through their action of pumping water throughout their bodies, are continually replenishing the body burdon and thus, continually bioaccumulating pollutants.

Western blot (immunochemical) analysis of microsomal fractions on *Aiptasia pallida, Anthapleura elegantissima* and *Bunodosoma cavernata* has been studied to characterize the presence of specific antigenic proteins in microsomes of these anemone species. Anti-trout P450 LMC2 (CYP 2K1), a P450 isozyme involved in steroid and fatty acid metabolism, recognizes a very intense band in sea anemone microsomes (10 μg per well), at approximately 39 KDa in two of the species, i.e. *Anthapleura elegantissima* and *Bunodusoma cavernata. Aiptasia palluda* , contains a protein that is strongly recognized by anti-LMC2 at about 67 KDa with a fainter band also seen at about 50 KDa. Further, an antibody to another trout P450 involved in sex steroid metabolism, LMC5, does NOT recognize a 39 nor a 67 KDa protein in these anemones. However, a 31 KDa band is recognized by anti-LMC5, although it is much fainter, even with a load of 33 μg per well, then we see with 10 μg per well with anti-LMC2. Anti-LMC2 also recognized a doublet in rat liver microsomes in the 50 KDa range, i.e. the expected range for cytochrome P450. These data suggest very unique proteins in sea anemones with epitope regions similar to those of higher vertebrates, e.g., fish and mammals. Future studies will focus on the responsiveness of these proteins to xenobiotic challenge.

Analyses of cytosolic fractions were conducted to assess the presence of possible stress or heat shock proteins in these organisms. Results of these studies will help to focus on target proteins as potential biomarkers of environmental contamination. Exposure of anemones to the model polynuclear aromatic hydrocarbon, 3-methycholanthrene (3MC) and cadmium caused an increase in a protein band of approximately 70KDa which was recognized in anemone cytosolic fractions by a monoclonal anti-Heat Shock Protein 70 IgG (Figure 3C.12).

As far as we know, this is the first demonstration of induction by a polycyclic aromatic hydrocarbon and cadmium in the sea anemone. A protein of about 90KDa that cross-reacted with a monoclonal anti-heat shock protein 90 IgM was also present in anemone cytosol (data not shown), although this protein did not appear to be induced by exposure to either 3MC or cadmium. A striking result was the induction of an immunoreactive protein band of about 90 KDa by exposure to 25 and 250 μg/liter of $CdCl_2$ that was recognized by a monoclonal antibody raised against scup CYP 1A1. Cadmium also induced a protein of about 96 KDa that was recognized by a trout polyclonal antibody to CYP 3A1. This isoform is steroid-inducible in mammals. Further studies will explore effects of metal exposure on these proteins.

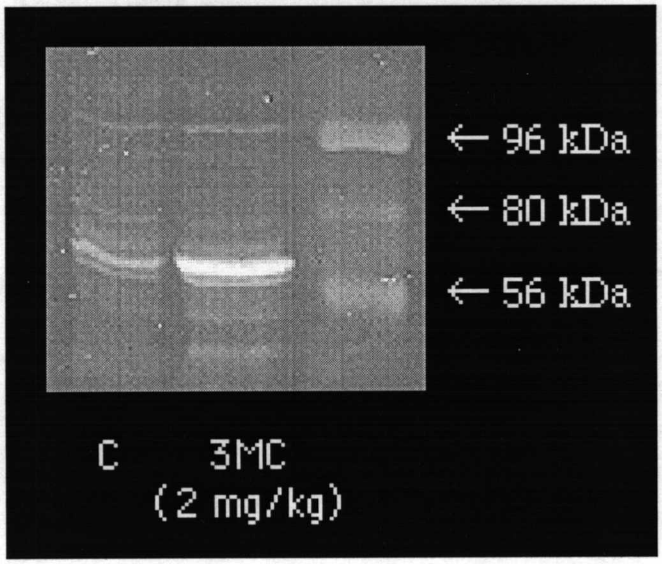

Figure 3C.12. Western blot of *A. elegantissima* cytosol probed with anti-HSP-70 IgG: Induction by 3MC.

Finally, we have measured and characterized the presence of a ferricytochrome c reductase activity in the microsomal fraction of the sea anemone *Anthapleura xanthogramica* (Figure 3C.13). This protein is a rate-limiting component of the microsomal mixed function oxygenase system and to date the only MFO component shown to be induced by environmental organic pollutants in marine invertebrates (Livingstone 1988).

In conclusion, sea anemone species show significant potential as sentinel organisms with respect to biological endpoints. Although biochemical responses are the most rapid to obtain and the most

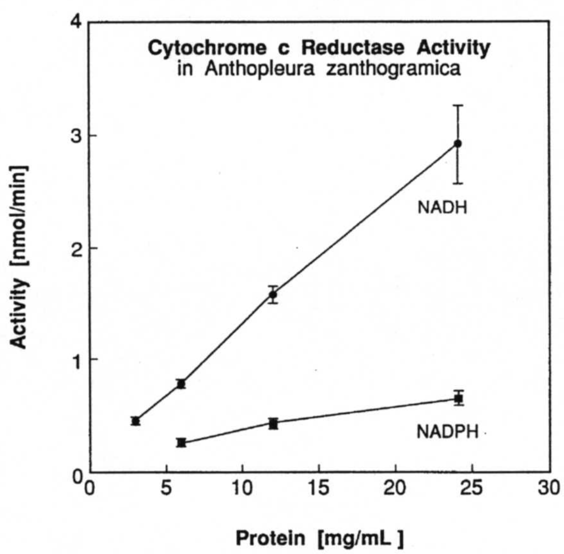

Figure 3C.13 NAD(P)H-cytochrome c reductase activity of *A. xanthogramica* microsomes.

sensitive, it is recognized that they are of limited ecological relevance. Thus, a suite of biomarkers would promote the most comprehensive evaluation of the impact of environmental upsets, whether natural or inadvertant. This is important if regulatory agencies are to be able to assess the impact of ecological perturbations on the higher levels of ecosystem development such as the population or community level. Conversely, ecosystem diversity has highly ecological relevance but suffers disadvantages in the time-frame to collect information and in the sensitivity of the response.

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Dr. Gary Winston has worked for Louisiana State University for the past ten years and serves as Chairman of the Department of biochemistry. His research areas include xenobiotic metabolism, chemical carcinogenesis and biomarkers of environmental contamination. He was an invited participant and facilitator to the NATO Advanced Research Workshop on Biological Markers, Netherlands Institute for Sea Research, Texel, the Netherlands, May, 1991. Dr. Winston received his B.S. in biology and chemistry from the University of Florida, his M.S. in human behavior from Florida Atlantic University, and his Ph.D. in Biochemistry at the University of Nevada.

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SESSION 3D

AGING INFRASTRUCTURE: PIPELINES AND OFFSHORE STRUCTURES

Session: 3D - Aging Infrastructure: Pipelines and Offshore Structures

Co-Chairs: Mr. Gary Rutherford, Mr. Alex Alvarado, and Mr. Felix Dyhrkopp

Date: November 16, 1994

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No manuscript submitted	Mr. Felix Dyhrkopp U.S. Minerals Management Service Gulf of Mexico OCS Region
No manuscript submitted	Dr. Charles Smith U.S. Minerals Management Service Gulf of Mexico OCS Region
No manuscript submitted	Mr. Paul Versowsky Chevron U.S.A., Inc.
Is Age a Major Factor in Pipeline Failures?	Mr. Jay Mandke Southwest Research Institute
No manuscript submitted	Mr. Larry Broussard Tenneco Gas

IS AGE A MAJOR FACTOR IN PIPELINE FAILURES?

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INTRODUCTION

The Gulf of Mexico (GOM) includes close to twenty thousand miles of submarine pipelines. Many of these pipelines are old and are approaching towars the end of their design lives. As a pipeline becomes older, it will be more susceptible to failure. Our experience with onshore steel structures supports such a statement. Hence, it is natural to expect that age may have a significant influence on the pipeline failures. This implies that a large portion of the total number of pipeline failures may be attributed to increase in the age of the associated pipelines. To verify this hypothesis, it is necessary to examine the historical data on pipeline failures. Minerals Management Service (MMS) maintains the most comprehensive data base on pipeline failures in the Gulf of Mexico available in the public domain (Minerals Management Service. "Pipeline Leaks and Breaks." New Orleans, Louisiana). This database contains information on pipeline failures in the GOM since 1967. An examination of a limited subset of this data was performed in order to investigate the correlation between the pipeline age and the number of failures. This paper presents these results.

Typical offshore pipeline is designed for a service life of about 30 to 35 years. It is worth noting that the only explicit calculations relating to design life that enter the design procedure are those relevant to corrosion protection of the line. In most cases this includes sizing of the cathodic protection system or anodes and determines the wall thickness allowance to accommodate loss from internal corrosion/erosion. These design measures protect the pipeline in a less than perfect manner, and with aging the pipelines do deteriorate and show signs of external or internal corrosion, erosion, pitting, and material strength degradation due to fatigue and in service conditions. Also, with the increasing age, the pipeline has an increased exposure to the factors that influence the risk of failure. Repairing a line that is at or beyond its design life becomes uneconomical, and the pipeline operators eventually abandon these old lines.

To understand the influence of age on the potential for pipeline failure during their useful service lives, it is necessary to recognize the different causes of the pipeline failures and the factors that contribute towards such failures.

FAILURE CAUSES

The MMS database includes information on all recorded pipeline failures along with the causes for these failures. These causes can be grouped in to the following principal categories:

- Corrosion, Erosion
- Natural Hazards: Storms, Mud slides
- Third Party Damage: Trawling, Anchors, Construction, Supply Boats
- Material: Weld Failure, Fatigue, Fabrication Defects
- Structural: Valves, Gaskets, Clamps, Connectors, Flanges
- Operational: Pigging, Pressure Surge, Fire/Explosion

Previous work by Mandke on the analysis of failure data for the GOM has shown that corrosion is the greatest source of pipeline failures (J.S. Mandke, "Corrosion Causes Most Pipeline Failures in the Gulf of Mexico," Oil & Gas Journal, October 29, 1990.) Other leading sources of failures include storms/mud slides and third party damage.

FACTORS INFLUENCING FAILURES

The key factors that influence the failures among the submarine pipelines are as follows:

- Pipeline Age
- Pipe Size
- Location (Risers, Proximity to Platform, Shore etc.)
- Product (Gas, Oil, Multiphase etc.)
- Design and Construction Procedures
- Operation, Inspection and Maintenance Procedures
- Water Depth

Not all of these factors could be evaluated in this study. Only the influences of pipe age and pipe size have been evaluated and reported.

FAILURE DATA & ANALYSIS

The MMS data for the years 1988 to 1994 have been evaluated. The database is being continuously updated and did not include all failures that occurred from 1988 and 1994. The subset considered here includes 1,143 reported pipeline failures. Those lines whose age could not be determined were deleted from the sample. This left 1,007 cases of failures analyzed. Figure 3D.1 shows the number of failures reported and analyzed for the years during the period 1988 to 1994. The high number of failures during 1992 are attributed to Hurricane Andrew. Figure 3D.2 shows the effect of grouping these failures into main cause categories. As reported earlier, corrosion is the major source of pipeline failures. The pipeline failures due to Hurricane Andrew are currently being studied under a separate project sponsored by MMS.

The failure database includes pipes in sizes ranging from 2 inches to 36 inches. For the sake of discussion, it is convenient to divide pipelines in to three groups based on the nominal pipe outside diameter (OD). These are: small (2"-6" OD), medium (8"-16" OD) and large (18"-36" OD). The total lengths of the lines installed in the GOM are respectively, 8,167 miles, 8,332 miles, and 3,776 miles for the small, medium and large size pipe groups. About 2,166 miles of these lines have been abandoned or put out of service. Thus, by grouping failure data according to pipe sizes and the failure cause, it is possible to ascertain the influence of the pipe age on the different sources of failures. These results are described next.

Corrosion

About 370 failures from 1,007 were attributed to corrosion. They include 37 in large pipe size, 134 in medium pipe size, and 199 in small pipe size. The average age of the pipeline at failure has been around 19 years. Figure 3D.3 shows the percentage distribution of failure data for each pipe size group according to age which is again grouped in to four categories: 0-10, 11-20, 21-30 and 31-40 years. This figure shows that for the large size pipes, the largest percentage of failures occurred during 21-30 years age of the lines, and the failure percentage increases with the age group. The medium size lines show a similar pattern except for a small percentage of lines that failed in the 31-40 years of age. Hence, for both groups, the pipe age seems to have a significant influence on corrosion failures. For small size pipes, the largest percentage of failures occurred during 11-20 years of age and a significant number failed during 0-10 years of age. For this group, pipeline age does not appear to have a significant influence on corrosion failures. If corrosion failures for all sizes are combined and grouped as per the age group of failed lines, the result is as shown in Figure 3D.4. This figure shows that for all pipe sizes, a majority of corrosion failures have occurred in the first 20 years of service life. There is no proportional correlation between the pipe age and the percentage of corrosion failures.

Third Party Damage

Sixty-six failures occurred from third party damage to pipelines. They include 7 among large size (average age 17 years), 18 among medium size (average age 12 years) and 41 among small size (average age 8 years) lines. Figure 3D.5 shows the failure data distribution for different size lines according to age group. This shows that for small and medium size lines, the largest number of failures have occurred within 10 years of age. The same trend exists when data for all pipe sizes is combined and grouped as per age (Figure 3D.6).

Storm/Mud Slides

The data included 418 failures due to storm and mud slides. Most of the damage has been among small size lines (352 cases). The large and the medium size lines had 16 and 53 failures, respectively. The average age of the failed lines was 16 years for large size, 15 years for medium size and 10 years for small size lines. Figure 3D.7 shows that for the small size lines, the majority of failures occurred within 10 years of age. For the large and the medium size lines, most of the failures occurred in the age group 11-20 years. Figure 3D.8 shows that the overall storm failures for all pipe sizes decrease with the increasing age group.

Structural Failures

Out of 59 structural failures in the analyzed sample, 33 were among medium size lines and 18 among small size lines. The majority failures (59%) occurred in the pipeline age group 11-20 years, 20% among the 0-10 years age group and the remaining 13% among the 21-30 years age group.

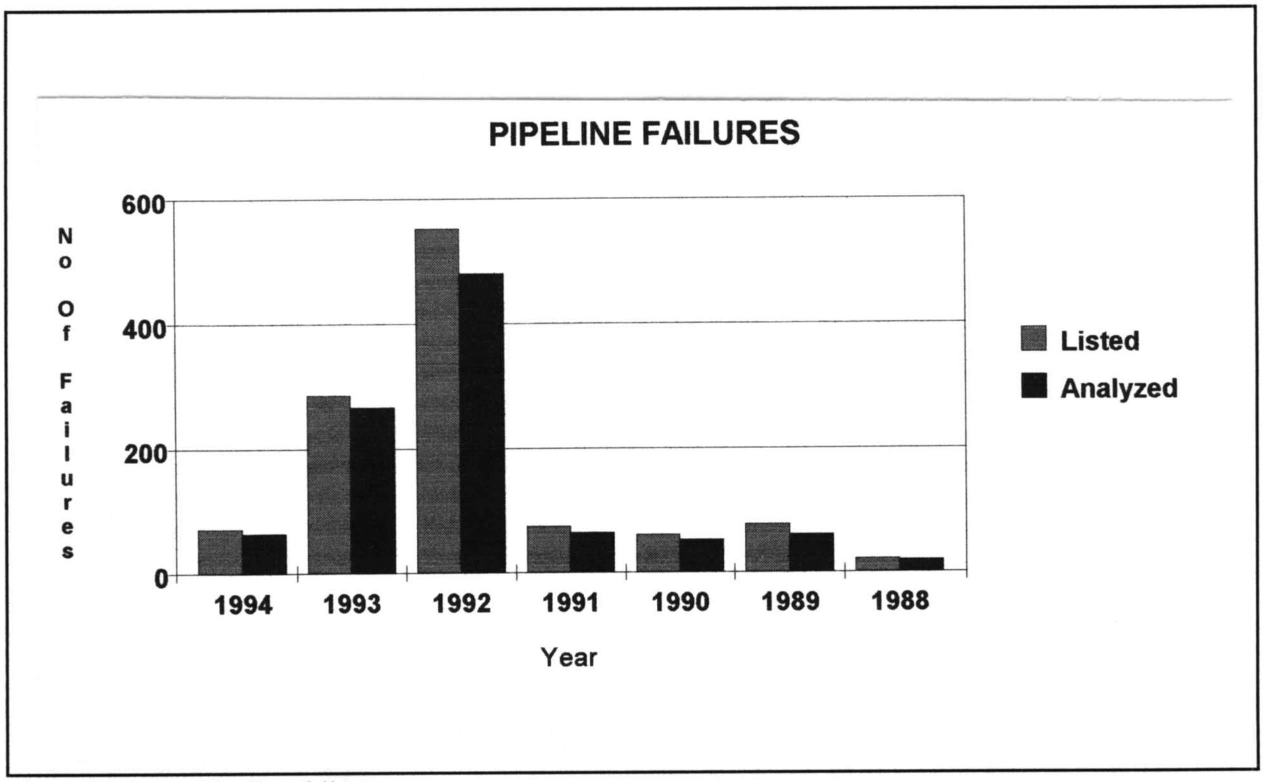

Figure 3D.1. Pipeline failures.

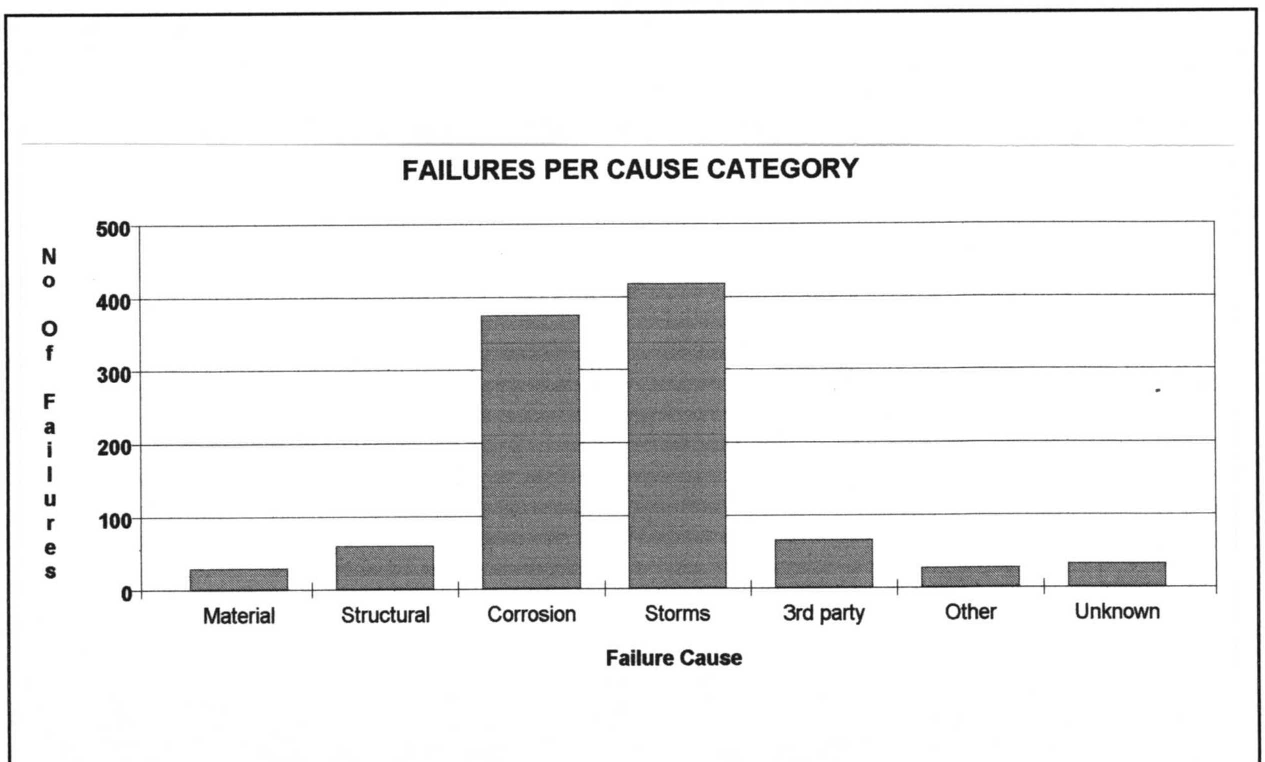

Figure 3D.2. Failures per cause category.

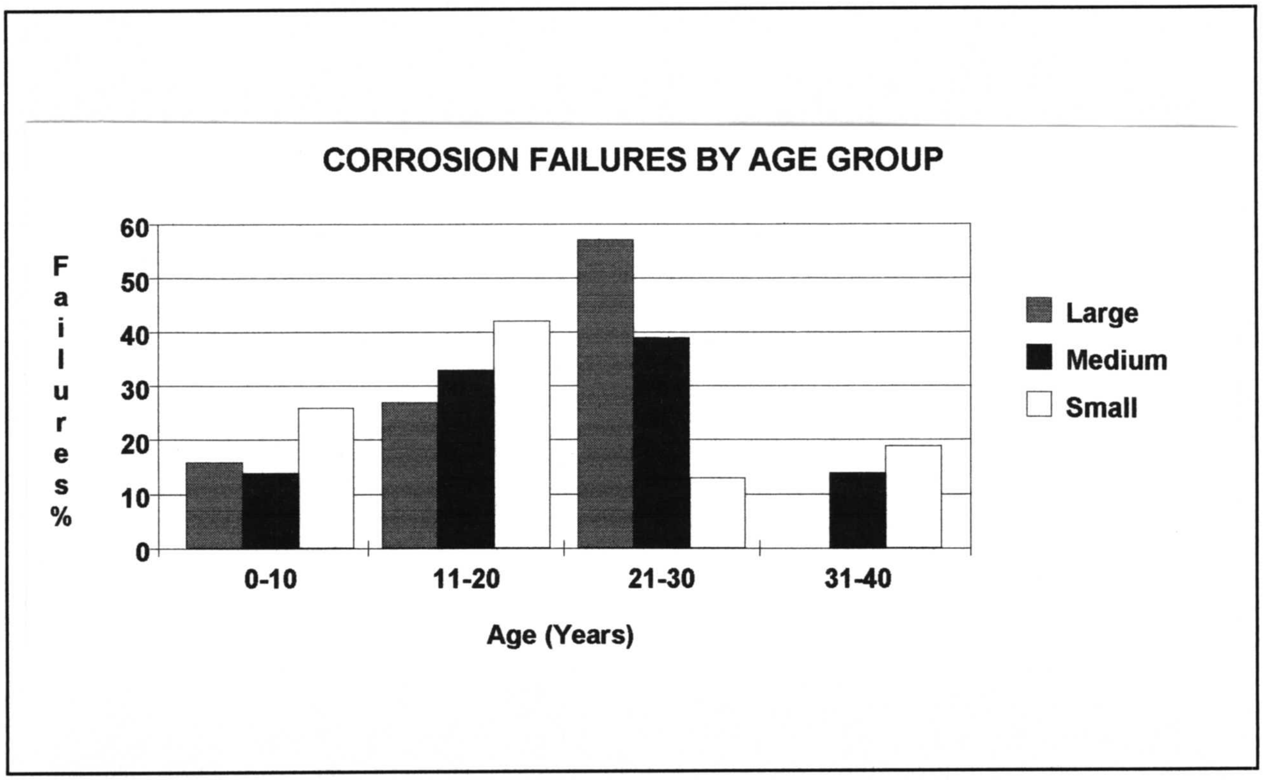

Figure 3D.3. Corrosion failures by age group.

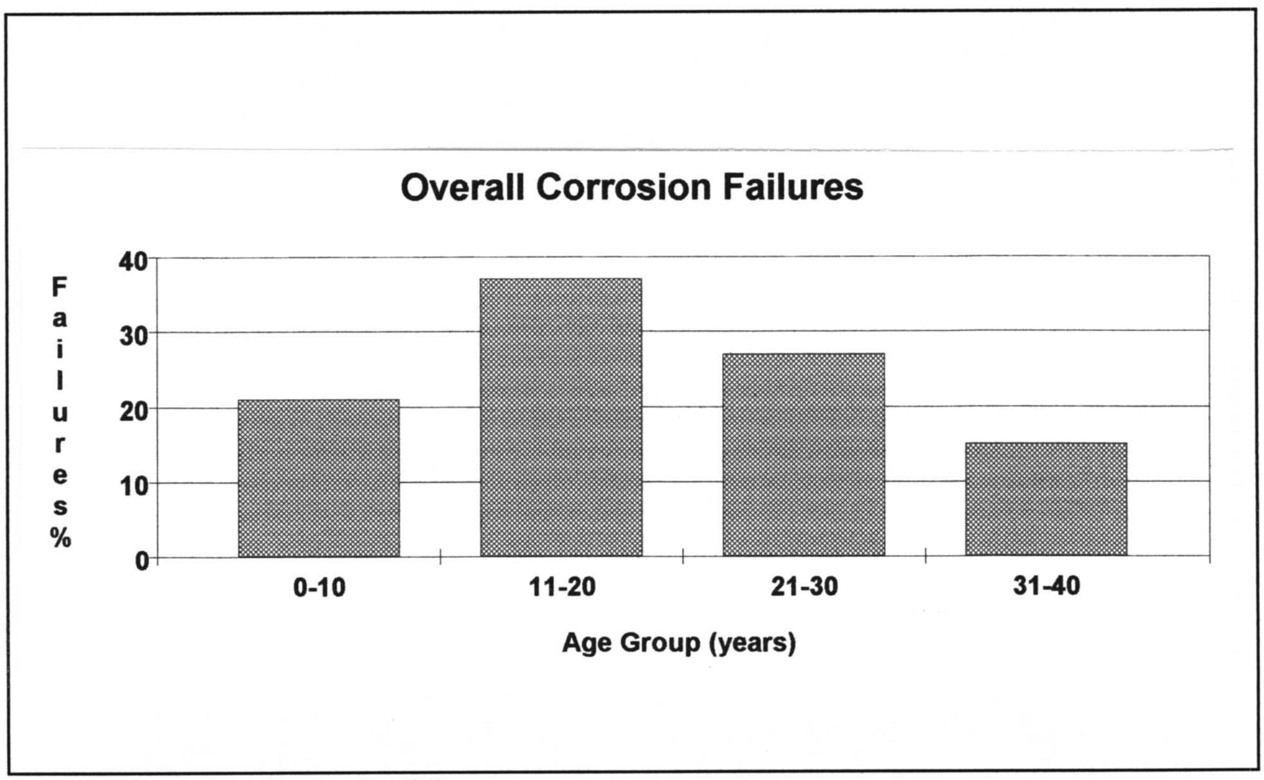

Figure 3D.4. Overall corrosion failures.

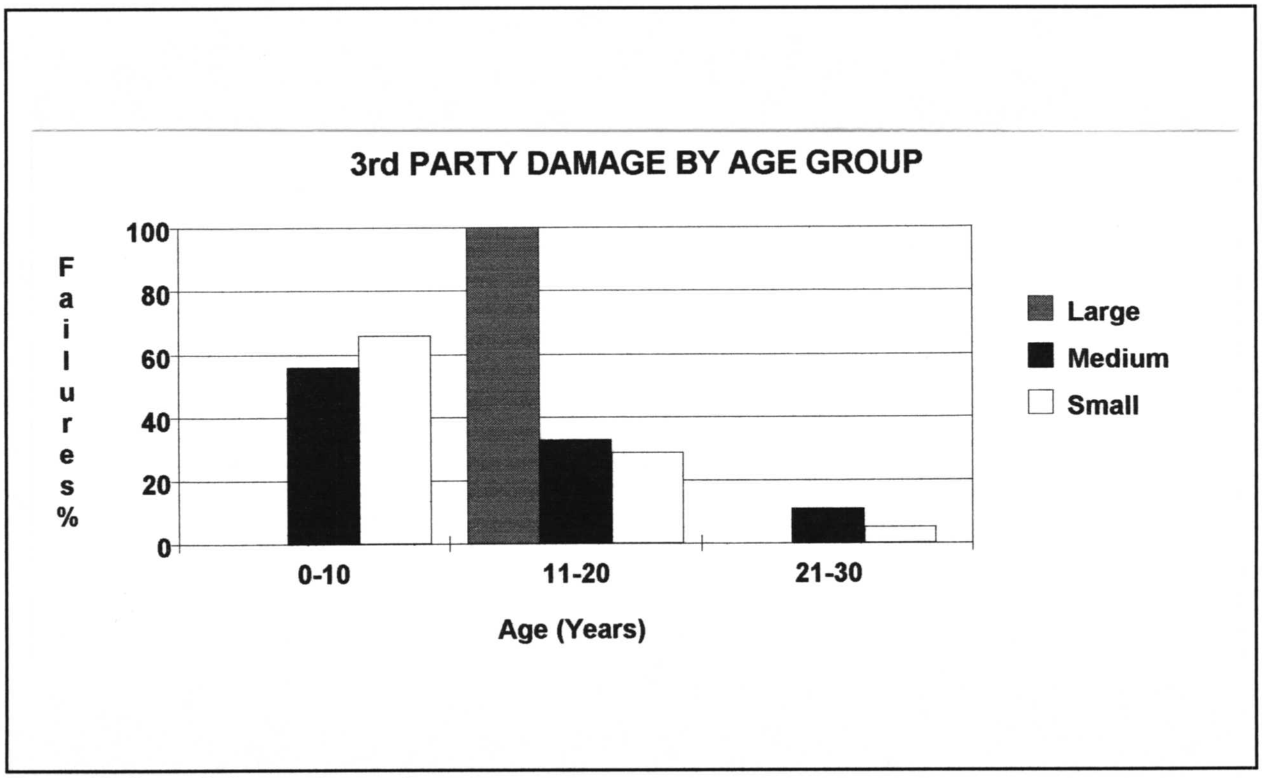

Figure 3D.5. 3rd party damage by age group.

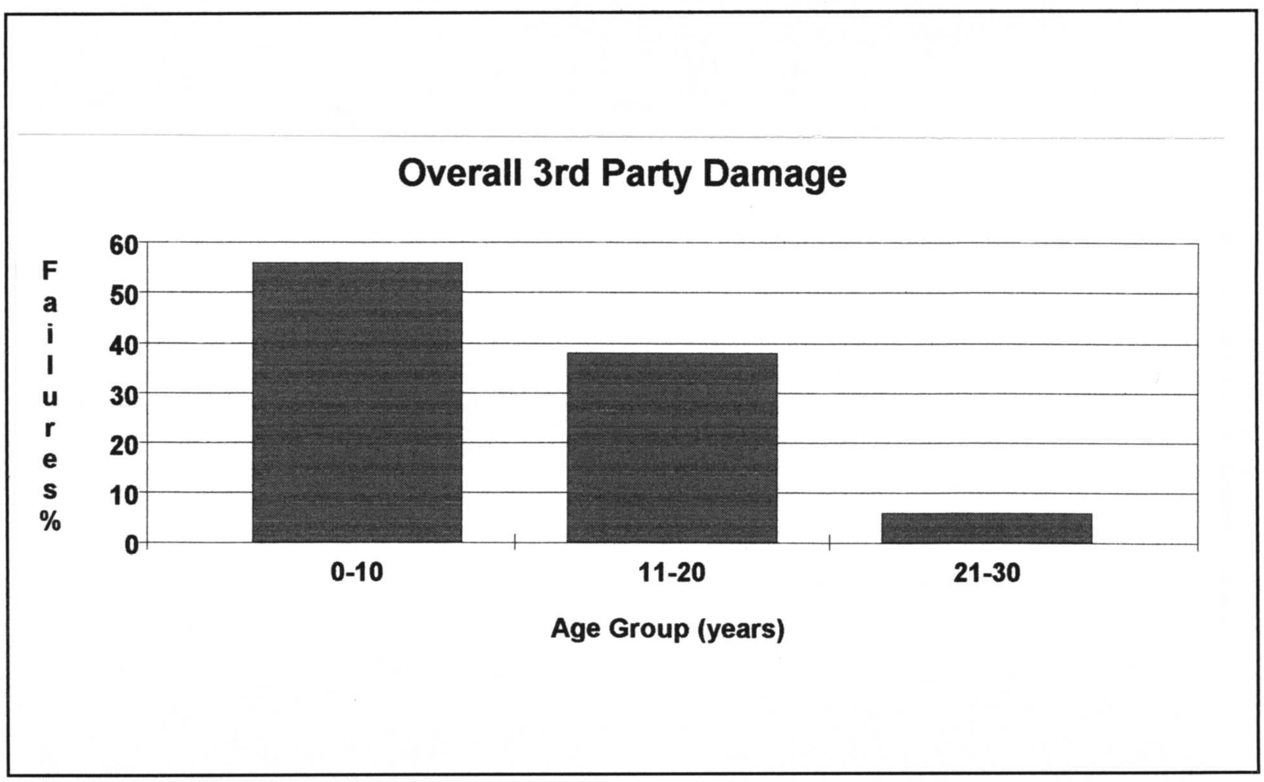

Figure 3D.6. Overall 3rd party damage.

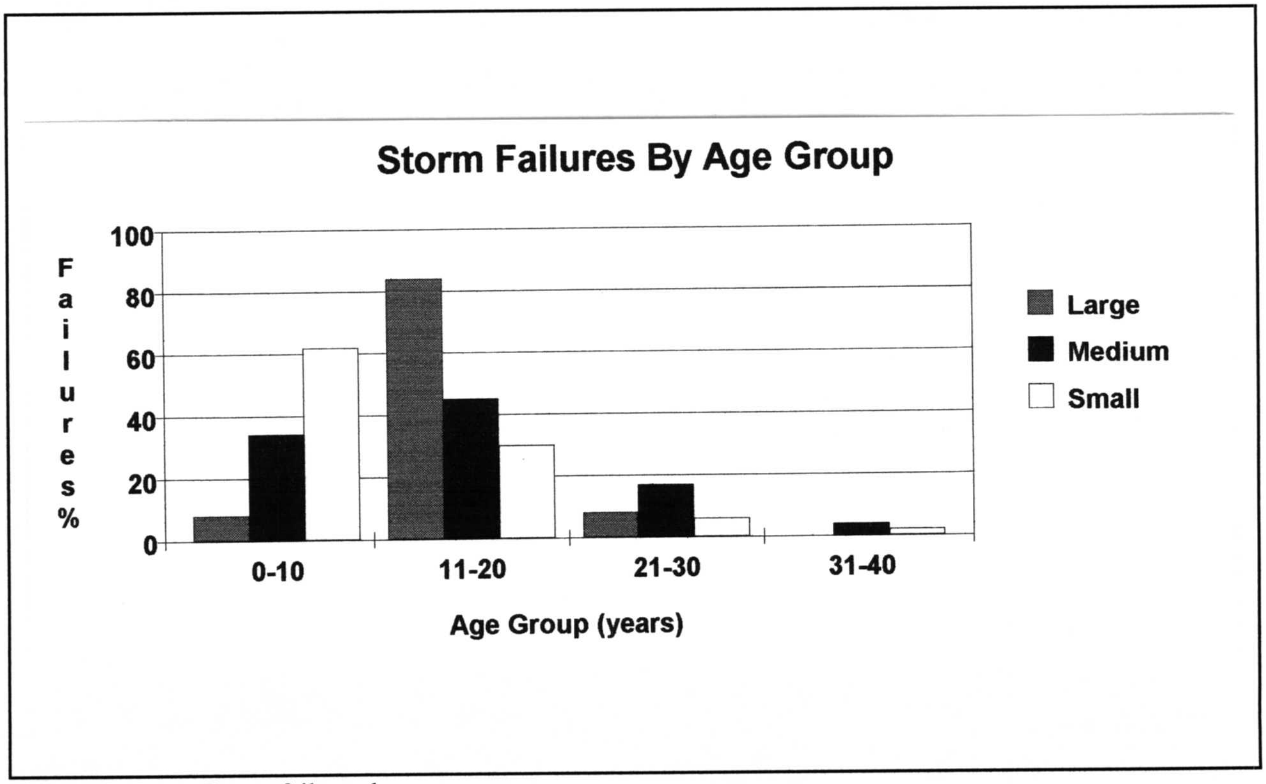

Figure 3D.7. Storm failures by age group.

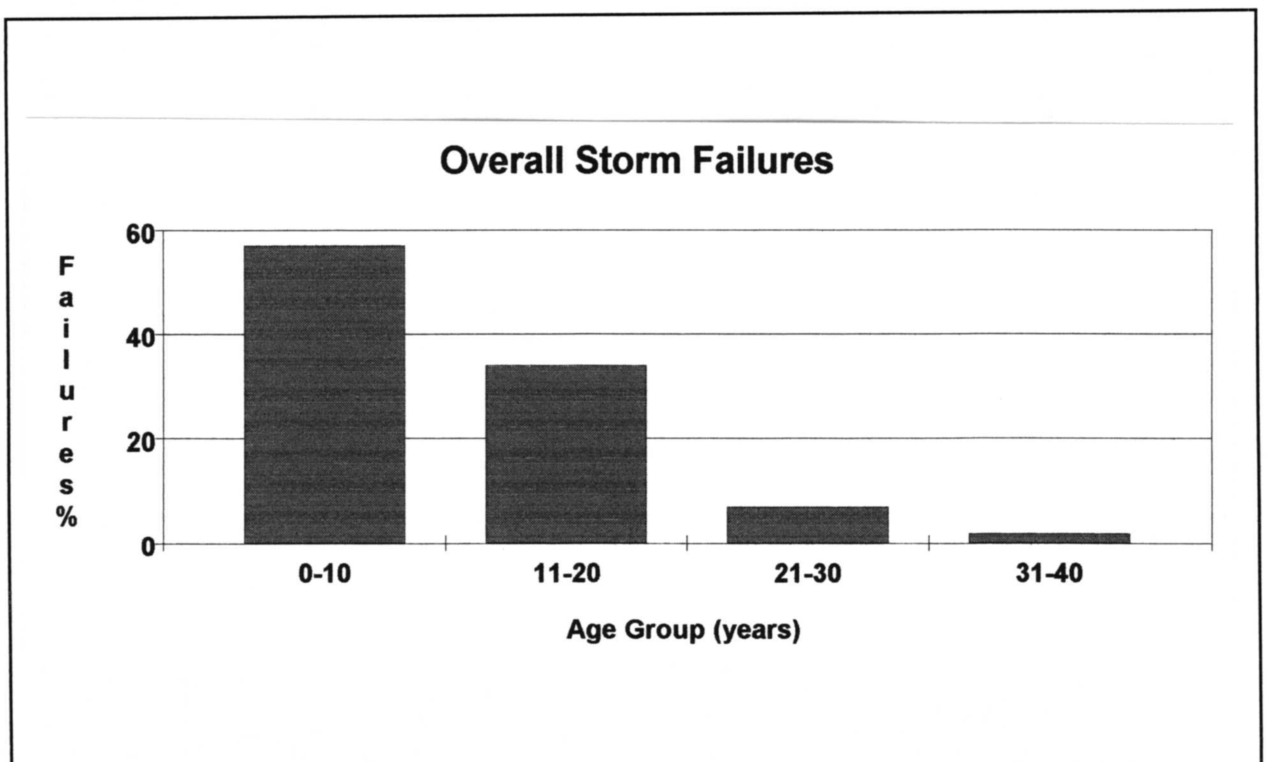

Figure 3D.8. Overall storm failures.

Material Failures

Twenty-nine cases of material failures were analyzed. They included 5 in the large size, 18 in the medium size and 6 in the small size lines. About 35% of failures occurred in the age group 0-10 years and 62% among the age group 11-20 years. Thus, like structural failures, most of the material failures occurred within the first 20 years of pipeline service life.

CONCLUSIONS

Obviously, the age is a determining factor in deciding when to abandon the pipeline. Most pipelines are put out of service after 30 to 35 years. But during their service lives, the failure frequency does not seem to have a strong correlation with the pipeline age.

Only for corrosion failures in large and medium size lines, pipe age seems to be an important factor. In all other cases of failures analyzed, the influence of age on pipeline failures is not a major factor. In these cases, most of the failures have occurred within the first 20 years of pipeline life.

For the data analyzed, largest number of pipeline failures have occurred among small size lines. Thus, pipe size has a more significant influence on failures than the pipe age.

SESSION 4A

LATEX-SEASONDE COOPERATIVE EXPERIMENT

Session: 4A - LATEX-SEASONDE COOPERATIVE EXPERIMENT

Co-Chairs: Dr. Alexis Lugo-Fernandez and Dr. Murray Brown

Date: November 17, 1994

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TexSonde '94: Project Overview	Dr. Donald O. Hodgins Seaconsult Marine Research Ltd. Vancouver, Canada
Satellite Observations During the TexSonde Experiment	Dr. Lawrence J. Rouse Coastal Studies Institute Louisiana State University Ms. Sally E. Tinis SeaConsult Marine Research Ltd. Vancouver, Canada
Current Meter Observations During the TexSonde Experiment	Mr. Edward T. Weeks, IV Dr. Stephen P. Murray Coastal Studies Institute Louisiana State University
Tracking Buoys for Oil Spills	Dr. Ron Goodman Imperial Oil Resources Ltd. Calgary, Alberta, Canada Ms. Debra Simecek-Beatty NOAA HAZMAT Hazardous Materials Response and Assessment Division Seattle, Washington
TexSonde '94: Current Prediction	Dr. Donald O. Hodgins Ms. Sally E. Tinis Seaconsult Marine Research Ltd. Vancouver, Canada
MMS and the TexSonde Field Experiment	Dr. Walter Johnson U.S. Minerals Management Service Headquarters Environmental Operations and Analysis

INTRODUCTION

Dr. Alexis Lugo-Fernandez
U.S. Minerals Management Service
Gulf of Mexico OCS Region

TexSonde '94 was a multi-agency study of the local circulation in the Gulf of Mexico off Galveston, Texas using SeaSonde HF radar technology. The experiment took place in March and early April 1994. The objectives of the experiment were to characterize the high-frequency variability of surface currents (spatial scales of < 1 km and time scales of 2 - 120 hours), gained a better understanding of the factors governing the currents in the approaches to Galveston, and examine the performance of the SeaSonde Radar technology in terms of accuracy and utility for use as oil spill mode input. This session's presentations addressed the logistical aspects of the experiment and the results obtained that helped achieve the objectives of the experiment. This experiment was a successful first step in evaluating the usefulness of SeaSonde radar technology for oil spill response and track prediction capabilities.

Dr. Alexis Lugo-Fernandez is an oceanographer with the Minerals Management Service, Gulf of Mexico OCS Region. His primary interest are physical processes on coral reefs and shelf circulation. Dr. Lugo-Fernandez obtained his B.S. in physics and his M.S. in marine sciences from the University of Puerto Rico and his Ph.D. in marine sciences—physical oceanography—from Louisiana State University.

TEXSONDE '94: PROJECT OVERVIEW

Dr. Donald O. Hodgins
Seaconsult Marine Research Ltd.
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BACKGROUND

Remote sensing of ocean currents using high-frequency shore-based radars has advanced rapidly in the past 10 years, and it is now possible to routinely collect hourly surface current maps showing circulation features with spatial scales of 1,000 m and less (Hodgins 1994). TexSonde '94 was a multi-agency study of the local circulation in the Gulf of Mexico off Galveston, Texas, conducted in March and early April 1994 using the 12.5 MHz SeaSonde HF radar. The project objectives were to

1) characterize the high-frequency variability in surface currents (spatial scales of 1 km and time scales of 2-120 hours),
2) provide a better understanding of the factors governing currents in the approaches to Galveston Bay, in particular, the behavior of estuary outflows as they interact with the coastal current,
3) examine the performance of the SeaSonde radar in terms of the accuracy of measured currents and the utility of the data for oil spill model input.

OBSERVATIONS

The field program provided a comprehensive data set, consisting of

1) hourly surface current maps for one month averaging 40 km in offshore range and 25 km alongshore, measured with the SeaSonde HF radar;
2) AVHRR imagery on all clear days (14 images);
3) overwater winds at buoy 42035;
4) water level at Galveston (Gulf of Mexico side);
5) current meter mooring with instruments at 4, 9 and 14 m;
6) CTD data along three transects at 5-km spacing;
7) current observations using GPS-positioned surface drifters during a one-day intensive program (24 March);
8) current observations using satellite-positioned drifters (various designs) collected as part of MMS's SCULP program.

The location of the various instruments is shown in Figure 4A.1. The objective was to obtain data suitable for evaluating the radar current maps, and as far as practical instruments were positioned to allow

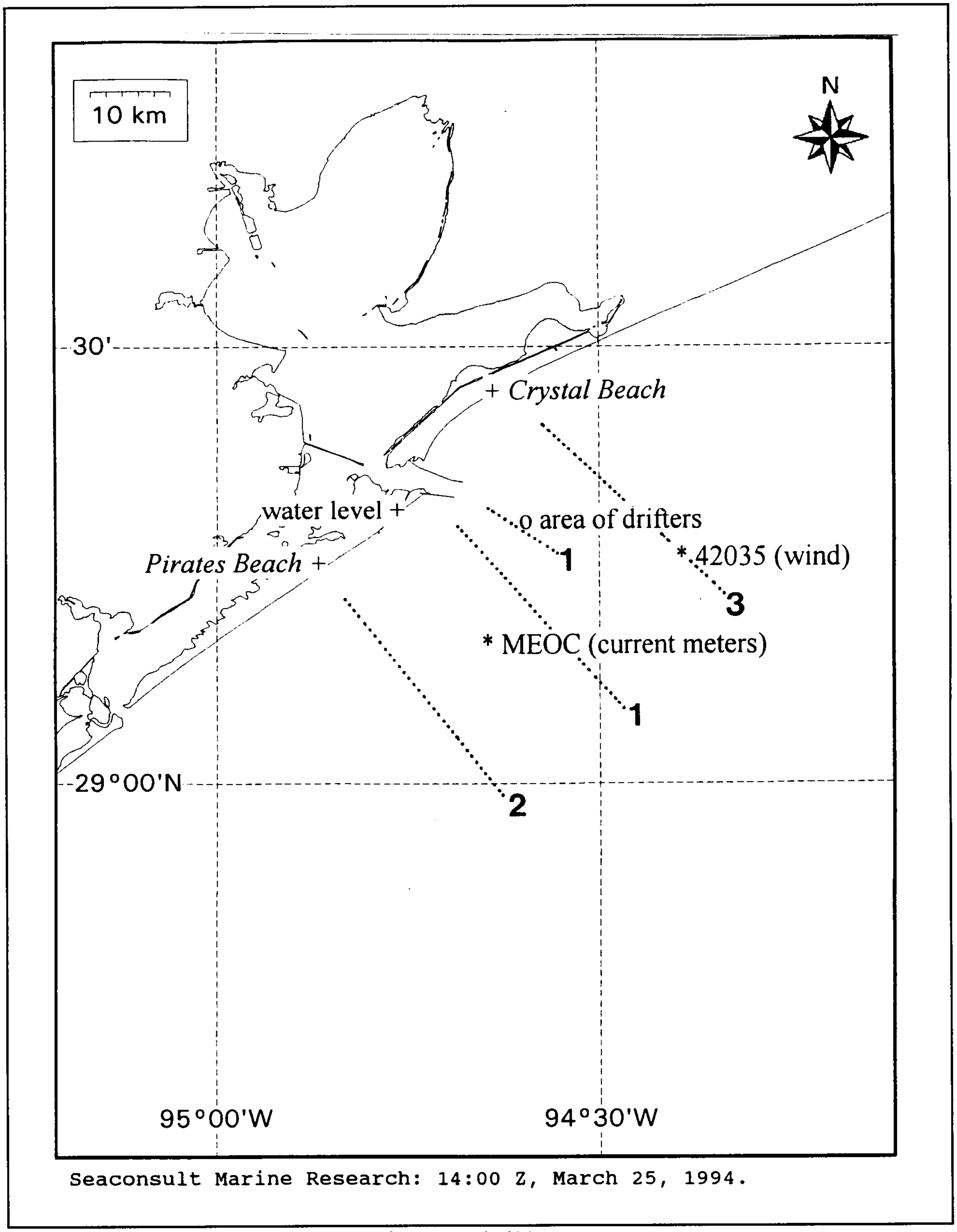

Figure 4A.1. Disposition of instruments for TexSonde '94.

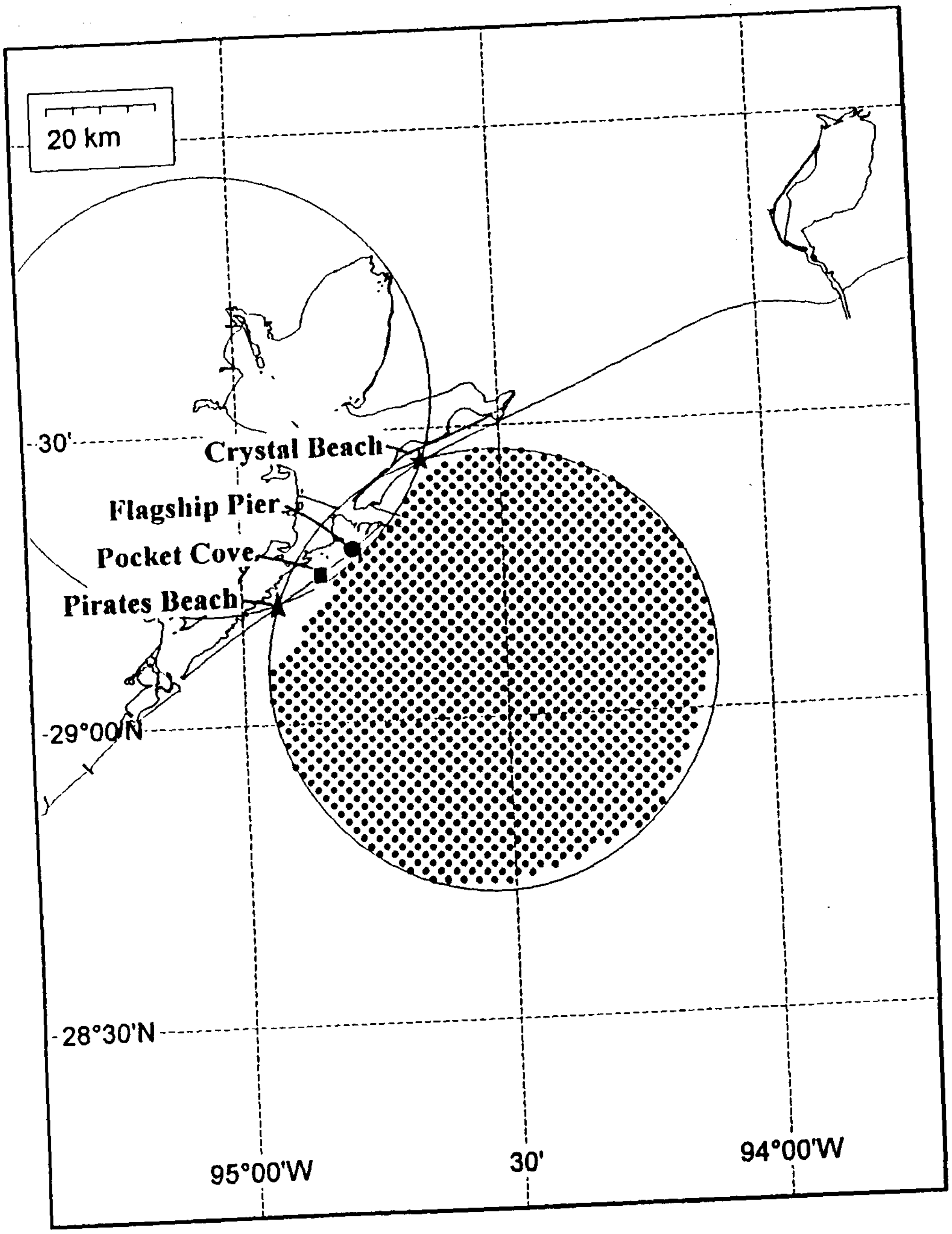

Figure 4A.2. SeaSonde coverage area for the first deployment.

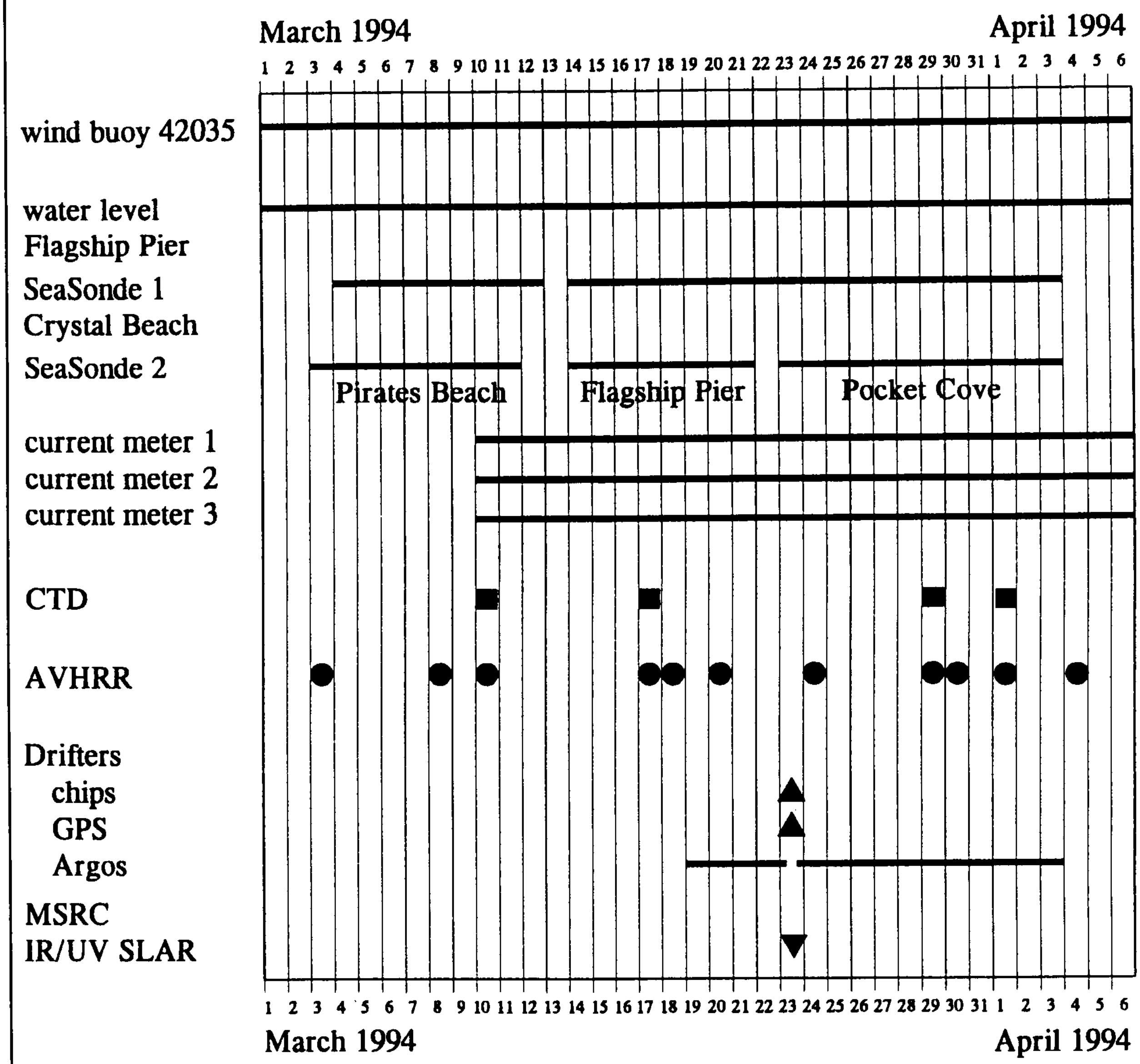

Figure 4A.3. Periods of data recovery for TexSonde '94.

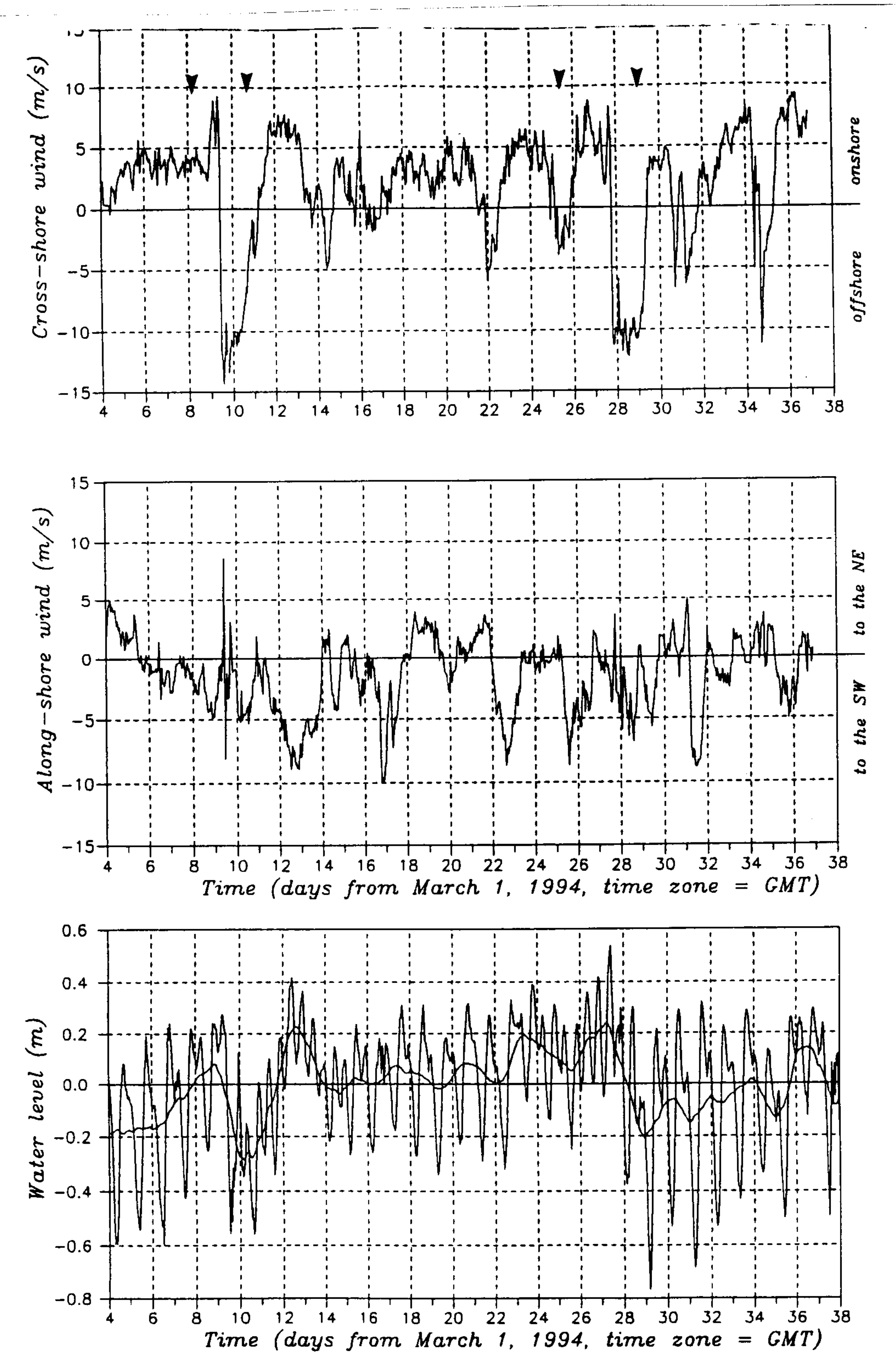

Figure 4A.4. Wind and water level records for TexSonde '94.

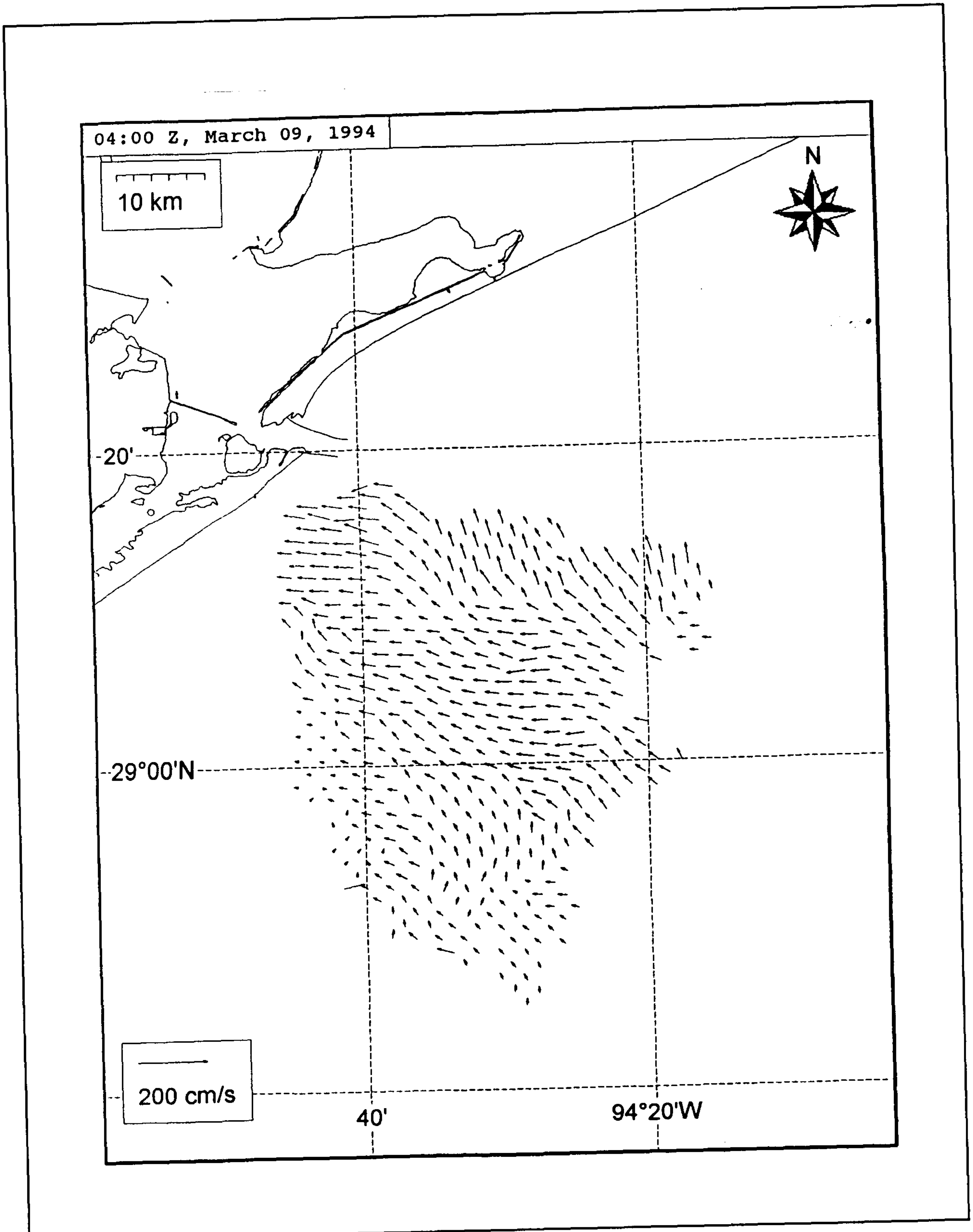

Figure 4A.5. Surface currents during onshore winds.

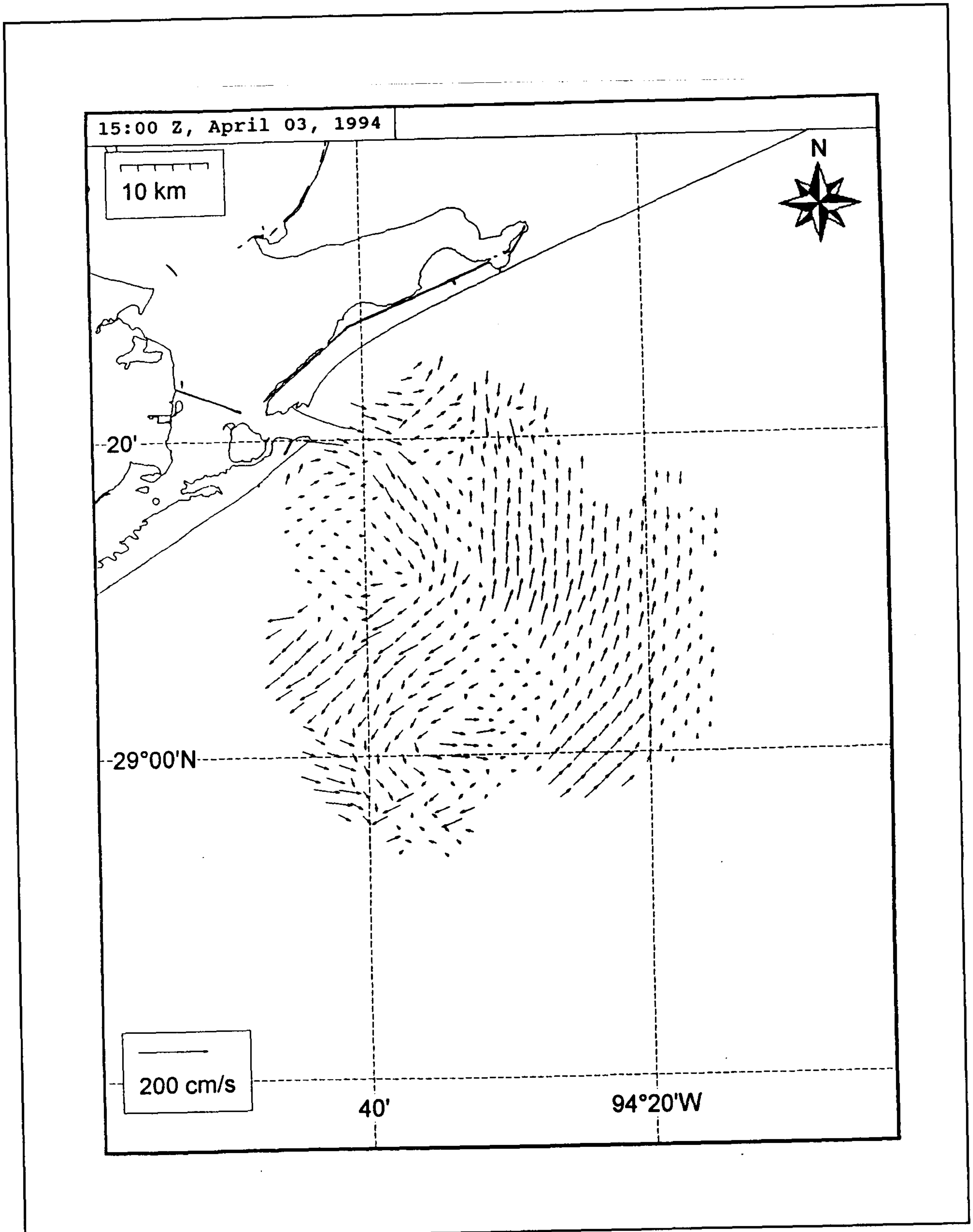

Figure 4A.6. Galveston Bay jet flow during offshore winds.

intercomparison between measurements. The SCULP drifters generally moved steadily through the radar coverage area (Figure 4A.2), providing only a few data points near Galveston.

The data recovery periods are summarized in Figure 4A.3. The radar was deployed in three congifurations, and, hence, the surface current maps are presented in three groups. Antenna pattern distortion reduced the reliability of the second group of maps compared with the first and third, which were nearly optimal in terms of antenna siting on the beach.

PRELIMINARY INTERPRETATION

The data provide insight into the mechanisms producing local changes in the coastal current. The wind record is shown in Figure 4A.4, rotated to illustrate along-shore and cross-shore flows. The arrowheads show the times of the AVHRR images. March is generally a windy month in Galveston, with a prevailing onshore, moist flow from the southeast broken intense episodes of offshore flow generated by transitory continental weather systems. The wind stress time-series is highly correlated with the water level record, showing a rise in level for the onshore wind and a fall in level for the offshore flow (wind surge). These low-frequency water level variations are larger than the local tide, which is less than 1 m. Figure 4A.5 is typical of conditions during onshore winds. The surface currents are predominantly directed onshore and to the southwest, and the influence of the discharge jet from Galveston Bay, which is weakly modulated by the tide, is scarcely evident. The record-length mean surface current was 35 cm/s alongshore, and approximately 5 cm/s onshore. During offshore winds brackish water from the bay flow out through Bolivar Roads and forms a jet penetrating into the coastal current some 15-20 km (Figure 4A.6). This jet deflects the alongshore flow further offshore, and creates a localized eddying motion behind the jet.

This jet can be explained by the effect of the wind stress. As the water level falls offshore, a pressure head is set up through Bolivar Roads that drives the bay water out. Although the tidal modulation is present it does not always change the direction of the pressure gradient, and the outflow persists for a day or more. The gradient is also maintained by the wind stress across Galveston Bay itself, which tends to pile water up along the barrier islands.

Once the wind changes back to the prevailing condition, the surface current flow is restored and the coastal current moves back closer to the shoreline.

CONCLUSIONS

The TexSonde '94 dataset provides valuable insight into the causes and strength of fluctuations in the surface current within 50 km of the coast, at periods of a few hours to a few days. The HF radar system yielded reliable data during the first and third deployments. Reception was found to be sensitive to the wind direction, and during periods of rapid wind reversal the current coverage was reduced through the absence of backscattering waves. The surface current maps and the AVHRR images showing contrasting water mass and fronts were found to be correlated (the current fields aided interpretation of the water masses distinguished in the imagery in terms of their sources and movement).

REFERENCE

Hodgins, D.O., 1994. Remote sensing of ocean surface currents with the SeaSonde Radar. To appear Spill Science and Techn. Bull.

Dr. Donald O. Hodgins is a physical oceanographer and Research Director for Seaconsult Marine Research Ltd. His interests include ocean circulation observation and modeling and satellite remote sensing. Over the past six years he directed Seaconsult's research leading to the development of the SeaSonde HF radar, and he has been the principal scientist on the coastal current studies carried out using this radar system.

SATELLITE OBSERVATIONS DURING THE TEXSONDE EXPERIMENT

Dr. Lawrence J. Rouse
Coastal Studies Institute
Louisiana State University

Ms. Sally E. Tinis
SeaConsult Marine Research Ltd.
Vancouver, Canada

During March 1994, we collected AVHRR imagery of the east Texas shelf in support of the TexSonde Experiment. The AVHRR imagery was collected by the Earth Scan Lab, Coastal Studies Institute, Louisiana State University. The data were calibrated, registered, and converted to sea surface temperature. The imagery were analyzed to enhance the structure of the sea surface temperature. The images were also subjected to a Sobel Filter to enhance frontal edges in the thermal imagery. Unfortunately, March 1994 was a cloudy month in the vicinity of Galveston, and we were able to acquire only 14 images of the sea surface between 1 March and the end of the experiment in early April.

As part of the analysis, we attempted to relate frontal positions and velocities determined from the AVHRR imagery with similar measurements acquired by the SeaSonde System of SeaConsult Marine Research, Ltd. In some cases there was no SeaSonde vector concurrent with the imagery or the concurrent field data set was extremely limited. In these cases, the closest (in time) vector map with broad coverage was compared with the satellite imagery.

Three image pairs were obtained—during the month of March. (Image pairs means two images of the area acquired within a 12 hour period). These image pairs were acquired on 3, 10, and 17 March, with separation times ranging from approximately 3 to 12 hours. No SeaSonde data were acquired coincident with the 3 March images (separated in time by two hours and 45 minutes). These images have the best examples of bay discharge plumes in the data set. By measuring the displacement of these plume fronts, the surface velocities were estimated to be on the order of 60 to 70 cm/s to the west-southwest (220°).

The second pair of images, on 10 March, were separated by a little less than eight hours. The surface temperature estimates for the first image (1425Z) indicated only weak thermal fronts south of Galveston. This weak thermal front seems to correlate with what appears to be a convergence front in the SeaSonde data acquired at 1400Z. The second image on 10 March (2220Z) has no corresponding SeaSonde data, but a moderate front appears to be present at the location of the weak front in the earlier image.

The third pair of images was acquired on 17 March. This image pair, separated in time by a little more than 11 hours, had the best examples of a coastal front. By tracking the movement of locations on these fronts, we estimated velocities to be on the order of 10 to 15 cm/s, to the southwest (230°). No SeaSonde data are available for the first image (1115Z). The nearest (in time) broad coverage SeaSonde data set for the second image (2235Z) was acquired at 2100Z. The SeaSonde data indicated a front about 20 km offshore and a hint of a front at about 40 km offshore. Between these two fronts, the flow is indicated to the northeast. At the front 40 km offshore, the velocities are very low, and it is this front that appears to be moving to the southwest in the imagery.

In the context of the TexSonde study, we find that the satellite imagery complements the data acquired by the HF radar and can aid in the interpretation of the data and extend it to a larger area. The small number of coincident images and HF radar derived surface current maps limits the reliability of the conclusions that can be drawn, but the combination of satellite imagery and HF radar data can provide information that can be useful in monitoring and predicting the movement of oil spills.

Dr. Lawrence J. Rouse is an Associate Professor with the Coastal Studies Institute and the Department of Oceanography and Coastal Sciences at Louisiana State University. His research interests are in the area of shelf and coastal physical oceanographic processes and remote sensing of these processes. He is presently a principal investigator on several funded research projects including Task B of the Louisiana-Texas Shelf Physical Oceanographic Program sponsored by the Minerals Management Service.

CURRENT METER OBSERVATIONS DURING THE TEXSONDE EXPERIMENT

Mr. Edward T. Weeks, IV
Dr. Stephen P. Murray
Coastal Studies Institute
Louisiana State University

The TexSonde Experiment was conducted in the coastal waters off Galveston, Texas (Figure 4A.7) in March and April 1994 to evaluate the "SeaSonde" instrumentation, a system that uses ground-wave radar to map near-surface ocean currents. Concurrently, Coastal Studies Institute (CSI) at Louisiana State University (LSU) deployed a three-level current meter mooring near the center of the radar footprint. Endesco large impeller current meters were positioned at 4, 9, and 14 meters below the surface in water 17 m deep. Data return was close to 100 percent over the one-month observation period. Mid-deployment CTD casts showed a two-layer hydrologic structure in the test area. The upper current meter (CM1) is embedded in a low salinity surface mexed layer that reads from the surface down to about eight meters. The lowest current meter (CM3) resides in the high salinity (32 psu) lower layer, while CM2 is in the transitional zone (halocline) between the two layers.

Vector stick plots (Figure 4A.8) of CM1 in the surface layer show a persistent southwesterly current with nominal speeds of 40 cm/s. Thus, the predominant flow is topographically constrained in the along-shore direction. This persistent current is interrupted by one- to-two-day periods of weak and even reverse currents. Tidal and intertidal current fluctuations are present but of considerably smaller magnitude. In contrast, CM2 and CM3 in the lower layers show considerably smaller nominal speeds of 15 cm/s, also to the southwest. Tidal or inertial oscillations are more apparent in these records.

Winds from a contiguous buoy indicate that wind energy, in contrast to the surface currents, is highly polarized in the north-south direction. A persistent southerly wind regime is interrupted at three- to-five-day intervals with northerly wind episodes associated with migrating pressure systems. Surprisingly, the upper layer currents and the local winds appear poorly correlated. For example, strong southwest currents on 14-17 March are coincident with a period of weak variable southerly winds. Similarly, the strongest frontal passage of the month, on 28 March, produced north-northeasterly winds of approximately 20 knots that had little effect on the already prevailing southwestward current. The longshore flow this time is apparently not driven by local wind forcing but rather by remote events on large scale pressure gradients.

Figure 4A.9 compares the SeaSonde radar current to the upper current meter record over a three-week period. Both records indicate a persistent southwestward flow interrupted by several-day periods of weaker and more variable currents. These are periods of reasonably good agreement between the radar and the current meter observations, such as on 24-27 March when both showed southwest currents of 40-50 cm/s. In general, radar currents appear to be about 1.5 times stronger than the current meter, which is perhaps related to vertical shear in the upper four meters. There are also periods of rather poor correlation, such as on 15 March and 1-4 April when the current showed southwest currents of 60-70 cm/s and the radar showed much weaker westward currents. Comparison of 40-hour low-pass time series of the U and V components also indicates only a general agreement between radar and current meter observations.

Progressive vector diagram plots of the current meters and the radar current are shown in Figure 4A.10. The persistently southwestward flow is evident in all traces, but the apparent displacement of the SeaSonde falls considerably short of the upper current meter.

The deployment of the current meters was supported by a cooperative agreement between the Minerals Management Service and Louisiana State University, entitled "Drifter Study in the Mississippi River Plume."

Mr. Edward T. Weeks, IV, is a Research Associate at Louisiana State University in the Coastal Studies Institute. He received a B.S. in atmospheric science from Northeast Louisiana University in 1992, and he has been working on Louisiana coastal currents since then.

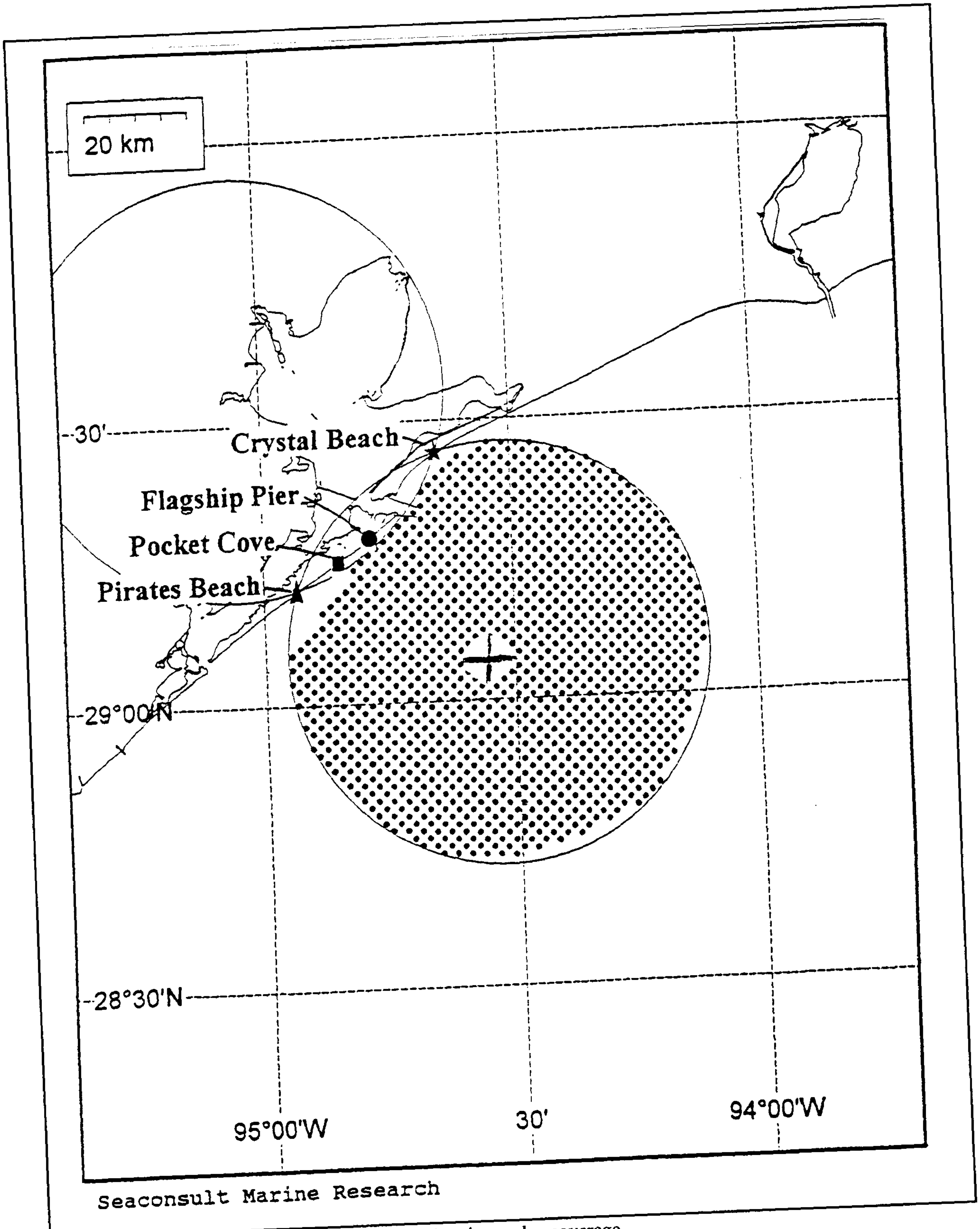

Figure 4A.7. Location of mooring array, showing radar coverage.

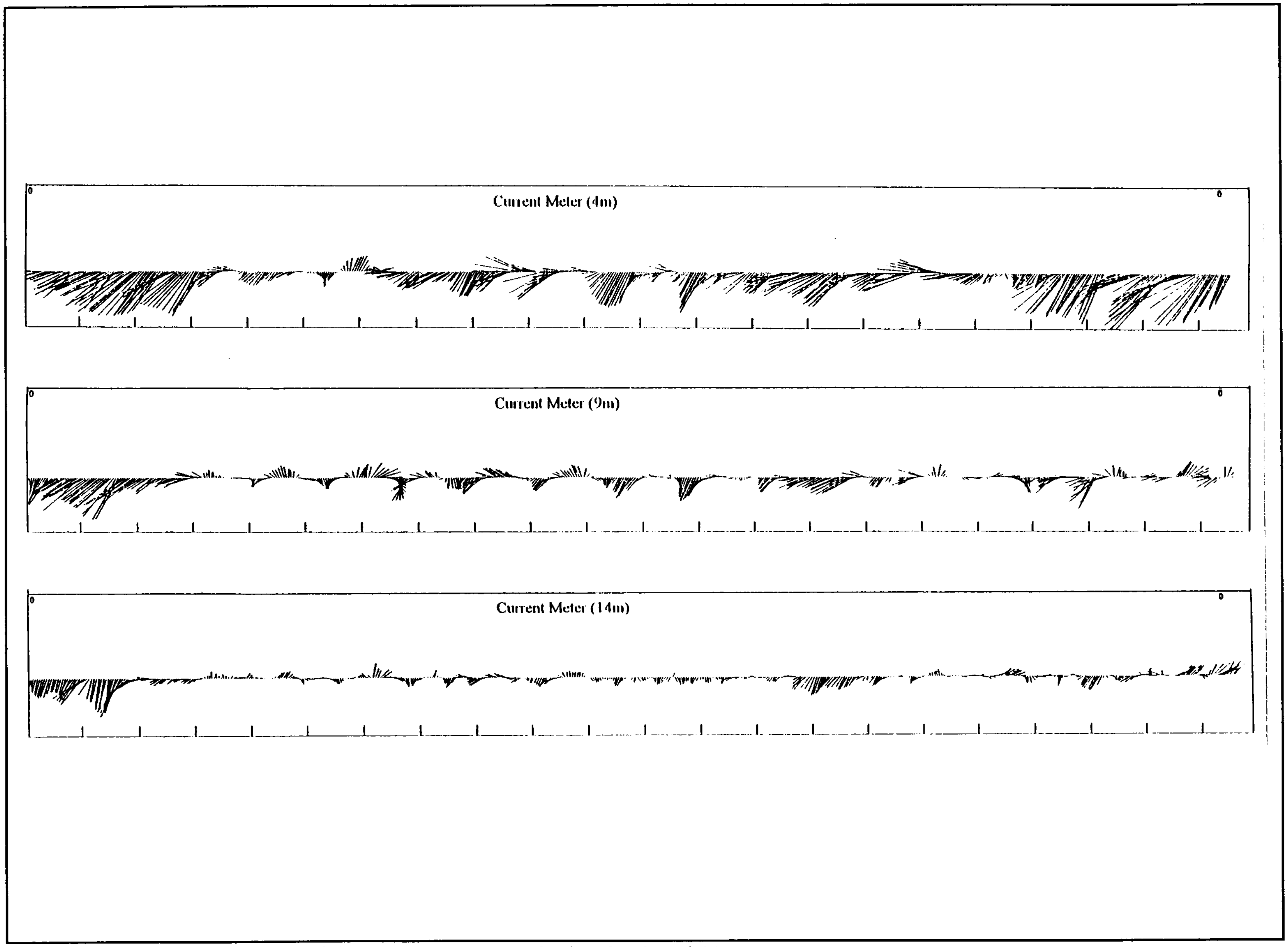

Figure 4A.8. Stick vector plots of three current meters, at depths of 4, 9, and 14 meters.

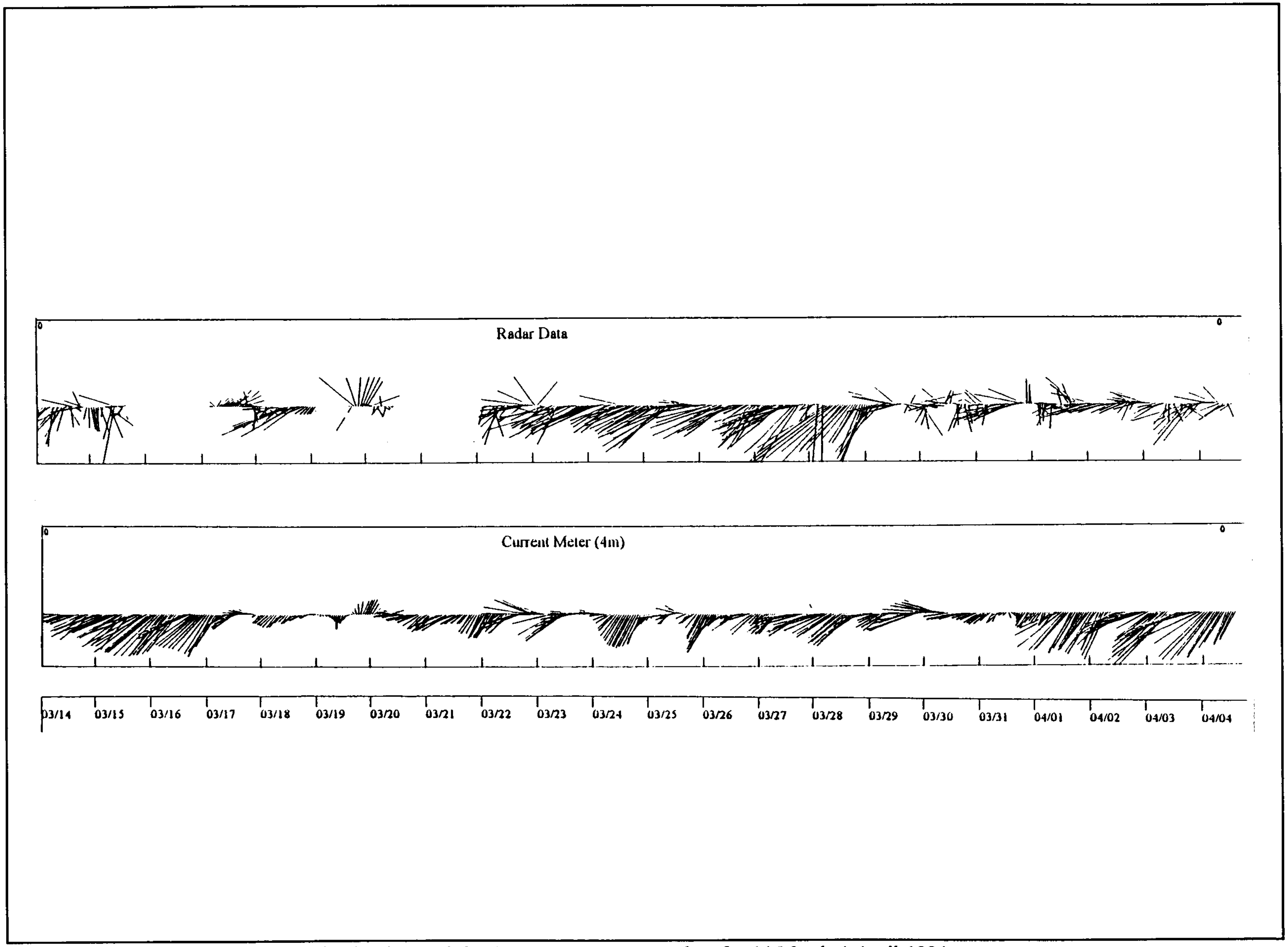

Figure 4A.9. Stick vector plots of radar data and the 4-meter current meter data for 14 March-4 April 1994.

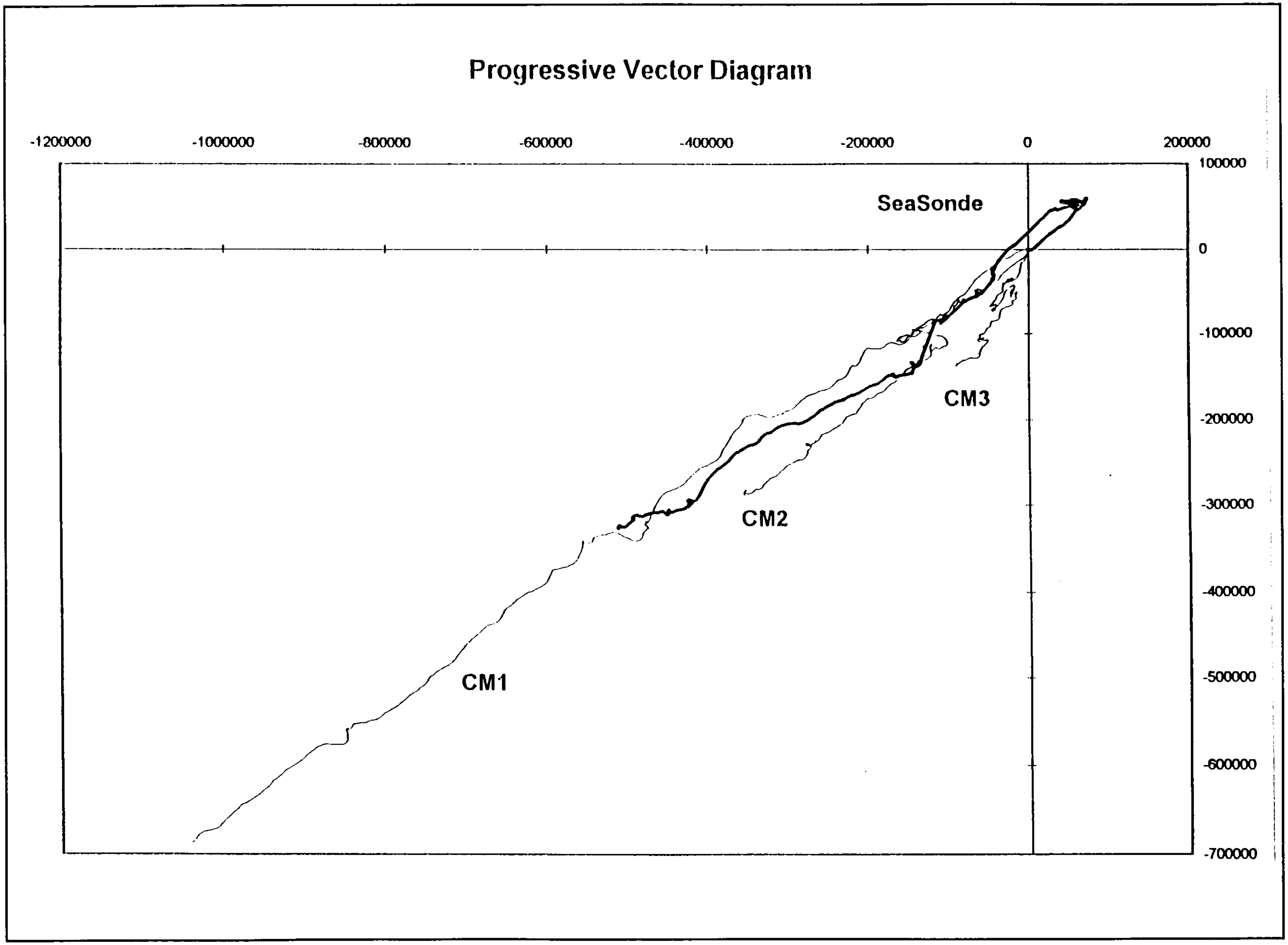

Figure 4A.10. Progressive vector diagram of the current meters and radar current.

Dr. Stephen P. Murray has 25 years of research experience in coastal and shelf waters. He is past Director of the Coastal Studies Institute at Louisiana State University, where he is pesently employed working on research projects on the physical oceanography of shelf, sea straits, and coastal waters. Dr. Murray received his Ph.D. in dynamical oceanography from the Department of Geophysical Sciences, University of Chicago in 1966.

TRACKING BUOYS FOR OIL SPILLS

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INTRODUCTION

In order to respond to an oil spill, it is necessary to know where the oil is and to be able to predict its possible motion. This can be accomplished by using visual observations, following the oil from the source of a spill, and using various remote-sensing techniques. In situations where such methods do not work due to poor visibility or the lack of equipment, the use of tracking buoys provides an alternate method of following the oil slick.

Data from drifter buoys is useful in relocating the slick after the weather has cleared or to provide information which is used as input into trajectory models. For tracking buoys to be effective, they must simulate the motion of an oil slick over a wide range of wind, waves and ocean currents. This is an extremely difficult task for several reasons. First, the slick is quite thin, a tenth of a millimeter to a few millimeters, while the drifters are, of necessity, orders of magnitude thicker. Due to the requirement to carry a power supply and transmitting equipment, drifter buoys have a minimum weight of several hundred grams. The heavier battery pack for power increases the mass and places limits on the hull shape. This means that the buoy interaction with winds, waves and currents is quite different from that of an oil slick. Second, the oil is dispersing, often becoming a collection of sub-slicks, each one seeing a different micro-current regime. A single drifter cannot duplicate this dispersion. Third, the slick-drift properties are changing as the oil weathers so that a drifter, calibrated to follow fresh oil, may not be able to track weathered oil correctly. Buoy designers attempt to overcome or minimize these problems by careful design of the buoy hull and proper ballasting.

This presentation will describe a series of experiments conducted in the Gulf of Mexico and Galveston Bay to measure the response of a number of buoy configurations. An oil simulator (wood chips) was used as a reference.

GALVESTON BAY AND GULF OF MEXICO TESTS

One component of the TexSonde'94 program was the testing of a number of oil-spill tracker buoys for a period of about six hours. Two experiments were performed: one in Galveston Bay and the other in the offshore area of the Gulf of Mexico, near Galveston, Texas.

The buoys were tracked visually from the surface and their location determined, using a hand-held GPS receiver (± 100 meter accuracy). In addition to the GPS measurements from the vessel, most of the drifters had internal systems to determine the buoy location. During the field test, five different hull designs and buoy location systems were tested.

1) Orion Hull

This hull is about 25 cm in diameter and 16 cm high. A 2-3 cm high stabilizing ring extends around the centre of the drifter. The hull is essentially flat with an upper and lower dome housing the electronics and power supply. The design of the hull is about ten years old. Recently, a number of different electronic packages have been designed around this hull shape. Some packages include only a pulsed transmitter, and the unit is tracked, using bearing measurements from a vessel. More recent designs include a GPS receiver and VHF telemetry system (Costanzo 1994). Both types were tested in these trials. The receiver for the bearing measurement was damaged in shipment, and these hulls were tracked visually.

2) Argospheres

The Minerals Management Service (MMS) of the U.S. Department of the Interior has developed a program to study the use of oil-tracking buoys to simulate the movement of spilled oil. As a result of a number of field tests performed in the Norwegian Sea, two drifter designs were selected for further testing (Reed *et al.* 1991). The first is a 30 cm. diameter sphere equipped with an ARGOS transmitter and tracked using TIROS satellites. Depending on the latitude at which the drifters are deployed, the satellites can provide a position determination approximately four or more times a day with an error of ±1 kilometer. In addition, two of the spheres were equipped with more accurate (± 100 meter) GPS receivers. The electronics in these spheres were programmed to collect GPS positions every 30 minutes, store the position locations, and relay a set of readings through the ARGOS satellite system. Ideally, for oil-spill emulation, the Argospheres are used without drogues and are ballasted to keep the drifter upright and floating at its equator. During this field test, the GPS feature worked correctly; however, the wind drift factor on the spheres was increased due to improper ballasting. As a result, the buoys moved faster than the simulated slick.

3) Draper or Discus Hull

A second drifter evaluated by MMS consists of two 20 cm diameter hulls of a concave shape which are fastened together to form a thick disk. The interior of this disk contains the electronics and power supply (Reed *et al.* 1991). Depending on the model of the buoy, the antenna was either external or moulded into the hull. Some versions of this buoy were tracked, using the ARGOS satellite system, while others used GPS location and VHF telemetry.

4) Davis-type Drifter

This drifter is based on a design by Davis (1985) and consists of a vertical 1-meter tube that contains a transmitter and batteries, as well as supporting an external antenna. Four sections of plasticized cloth, extending 0.5 meters from the tube, are supported by four small floats. Since the effects of wind drift and surface waves on this drifter are negligible, it is a very accurate method for measuring near-surface currents. Two Davis-type drifters were deployed, during the field tests, to provide an indication of how the oil-tracking buoys moved, in relation to surface currents. The drifters were tracked visually from the surface and through the ARGOS satellite system.

5) Tire Drifter

This buoy consists of a small tire and drogue system, and has been developed by a group in the Galveston Bay area.

RESULTS

The Galveston Bay and Gulf of Mexico field tests illustrated the differences in the drift behaviour of the various types of buoys designed to simulate the motion of oil slicks. However, due to the short duration of the field studies, several difficulties occurred when evaluating the performances of the drifters. First, in the Gulf of Mexico, the movement of the Davis-type drifters indicated that there was a weak current flow and on-scene winds were very light. Most of the drifters probably stayed with the wood chips because there was very little net movement. Second, the wood chips showed some drift characteristics of an oil spill (e.g. windrow formation). There is no data on whether the wind drift factor for wood chips is the same as for oil. Within a couple of hours after the release, the drift factor changed as the wood chips absorbed water later in the experiment. An additional error was caused by the hand-held GPS receiver which was used for position measurements. The error in location was of the same order of magnitude as the scale of the experiment. Visual observations of the drifter location relative to the wood chips are probably more reliable than the coordinates recorded by the hand-held GPS. One of the tire buoys and all the Orion-shaped hulls stayed in the same location and followed the motion of the wood chips. The discus-shaped buoys moved away from the area of the wood chips and the Orion buoys, in a few hours. The Argospheres moved in the same direction as the discus buoys but deviated from the wood chip position more rapidly.

In the Galveston Bay component of the program, the Davis-type drifters moved into the prevailing wind and in the opposite direction of the simulated slick and the other buoys. Since the Davis-type drifter is designed to track the motion of the upper one meter of the water column, it is presumed to move with the surface current. It is likely that the movement of the Davis-type drifters was probably the result of tidal influences inside the bay.

During the Gulf of Mexico field test, the Davis-type drifters lagged considerably behind the simulated slick and other buoys, but did slowly move in the same general direction. The observation is consistent with the field experiments conducted in the Gulf of Oman with the same type of buoy (Simecek-Beatty 1994). One of the tire buoys moved more slowly than the slick. The receiver of one of the GPS systems did not work, while the other two systems worked well. One system had higher power and hence greater range.

A summary of these observations is shown in Table 4A.1.

Table 4A.1. Summary of Experimental Observations.

Buoy	Hull Shape	Location	Telemetry	Battery Life	Weight
Tire Tracker	Small tire with flag and weight	Visual tracking	None	N/A	Medium
Orion	Plate shaped with top and bottom edges	Triangulation or bearing to visual sighting	Chirp transmitter	Two-Three Weeks	Light
Radio Satellite Integrators	Discus shaped Draper hull	GPS	VHF Data Link	Weeks	Medium
Trimble	Same as Orion	GPS	VHF Data Link	Days	Light
Met Ocean	Same as Orion	Not tested	Not tested	Not determined	Light
Argospheres	Sphere	Satellite	Satellite	Months	Light
Davis Drifter	Cylinder with curtains	Satellite	Satellite	Months	Medium Difficult Handling

CONCLUSIONS

The Orion-hull based systems appeared to move in a similar manner to the wood chips. This is consistent with information obtained in 1993, during an experiment in the Straits of Juan de Fuca (Hodgins 1993). The discus-shaped buoys moved out of the wood chip area in a few hours. Again, a similar result was obtained in the Juan de Fuca experiment. The Argospheres consistently moved in a different manner to the wood chips. This was probably due to the ballast of the units, which rode high in the water and therefore had a higher wind-drift factor. Figure 4A.11 shows the data from Galveston Bay for all the buoys, and Figure 4A.12 gives the same data for the Gulf of Mexico.

Both the wood chips and cottonseed hulls acted in a manner similar to an oil slick. Some time after deployment they formed into windrows. Both drifted in the same manner and moved in concert. Both materials remained on the water for the duration of the experiment.

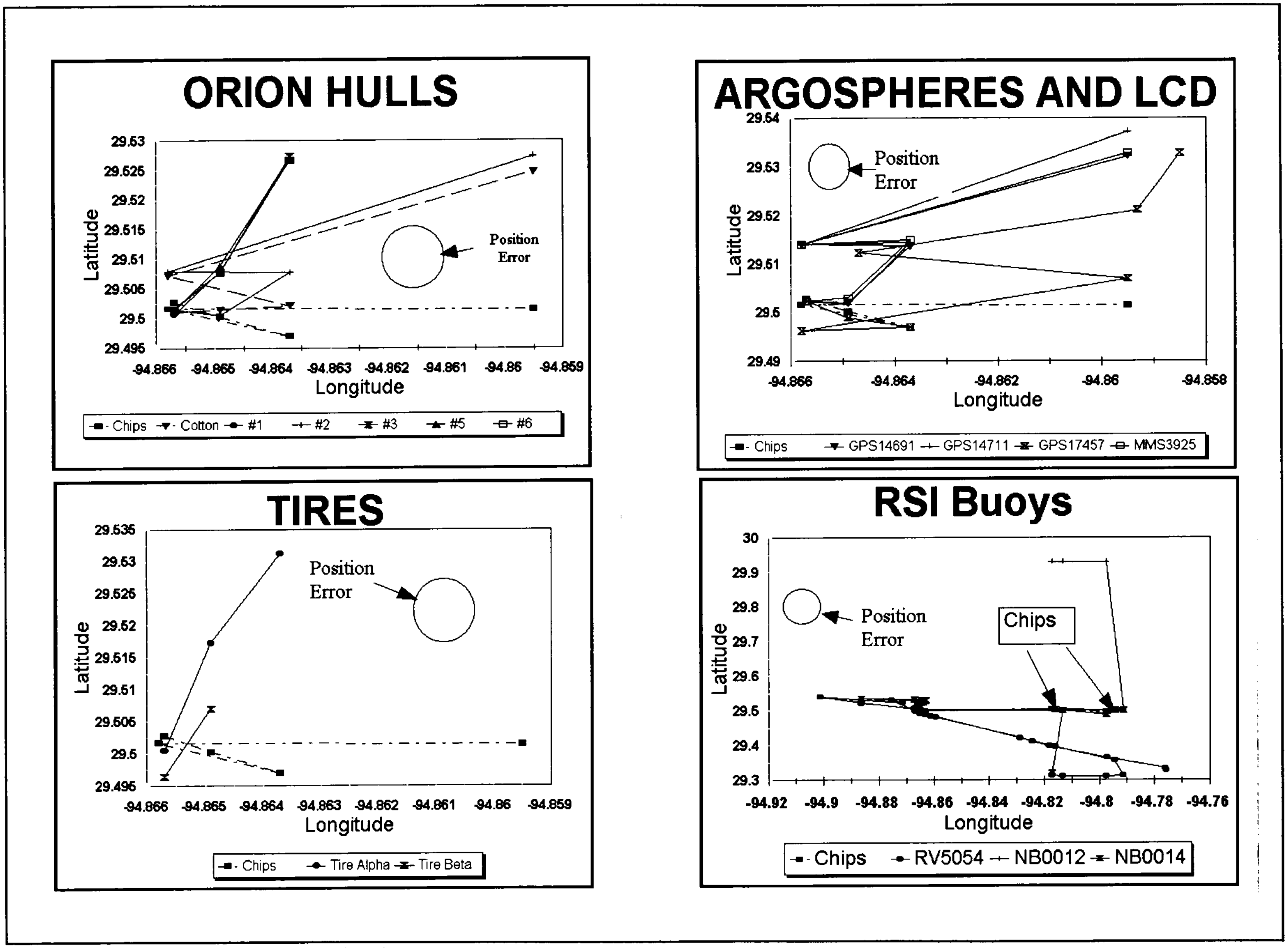

Figure 4A.11. Galveston Bay oil tracker data.

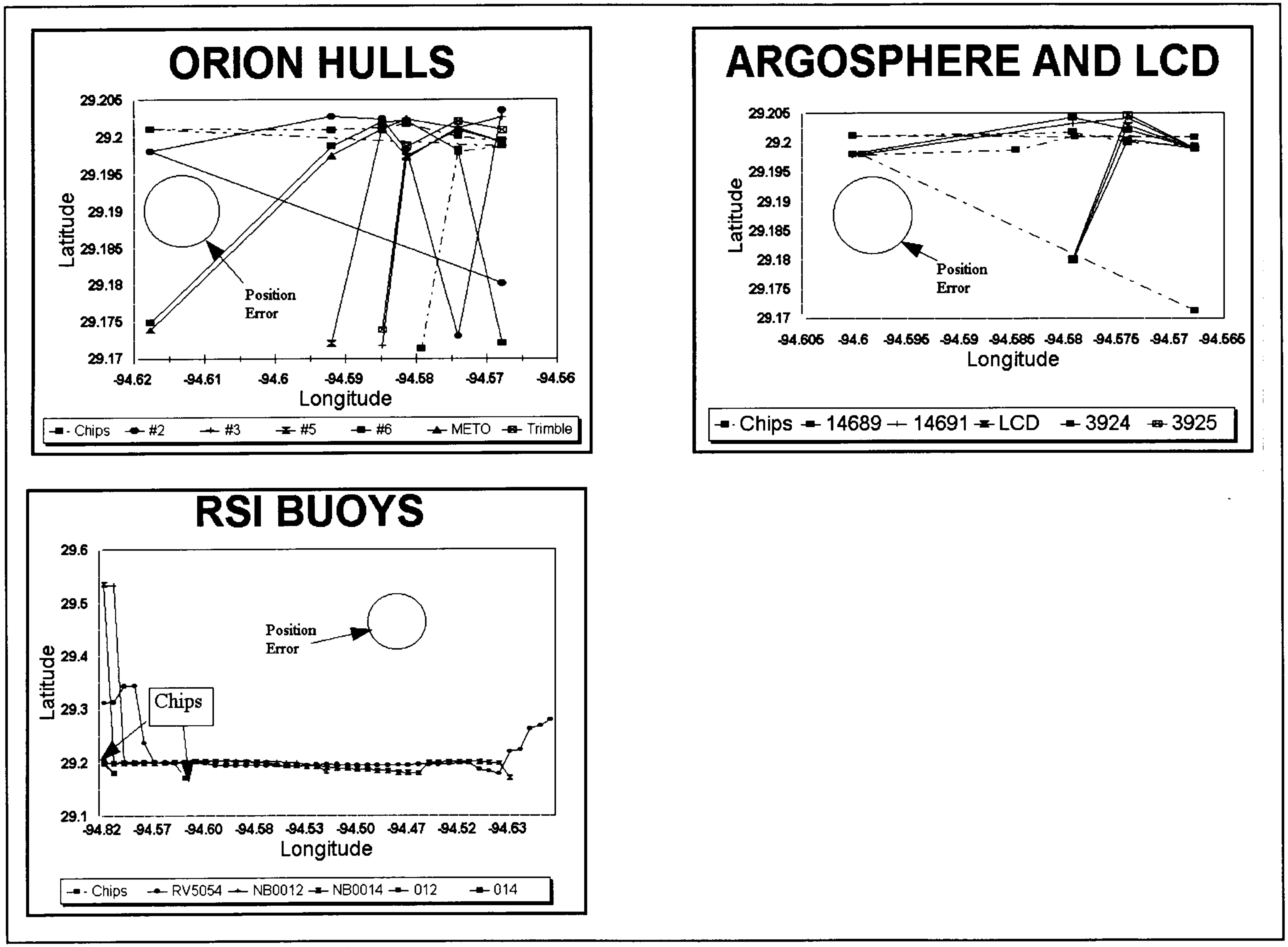

Figure 4A.12. Gulf of Mexico buoy data.

RECOMMENDATIONS

The lack of overall movement, and the limitations of the location system, resulted in data that is difficult to interpret. Future field tests should last longer in order to provide more differentiation between the various buoys. A 24-hour experiment would be more realistic. The drifters that were painted a bright fluorescent orange were easier to track visually. During both drills and spills, a number of drifters should be deployed so that some understanding of the dispersion of the buoys can be obtained.

ACKNOWLEDGEMENTS

The authors would like to thank the sponsors of TexSonde'94 (U.S. Minerals Management Service, Texas General Land Office, Marine Spill Response Corporation and Exxon) for their assistance with this test program. The support services provided by the Oil Spill Training School of Texas A&M were an essential component of the experiment and are gratefully acknowledged. All the manufacturers of the oil-tracker buoys (RSI, Trimble, and MetOcean) provided the buoys, support equipment, and staff at no cost to the project. Without this effort, the experiment could not have been conducted. The authors would like to thank their respective organizations for their support of this oil-spill research activity.

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Dr. Ron Goodman has worked at Imperial Oil Resources in Calgary, Alberta for the past sixteen years and for the last ten has been head of an environmental research team. He has more than twenty years' experience in oil spill response techniques. He has been involved in a number of responses to oil spills including the Exxon Valdez. His major interests are the remote-sensing of oil on water and the use of models in spill response. Current interests include the use of dispersants and in-situ burning in spill clean-up operations. Ron Goodman has a PhD. in physics from McMaster University in Hamilton, Ontario, Canada.

Debra Simecek-Beatty is a member of the spill response group for the Hazardous Materials Response and Assessment Division of the National Oceanic and Atmospheric Administration (NOAA/HAZMAT) in Seattle, Washington. Debra has participated in a number of drifter buoy experiments around the world. She is currently finishing her M.S. in marine affairs at the University of Washington in Seattle.

TEXSONDE '94: CURRENT PREDICTION

Dr. Donald O. Hodgins
Ms. Sally E. Tinis
Seaconsult Marine Research Ltd.
Vancouver, Canada

OBJECTIVE

As shown in TexSonde '94 and previous experiments, it is now possible to measure surface current maps in real time at a regular frequency (e.g., hourly). These maps cover a few hundred square kilometres of ocean with resolution scales of 1,000 m and 1-2 hours. In order to utilize these data for oil spill response it is desirable to predict 24-48 hours of flow field information using readily available data; specifically, the surface current information from the past few days and the local wind.

One of the simplest data-based models that can be applied for this purpose is an auto-regressive (AR) model utilizing the SeaSonde data collected for 1-10 days, the local overwater wind record for the same period, and the wind forecast for the prediction interval. As part of the TexSonde '94 study an AR model was applied to current and wind measurements from the end of March and the first two days of April.

METHODS AND RESULTS

The AR model incorporated the correlation between measured current components and between the current and the local wind (Figure 4A.13) after removal of the tide by harmonic filtering. The correlation coefficients were determined for input intervals of three, five and seven days. The input current time-series is shown in Figure 4A.14: the solid lines denote the input record, and the dashed lines are the measurements over the prediction interval against which the predicted currents were compared. The AR model was tested for various orders of current and wind up to a maximum order of 32. The optimum order of the process was determined by minimizing the rms error between the measurement and prediction. Orders of $i=5$ for current and $j=4$ for wind were found to be about optimum, giving rms errors of approximately 8-10 cm/s in u and 11-13 cm/s in v. A comparison of the predicted and measured current components for this model are shown in Figure 4A.15 for $\varepsilon=0$ (no white noise). Higher orders (> 15) led to instabilities in the predictions. The five-day input time-series provided the lowest error.

CONCLUSIONS

Simple AR models were shown to capture successfully some of the pertinent characteristics of the non-tidal surface current features off Galveston. These models were based on three-seven days of measured input (current+wind) and two days of wind forecast data. RMS errors were of the order of 10 cm/s in flows ranging up to 40 cm/s. While the model obviously exhibits some time-series prediction skill, the magnitude of the flow errors is large relative to typical current speeds. The consequence of such errors in terms of oil spill prediction under emergency conditions (i.e., with frequent re-initialization) is presently unknown, and should be determined as the next step in evaluating the usefulness of an AR class of model.

Dr. Donald O. Hodgins is a physical oceanographer and Research Director for Seaconsult Marine Research Ltd. His interests include ocean circulation observation and modeling and remote sensing using radar and satellite sensors.

Ms. Sally Tinis is a remote sensing analyst with Seaconsult and has been responsible for the analysis of the AVHRR data from TexSonde '94.

TexSonde '94

Current Prediction

- ☑ AR model correlating current components and wind components

$$\mathbf{u}_t = \alpha_1(\mathbf{u}_{t-1}) + \alpha_2(\mathbf{u}_{t-2}) + \ldots + \alpha_i(\mathbf{u}_{t-i}) +$$
$$\beta_o(\mathbf{W}_t) + \beta_1(\mathbf{W}_{t-1}) + \beta_2(\mathbf{W}_{t-2}) + \ldots + \beta_j(\mathbf{W}_{t-j}) +$$
$$\epsilon_t + \gamma_1\epsilon_{t-1} + \gamma_2\epsilon_{t-2} + \ldots + \gamma_k\epsilon_{t-k}$$

- ☑ 3, 5, 7-day input series, various model orders
  - predicted 48 h
  - rms error in prediction

Figure 4A.13. Description of the AR model.

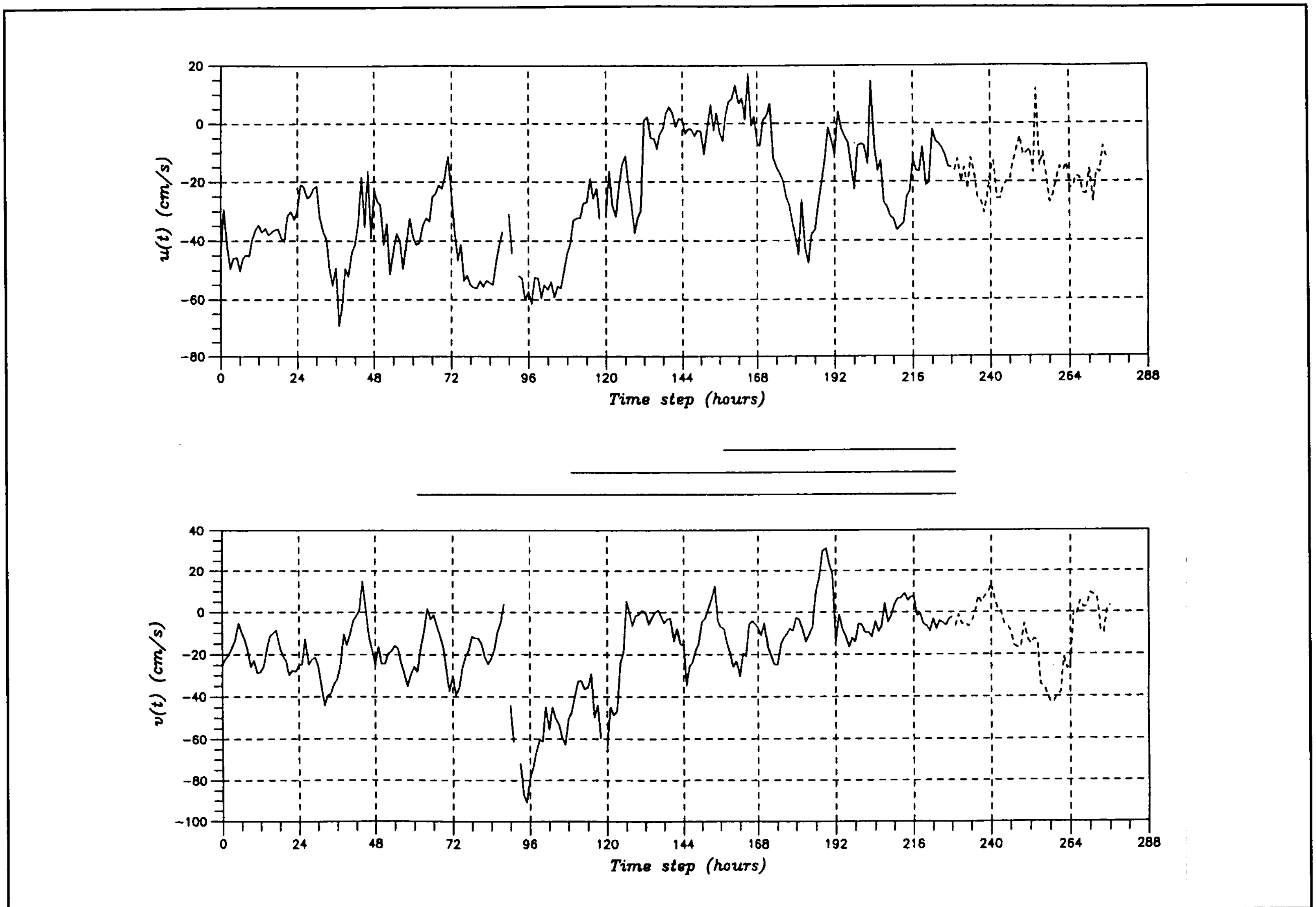

Figure 4A.14. Sample surface current time-series used for input to the AR model. The solid line denotes the input data period, and the dashed line represents the measured current during the prediction interval. The three solid bars between the panels show the three input records lengths for the AR model.

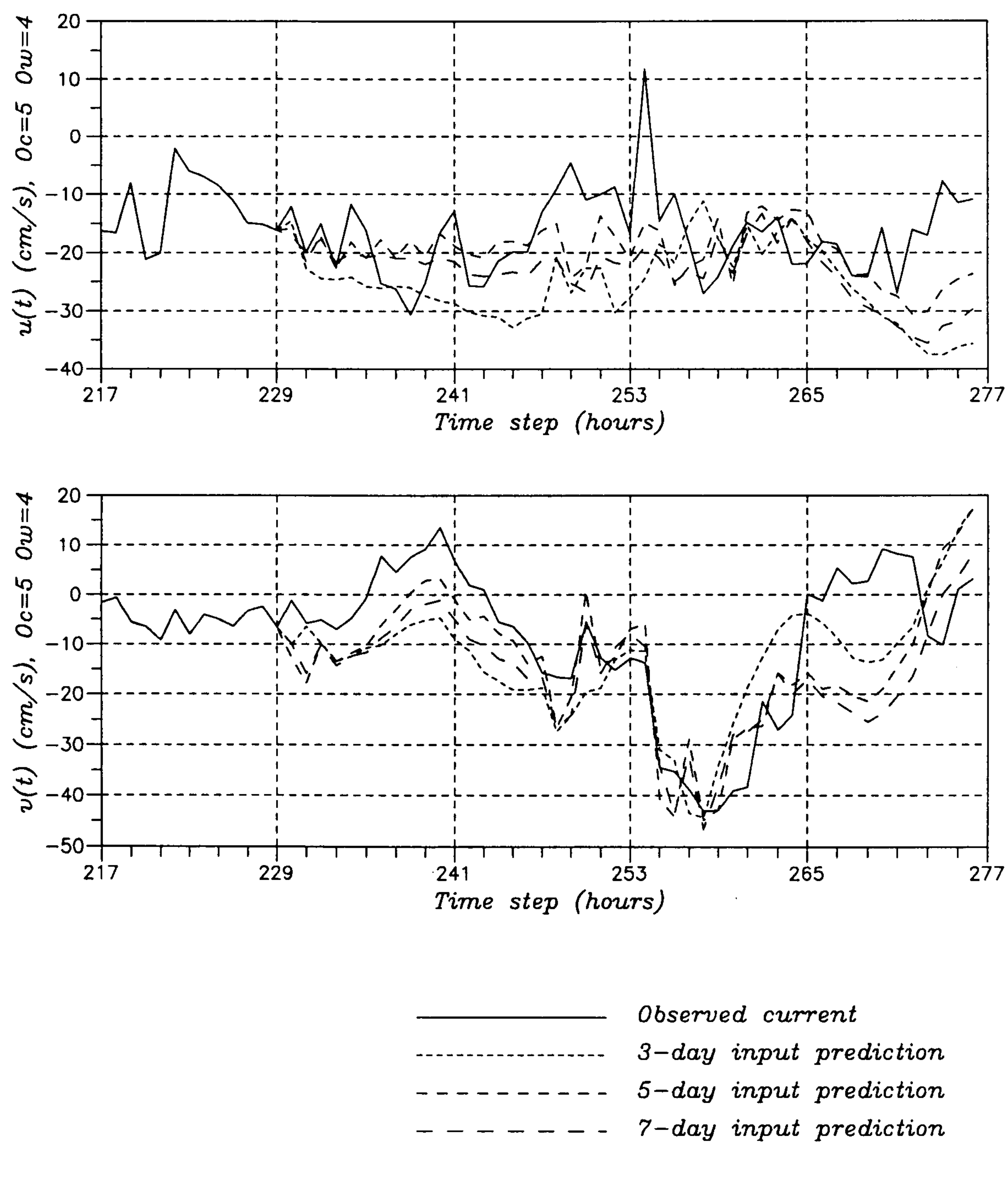

Figure 4A.15. Comparison of the measured and predicted current time-series (48 h) for an AR model of order 5 for current and 4 for wind.

MMS AND THE TEXSONDE FIELD EXPERIMENT

Dr. Walter Johnson
U.S. Minerals Management Service Headquarters,
Environmental Operations and Analysis

The Minerals Management Service (MMS) participated in the TexSonde field experiment because it brought together several research initiatives being pursued under separate efforts. The ONDE experiment included an ocean current-measuring radar system, drifting buoys, wood chips as proxy for spilled oil, and "oil-following" drifting buoys employed to help track the hypothetical spill.

The MMS has funded radar systems designed to measure ocean surface currents for several years, with varying success. In the past three years, the MMS has been a cooperating partner in three deployments of radar systems: (1) off Cape Hatters, North Carolina, with the University of Miami, funded by the Office of Naval Research; (2) off Galveston, texas, with SeaSonde, funded by the Texas General Land Office and oil companies; and (3) off Monterey Bay, California, with the Naval Postgraduate School and other organizations as part of the Monterey Bay Consortium. These projects have used a variety of measuring systems and ONDE was the only one using simulated oil spills.

The MMS has been involved in several major ocean drifter studies in the past several years. The projects with the largest number of deployments are the Surface Current Langrangiandrift Program (SCULP) in the Gulf of Mexico and the Santa Barbara Channel study off California. The purpose of these studies is to use drifting buoys as primary instruments to determine the ocean surface circulation and then augment the statistical analyses with fixed current meter time series. This approach will give additional understanding of the general circulation.

Besides the drifting buoy studies, the MMS has been studying the use of small satellite-tracked drifters as proxy for spilled oil. The so-called "oil-following" drifters were tested in experimental oil spills off Norway and were also deployed in several accidental spills by the National Oceanic and Atmospheric Administration, Hazardous Material Response Branch (NOAA HAZMAT) as part of their data gathering during the response to the spills. These tests are still ongoing, and additional trials with oil and other proxies for oil will be conducted. The MMS expects that limited oil-spill-risk characterization of specific sites may be possible by using these "oil-following" drifters in addition to the traditional methods of trajectory modeling.

The ONDE experiment was supported by the MMS because of the interest in all of the measurements being brought together and because our drifting buoys in the SCULP project were drifting through the operating area of the experiment. "Oil-following" buoys were deployed during the experiment by Debra Simecek-Beatty of NOAA HAZMAT and Cort Cooper of Chevron. Plots of the tracks of these drifters appear in Figure 4A.16.

Plots of velocity vectors derived from the drifting buoy positions are shown in Figure 4A.17. We plan to compare these velocities to those of the current meter and SeaSonde data. The analysis of these data is not complete, but the field report stated that the "oil-following" buoys separated from the wood chips (oil proxy) rapidly. This separation probably was due to a lack of ballast in some types of the buoys, causing increased wind forcing of the buoys.

The data will require additional analysis. The calculations we intend to perform are:

(1) Comparison of the SCULP drifters in the vicinity of Galveston to the SeaSonde velocities.
(2) Comparison of the MMS drifters to the other drifters deployed.
(3) Comparison of the oil-following drifters to the wood chips and the estimate of the wind-drift.

When these calculations have been performed, we will communicate the results to the other TexSonde participants.

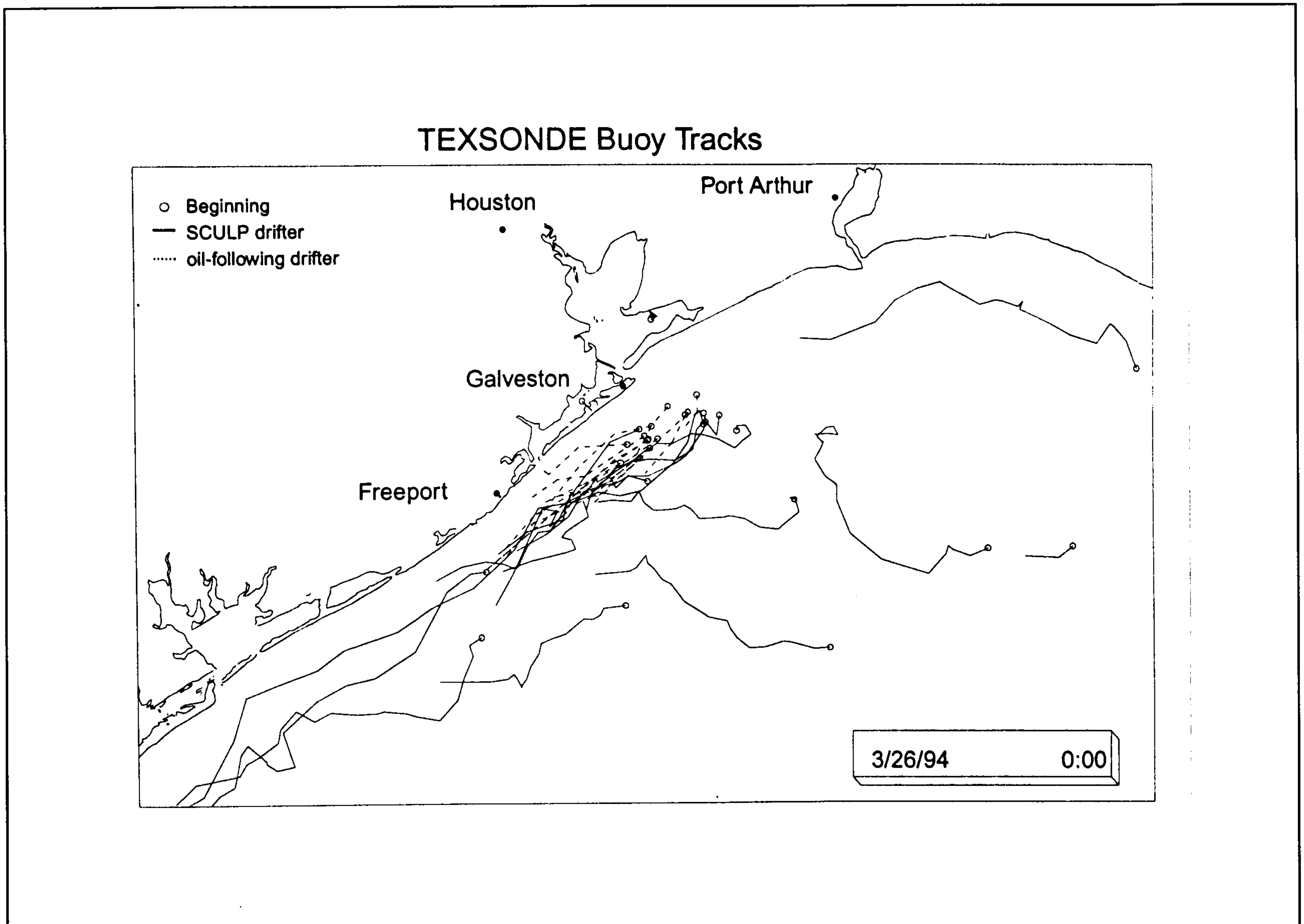

Figure 4A.16. Tracks from SCULP and oil-following drifting buoys offshore Galveston, Texas, during the TEXSONDE experiment. Track lengths of two days or less are shown.

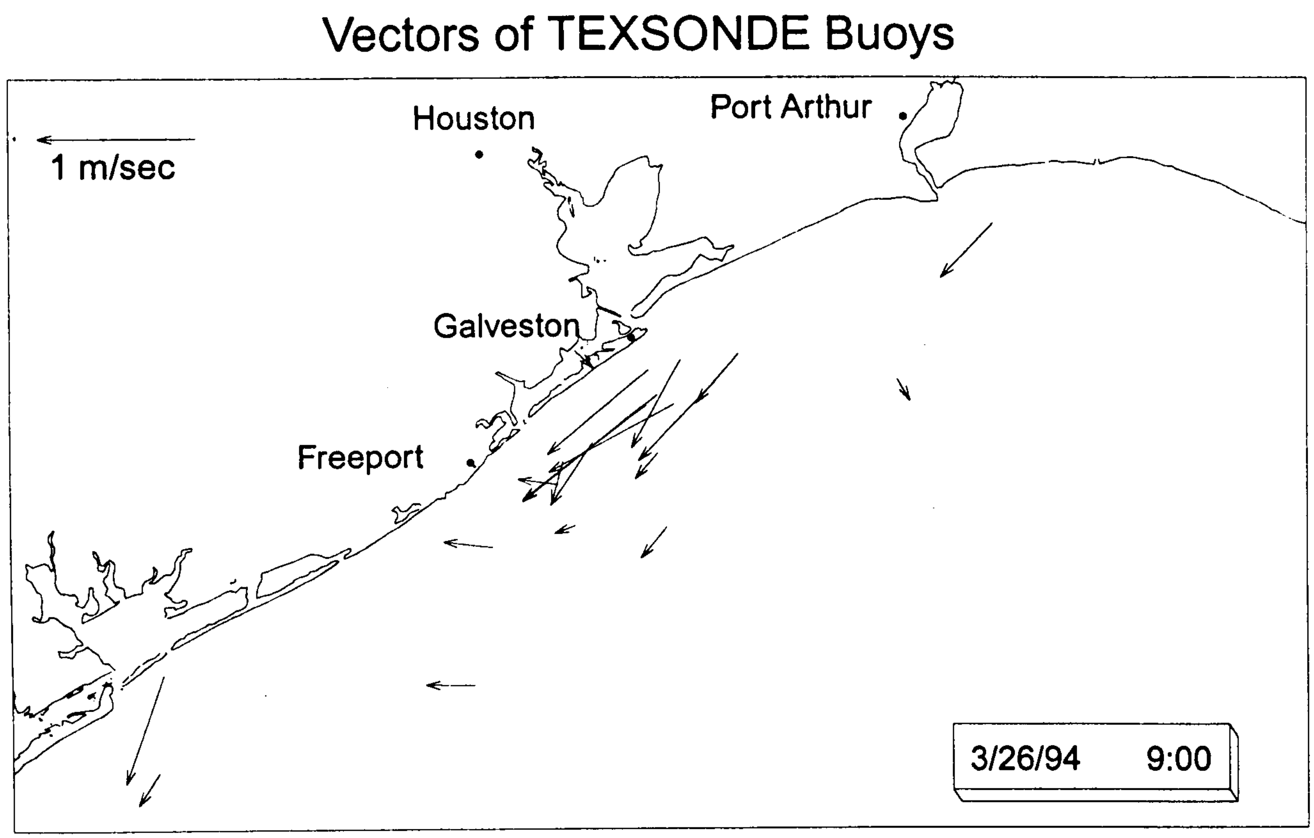

Figure 4A.17. Vectors indicate the velocity of buoys in the TEXSONDE experiment offshore Galveston, Texas.

SESSION 4B

MARICULTURE ASSOCIATED WITH OIL AND GAS STRUCTURES, PART I

Session: 4B - MARICULTURE ASSOCIATED WITH OIL AND GAS STRUCTURES, PART I

Co-Chairs: Mr. Villere Reggio and Mr. Dave Moran

Date: November 17, 1994

Presentation	Author/Affiliation
Mariculture Associated with Oil and Gas Structures	Mr. Villere C. Reggio, Jr. Mr. Dave Moran U.S. Minerals Management Service Gulf of Mexico Region
Mariculture from Offshore Oil and Gas Leases	Mr. John Mirabella U.S. Minerals Management Service Headquarters Herndon, Virginia
Oil and Gas Industry Views on Use and Reuse of Petroleum Structures for Mariculture	Mr. David A. Dougall Agip Petroleum Company
Mariculture in the Gulf of Mexico: Sea Pride Industries' Sea Trek and Sea Star Systems	Dr. Edwin Cake, Jr., Chief Science Officer Mr. John D. Ericsson, Chief Executive Officer Sea Pride Industries, Inc. Gulf Breeze, Florida
The Engineering of Mariculture Pens in Association with Oil and Gas Structures	Mr. Clifford A. Goudey Massachusetts Institute of Technology Sea Grant College Program

MARICULTURE ASSOCIATED WITH OIL AND GAS STRUCTURES

Mr. Villere C. Reggio, Jr.
Mr. Dave Moran
U.S. Minerals Management Service
Gulf of Mexico Region

INTRODUCTION

Increasing competition and regulation along with declining economic success of ocean capture fisheries portends increasing interest and opportunities for aquaculture and mariculture. Growing public demand for a consistent source of quality, healthful seafood has already stimulated offshore fish culture proposals in the quality, temperate offshore waters of the Central and Western Gulf. Notwithstanding the legal uncertainties of open ocean mariculture, researchers and entrepreneurs are keying on the potential availability of extant petroleum structures to test the feasibility and potential for fish husbandry in the Gulf of Mexico.

In the spirit of reinvention MMS organized a session designed to bring together regulators, researchers, and aspiring offshore fish culturist to evaluate the potential and problems of dedicating offshore petroleum structures to growing fish for market. Buoyed by the long-term success of Ecomar's harvest of marketable shellfish from OCS structures in the Santa Barbara Channel, representatives from MMS, the oil and gas industry, academia, the fishing industry, and the private sector offered visionary concepts, thoughtful opinions, and serious constraints to extended economic development of ocean resources tied to the multiple use potential of offshore petroleum structures. The documentation that follows should serve as a useful source of information to all who can see the wisdom of developing fuel and fish from a common base of operations.

Mr. Villere C. Reggio, Jr., is an Outdoor Recreation Planner with the Minerals Management Service, Gulf of Mexico OCS Region. His responsibilities include assessment, research, and reporting on the interrelationship of the OCS oil and gas program with the recreational elements of the marine and coastal environment throughout the Gulf region. For the past 20 years Mr. Reggio has had a special interest in evaluating the fisheries value and potential of oil and gas structures.

Mr. Dave Moran is a General Biologist under the Regional Supervisor for Leasing and Environment, Minerals Management Service, Gulf of Mexico OCS Region. Dave's primary responsibility encompasses environmental assessment of offshore oil and gas operations.

MARICULTURE FROM OFFSHORE OIL AND GAS LEASES

Mr. John Mirabella
U.S. Minerals Management Service Headquarters
Herndon, Virginia

Oil and gas operations have been occurring in offshore waters, bringing jobs to the area and oil and gas to the country. We have tended to ask the question, "Can we conduct oil and gas operations without interfering with other users of the offshore waters?" The parties involved have worked to solve most problems encountered, and, for the most part, the oil and gas companies have been good neighbors to the other offshore users. However, mariculture provides a new opportunity. We are now asking, "Can a functioning oil and gas facility provide an offshore platform for launching a new industry?" Rather than having oil and gas operations and mariculture activities just "not interfere" with each other, these two activities are looking to assist each other. If the expense of maintaining an offshore platform can be shared between two users—then maybe a mariculture enterprise that would otherwise be marginal can become profitable, and an oil and gas operation can continue production long after the field would have otherwise been abandoned.

From the start, MMS believed this to be a worthwhile and interesting project and assembled a workgroup to evaluate the potential project and determine what further information was needed. The MMS also facilitated communications with the National Marine Fisheries Service, the Department of Energy, the Corps of Engineers, the Environmental Protection

Agency, the oil and gas industry, and the Congress; all showed an interest.

Much progress has been made—but questions remain concerning extra stress on platforms, the effect on current and future production from the platform, liability for damage and end-of-lease obligations, and involvement of other government agencies at the federal, state, and local levels. Some of these issues are straightforward. For example, MMS regulates the design, construction, and installation of all platforms in the OCS. If a new platform is to be built, MMS is prepared to work with the Corps of Engineers or other agencies to help develop and implement appropriate regulations.

Once a platform is constructed, the lessee must perform periodic inspection and maintenance. With regard to some aspects of maintenance, annual costs are independent of the level of production. The MMS must ensure that if minimal production operations continue to prevent the lease from expiring, then maintenance and inspection also continue.

Other agencies will also need to add their experience to facilitate the establishment of mariculture projects. The Corps of Engineers has responsibility for prevention of obstructions to navigation, and the U.S. Coast Guard has responsibility for ensuring that platforms and artificial islands are marked so as not to be a hazard to navigation. Marking may be more complex if large nets are placed adjacent to platforms. The Corps of Engineers and the U.S. Coast Guard have extensive experience with their respective areas and problems are not anticipated.

Regulation of worker safety is less clear. The U.S. Coast Guard and the Occupational Safety and Health Administration have a Memorandum of Understanding covering the working conditions for oil and gas activities. What happens when mariculture activity takes place on the same platform? This is an area the two agencies would need to work out.

Consideration of end-of-lease obligations and bonding issues is important. In the event of a request for reassignment, MMS will evaluate the ability of the new company to satisfy all end-of-lease obligations. Just as with requests for assignment to oil and gas producing companies, MMS will cooperate with all parties to explore ways to protect the Government without undue burden on small companies.

Where do we go from here? Clearly a number of questions still exist. The MMS will need to work within its governing laws and regulations to search for solutions. One important key will be communication. The MMS will work with other government agencies and mariculture companies; oil and gas companies will need to work with each other and with the government agencies. The meetings that have already occurred and this session are good starting points.

OIL AND GAS VIEWS ON USE AND REUSE OF PETROLEUM STRUCTURES FOR MARICULTURE

Mr. David A. Dougall
Agip Petroleum Company

INTRODUCTION

Harvesting fish and shellfish has been a major source of food throughout the history of civilization. Recent over-harvest of our ocean resources has raised concern about the future of our fish stocks. In the United States, the authorities have evolved a system of allocating fisheries resources through a combination of seasonal closures, zone closures, and catch limits, administered by the National Marine Fisheries Service (NMFS).

Cultivating fish and shellfish has also been with us since long before Christ. Today, aquaculture is a major business. Farm raised trout, catfish, and crawfish are familiar to most of us. These commercial operations take place in ponds and raceways from the extremely large to the quite small. Within the last few years, considerations have been given to the use of oil and gas structures to aid in marine aquaculture—mariculture. This paper is provides an industry perspective on the opportunities and obstacles presented by the use of petroleum structures in mariculture operations.

PERSPECTIVE

This paper is prepared from the perspective of an offshore oil and gas operator. While the paper deals with fisheries issues, the author claims no fisheries expertise. Information presented herein is based upon limited literature review and discussion with other oil and gas operators. Views expressed in this paper are those of the author.

OIL & GAS PLATFORMS

There are nearly 4,000 oil and gas platforms in the Gulf of Mexico. These structures range in age from brand new to roughly 30 years old; in size from single well caissons to large, multi-pile; in water depths from a few feet to over 1,000, and in distance from shoreline to more than 130 miles. Platforms consist of a supporting structure (jacket or caisson) and a topside structure (deck), which supports production, processing and safety equipment, quarters (if any), and helideck (if any).

Platforms present some obvious opportunities for mariculture operations:

* They would provide a more or less permanent, solid platform from which to conduct operations. The decks would provide a stable place for storage, feed delivery equipment, and utilities (power, navigation aids, communications, and environmental monitoring). The structure would provide support for anchoring containment and winching systems. Further, the offshore oil service infrastructure (service boats, air transportation, and port facilities) offers an existing transportation system for personnel, supplies, and products.

* Platforms are well known as artificial reefs, providing healthy ecosystems which are major destinations for recreational fishing. This abundance of associated sea life suggests a healthy environment suitable for cultivation of fish and shellfish.

* The offshore location tends to moderate swings in water temperature, and water currents make the system essentially self-cleaning, providing new, oxygenated water and removing wastes from fish and feeding.

PROJECTS

A Santa Barbara, California firm, Ecomar, presents a real success story and an object lesson relevant to considering oil and gas structures for mariculture. Ecomar contracts with a number of oil and gas operators offshore of the California coast to remove what is considered biofouling by oil and gas operators from their platforms. The substantial buildup of sea life attached to the underwater support for the platforms causes enough wave and current drag to present structural concerns. To alleviate this problem, operators pay up to a few hundred thousand dollars every few years for divers to remove the growth.

One man's biofouling is another's gourmet dinner, and Ecomar has for about ten years been separating, cleaning, and marketing mussels removed from platforms to an increasing list of restaurants.

Two things to bear in mind about the Ecomar harvesting operation:

1. Operators view this as a very good way to conduct essential platform maintenance. Because Ecomar is able to market the product, the operators get a cost break on the removal operation. An additional benefit is showcasing the healthy environment that surrounds these platforms.

2. In spite of what should seem an obvious win-win proposal, it took Ecomar's owner, Bob Meek, the better part of ten years to sell the idea to the oil and gas operators and the regulatory authorities. Operators' reluctance can be summed up in two issues: liability and interference in operations.

A related success story is the Rigs-to-Reefs Program in Texas and Louisiana. At the end of a platform's useful life, oil and gas operators are required to plug and abandon all the wells, sever all structures below the mud line, and physically remove the structure from the lease. Simply stated, the Rigs-to-Reefs Program offers an operator the opportunity to move the structure to a designated reef site rather than hauling it all the way to shore for scrap.

From the oil and gas operators' point of view, the Rigs-to-Reefs Program is highly successful for two very good reasons:

1. Liability: The Rigs-to-Reefs Program presents the operator with an opportunity to fulfill his responsibilities in clearing the oil and gas lease in such a way that long term liability for the structure is transferred to another financially responsible entity (i.e., a government agency).

2. Economics: The cost to clear a platform from a lease can be anywhere from $½ to $15 million or more, depending on water depth, location, condition and configuration of the structure, and salvage value of parts. This cost can sometimes be dramatically reduced by participation in the Rigs-to-Reefs Program. One-half of the estimated savings goes to the agency to pay for long-term maintenance of the reef and for accepting liability.

Mariculture around oil and gas platforms in the Gulf of Mexico has been discussed and conceptualized for over 10 years. To date, only one mariculture project has been conducted in association with oil and gas platforms in the Gulf of Mexico. This project, funded by an oil company, in cooperation with Texas A&M, has been ongoing for several years. The project team has raised redfish, but not as a commercial success. The project began on a producing platform and is now based on one that is no longer active.

The operator of this project has indicated a number of obstacles, institutional as well as technical, which must be overcome before large-scale mariculture operations at offshore oil and gas platforms are likely to become a reality. The validity of these concerns was largely confirmed in discussions with other operators not presently involved in mariculture activities but with whom proponents would probably deal.

INSTITUTIONAL OBSTACLES

The following issues are of an institutional nature. Some should be addressed by the appropriate regulatory authorities; others should be considered by mariculture proponents when they are fashioning proposals.

LIABILITY

The greatest concern expressed by oil and gas operators is liability, liability for accidents and liability for lease abandonment. Whether mariculture operations are conducted on a producing or an inactive platform, the issue of liability for personal injury, property damage, and environmental damages must be resolved. Not only are authorized personnel working on and under the platform at risk, so are intruders, on and under the platform. Risk of injury, property and environmental damages from collision and natural disasters also must be resolved.

The longer term and probably more difficult issue is liability for lease clearance. If an inactive platform is to be used for mariculture operations, somehow the ultimate fate of the structure and eventual cost for dealing with it must be resolved.

In light of what most consider the "deep pockets" theory, the willingness of a somewhat tentatively financed entrepreneur to accept the liabilities associated with a platform-based mariculture operation is not likely to be adequate. Aquaculture in the United States has a history of failures. Companies that fail quite often file bankruptcy, in this case, possibly leaving the previous operator with the liabilities. Somehow, the oil and gas operator has to be relieved of liability as a <u>previous</u> owner.

Finally, there are requirements for maintaining a platform. Navigation aids, cathodic protection, and minimal repair and upkeep of the structure are expense items which must be factored into the economics of such an operation. Together, these costs can exceed $10,000 per year.

OPERATING PRIORITIES

Another major concern is interference with the operations of the platform. Operations on these facilities are entirely focused on production of oil and gas. Any activities which do not fall within that focus will be met with reluctance unless they can be shown to be: (1) valuable and (2) conducted in a manner that will not be "under foot."

PERMITTING

Oil and gas operators are accustomed to working within a tightly regulated environment. However, the agencies with which we work generally have well-defined and understood areas of authority. Reportedly, working through the regulatory framework to obtain all the necessary authorizations to conduct a mariculture operation from an oil and gas platform can be a major challenge. Conflicts include overlapping areas of authority and standards to be applied to the operations.

SPATIAL CONFLICTS

Oil and gas operators lease mineral rights from the U.S. or a state government and obtain authorization to temporarily place structures on those leases and produce the mineral resources. Conducting mariculture operations in association with oil and gas structures opens up new issues of private use of public resources. A new "user group" conflict may arise with commercial fishing operations and with recreational fishing and diving interests, all accustomed to benefitting from the presence of these structures.

FINANCING

Finally, there is an inclination on the part of proponents of projects relating in some way to oil and gas facilities to anticipate major investment, if not outright underwriting of the project, by the petroleum company involved. Oil companies, large and small, have been trimming budgets and focusing investments on core business. Project proponents should not make grand assumptions about financial participation on the part of the oil companies in these ventures. If companies do get involved, they will be likely to consider the platform infrastructure to be a major investment in itself.

TECHNICAL CONSIDERATIONS

Certainly, persons who have been engaged in research and applied aquaculture activities are the technical experts in this area. However, discussion with other operators suggested the following items in need of improvement.

Cage Construction

A number of approaches have been designed for containment of fish in cages. However, placement of cages in association with oil and gas platforms presents current forces far beyond those experienced in nearshore operations. Cage construction and anchoring/retrieval systems must be well-designed, adapted, and field tested for this environment.

Target Species

The high cost of marine farming in comparison with onshore aquaculture suggests that high dollar species must be cultivated to achieve the necessary profit margin. Successful spawning and stocking of high dollar species is reported to be a major problem.

SOLUTIONS/SUGGESTIONS

Ultimately, the obstacles enumerated above will be favorably resolved. From the perspective of an oil and gas operator, the following are some suggestions which, if implemented, would help move mariculture toward commercial reality.

Relief from Lease Responsibilities

Long term liabilities and lease clearance responsibilities are a major obstacle to mariculture on oil and gas platforms. Proponents are most likely to be entrepreneurs without the financial backing to adequately take on these responsibilities; at the same time, oil and gas operators will not be wiling to retain long term liabilities. A possibility to consider is a mechanism for site clearance to be funded up front and placed in an appointed trust and the oil and gas operator provided with a legally binding release from future liabilities.

Streamline Permitting Requirements

Some means of simplifying the permitting process is essential. Use a lead agency approach, and work between the agencies to clarify roles, eliminate overlap, and streamline the process.

Grant Lease Rights to the Mariculture Operations

Some means should be established to protect the mariculture operator from damages to his crop from other fishing and diving activities. Since a process exists to set zone and species closures, the NMFS should be able to create some sort of lease rights for the mariculture operation.

CONCLUSION

Oil and gas operators consider offshore platforms to be sort of an idyllic microcosm of sea life. We provide structure where one did not previously exist, and sea life is attracted and thrives. It makes a great deal of sense that these circumstances should somehow be capitalized upon. The Rigs-to-Reefs Program is a positive step. Commercial farming in association with these structures appears to be an additional opportunity. Over time, the obstacles, both institutional and technological, will probably be resolved, and mariculture could evolve into a major business and a major food source contributor.

Mr. David A. Dougall is Manager of Environmental Affairs & Safety for Agip Petroleum Company, with drilling and production operations in the Gulf of Mexico. Mr. Dougall's background includes consulting for Pilko & Associates, where he conducted environmental risk assessments, compliance audits and permitting activities. His background also includes corporate and field assignments for Phillips Petroleum Co., including several years coordinating Phillips' permitting and compliance efforts in California. He received his M.S. degree in Environmental Science and B.S. degree from the University of Oklahoma and is a registered professional engineer in Oklahoma and Arkansas.

MARICULTURE IN THE GULF OF MEXICO: SEA PRIDE INDUSTRIES' SEA TREK AND SEA STAR SYSTEMS

Dr. Edwin Cake, Jr., Chief Science Officer
Mr. John D. Ericsson, Chief Executive Officer
Sea Pride Industries, Inc.
Gulf Breeze, Florida

Sea Pride's innovative plans for mariculture in federal waters of the U.S. Outer Continental Shelf (OCS) include (1) installation and operation of the Sea Trek Ocean Farming System® for cage-culture of native finfishes in the open sea and (2) operation of the Sea Star Oyster Relaying System for cleansing and improving of oysters from inshore waters that may not meet federal water-quality criteria. Sea Pride has spent hundreds of thousands of dollars researching, designing, developing, and permitting these systems for use in the Gulf of Mexico.

The patented Sea Trek System (Figure 4B.1) will consist of a ballastable, concrete platform (similar to those already in use by the oil and gas industry on the Gulf of Mexico OCS) that rests on the sea floor and six ballastable, net-covered, barrel cages arrayed radially around the platform. The inner end of the cages will be chained to the platform and the outer end will be anchored to the sea floor. The barrel cages will be ballasted vertically and/or rotated horizontally to facilitate fish harvesting, net cleansing, biofouling reduction, and storm protection. Systems for feeding, aeration, and vacuum transfer of the fishes will link each cage with the platform via an umbilical connection.

The Sea Trek System will be located four miles southeast of the mouth of Mobile Bay, Alabama, in 50 feet of water on the south-western corner of Exxon Energy Company's OSC Lease Block 827. The five-acre U.S. Army Corps of Engineers-permitted mariculture site will be surrounded by a floating AquaFence® that encloses 13 acres and reduces floating hazards and user conflicts. The Sea Trek System has been designed to rear up to three million pounds per year of native finfishes including red drum, red snapper, hybrid striped bass, and mahimahi (dolphin fish) and will be supported by a land-based or platform-based hatchery facility. The Sea Trek platform will be manned 24 hours a day except during hurricane conditions when the cages will be ballasted to the sea floor and/or released on independent anchoring arrays for fish and cage protection.

Sea Pride received its U.S. Army Corps of Engineers (USACOE) permit (#AL93-01004-M) under Section 10 of the 1899 Rivers and Harbors Act in October 1993. Sea Pride received its U.S. Environmental Protection Agency (USEPA) Ocean Discharge Permit (#AL0067237) under Section 403 of the amended 1972 Federal Water Pollution Control Act on 20 September 1994. To our knowledge, these are the first permits issued for mariculture operations and related ocean discharges anywhere in U.S. Federal OCS waters.

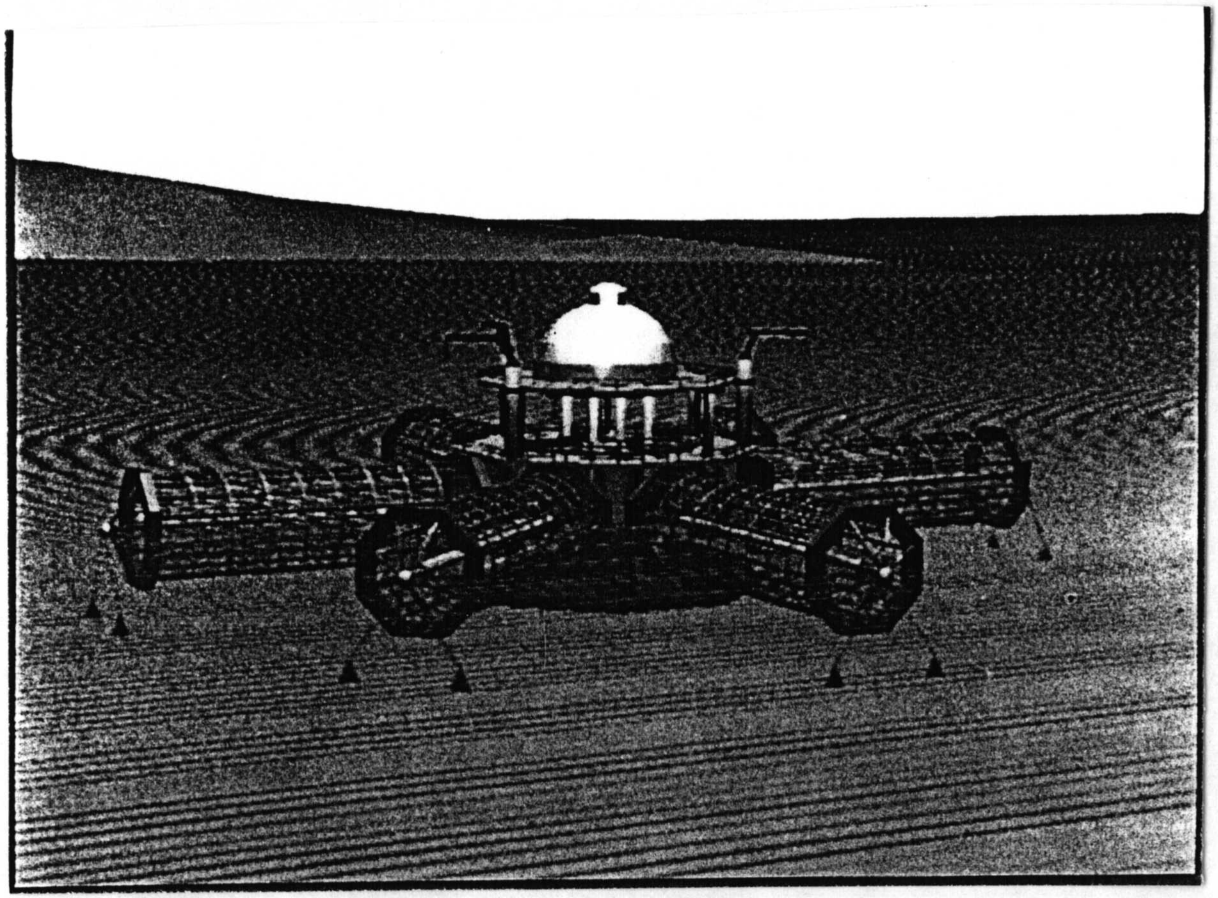

Figure 4B.1. Horizontal view of computer-assisted drawing of the Sea Trek Ocean Farming System® resting in 50 feet of water showing the central platform and the six semisubmerged barrel cages. The cages will be 170 feet in length and 40 feet in diameter. The octagonal platform will be 112 feet in diameter and will rise 125 feet from the sea bed.

The patent-pending, Sea Star Oyster Relaying System (Figure 4B.2) is a ballastable device for holding, deploying, cleansing, enhancing, and recovering oysters to be relaid from coastal waters that do not meet federal water-quality criteria for shellfish growing areas. Oysters that are relaid from contaminated coastal waters to "approved" waters of the open Gulf of Mexico will purge themselves of potentially-pathogenic bacteria and viruses during the required 14-day relaying periods. The oysters will also be enhanced by increasing their internal salt content (or "salty" flavor).

Each Sea Star unit will hold approximately 60,000 3-inch-plus oysters in 288 plastic trays. A fully-loaded unit will contain eight racks (two stacked racks per side x four sides), and each rack will contain 36 trays of 200+ oysters each. The Sea Star units will rest on the bottom near the Sea Trek site off Alabama and/or at an OCS site approximately 3 miles south of Ship Island, Mississippi. As many as 12 Sea Star units will be utilized at each site and will be deployed and recovered via jack-up vessels or other marine equipment. USACOE permits (Rivers & Harbors Act, Section 10) are pending for commercial oyster-relaying operations at the two OCS sites. Public notices were issued by the USACOE Mobile District on 6 February 1995, and the permits should be granted in March 1995 if no conflicts arise.

The Minerals Management Service (MMS) of the U.S. Department of the Interior facilitated Sea Pride's contacts with and ultimate "letter-of-agreement" from Exxon for the operation of the Sea Trek Ocean Farming System®. At present, the MMS has no specific regulatory authority or policies relative to mariculture activities or operations on the OCS in the Gulf of Mexico. Between now and the year 2000 hundreds of OCS platforms that will be abandoned in the nearshore waters of the Gulf of Mexico may be suitable for mariculture applications. The MMS will have an opportunity to facilitate additional mariculture ventures and may exert some regulatory authority over such ventures when the abandoned platforms are converted for mariculture rather than removed as required by current MMS regulations.

Sea Pride Industries chose its permitted Sea Trek/Sea Star site off-Alabama for many reasons, including excellent prevailing water-quality conditions (high salinity and dissolved oxygen, low nutrient loading, acceptable current flows, lack of pollution sources, etc.), geological bottom stability, and close proximity of ports, infrastructure, and seafood processing facilities. Other positive aspects of the nearshore Alabama site included the "accepted" presence of natural gas exploration and production platforms, reduced user-conflict issues, and the pro-mariculture philosophy of the Alabama Marine Resources Division which operates the Claude Peteet Mariculture Center at nearby Gulf Shores.

The acquisition of requisite USEPA and USACOE permits for Sea Pride's mariculture activities has been a long and cumbersome, yet successful process. At the outset, Sea Pride tried to anticipate the environmental information needs of the various federal and state regulatory agencies. Sea Pride prepared and submitted environmental assessments and monitoring proposals to the USEPA knowing that its Region-IV staff had never considered a permit for ocean discharges from a mariculture facility in federal waters. Sea Pride and the USEPA negotiated in good faith, and all permit issues were resolved satisfactorily.

Sea Pride has designed and will operate environmentally-sound systems in the Gulf of Mexico. Sea Pride cannot afford to adversely impact the area's water quality because to do so would adversely affect the finfish and shellfish stocks that will be cultured and/or cleansed.

The presence of the Sea Trek and Sea Star Systems will attract numerous commercially- and recreationally-important finfishes and shellfishes to the area. Those fishes will in turn attract sports fishermen and increase fish catches in the immediate vicinity of the platform. The aqueous finfish and shellfish wastes that will be diluted and disseminated by tidal currents will increase general primary production over adjacent areas of the OCS.

Sea Pride recognizes the worldwide and areawide reductions of finfish and shellfish landings and is attempting to solve some of the fish shortage via mariculture. It has plans to fabricate and deploy Sea Trek Ocean Farming Systems® in Micronesia and other international areas where native finfish populations are being depleted via overharvesting, or shellfish populations are being threatened by increasing human "pollution."

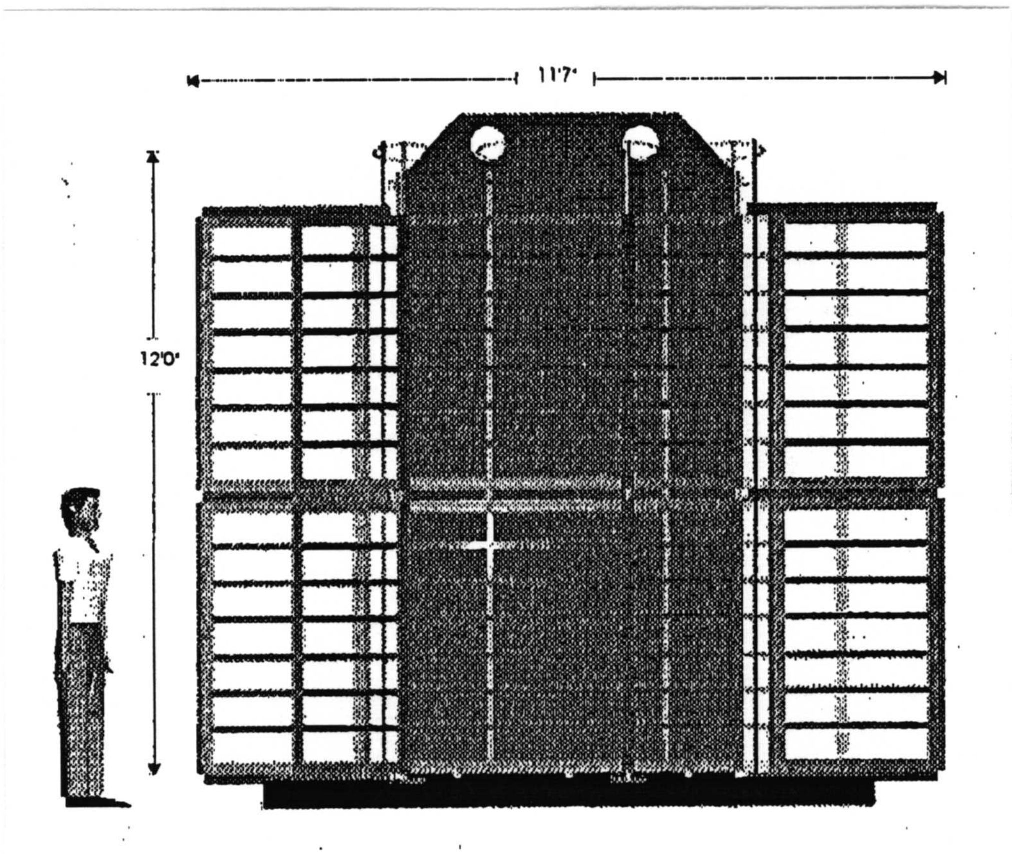

Figure 4B.2. Horizontal view of computer-assisted drawing of the Sea Star Oyster Relaying System showing eight oyster racks around the central ballast tank. The system size will approximate a 12-foot cube.

Finally, Sea Pride's believes that its Sea Trek and Sea Star operations in the Gulf of Mexico will start a new mariculture industry similar to the $75-million-a-year salmon-culture industry in the U.S. Pacific Northwest. A successful Gulf of Mexico mariculture industry would reduce U.S. dependence on imported fishery products, thereby reducing the Federal deficit; increase the availability of high-quality finfish and shellfish products; increase job opportunities for underemployed or out-of-work fishermen and newly-trained mariculturists; expand the market for regional grain products that will be needed for feed formulation; and develop new culture systems (platforms, cages, racks, etc.) that can be fabricated and serviced by existing industries along the Gulf coast, thereby boosting local economies.

THE ENGINEERING OF MARICULTURE PENS IN ASSOCIATION WITH OIL AND GAS STRUCTURES

Mr. Clifford A. Goudey
Massachusetts Institute of Technology
Sea Grant College Program

SUMMARY

Many oil and gas structures in the Gulf of Mexico are no longer producing energy and present attractive sites for offshore mariculture. By incorporating the existing structure into a fish pen system, its removal cost can be avoided and the overall system cost can be reduced. However, the exposed locations of candidate structures are unlike anything experienced by conventional, sheltered-water mariculture operations and present new challenges.

Techniques for the design and performance prediction of oil and gas structures are well established. The prediction of pen system behavior and the estimation of loads generated by waves, currents, and extreme events have only recently received attention. The flexible nature of most pen systems is essential to their survivability but it complicates their analysis since their geometry is variable. Of the many engineering issues confronting the mariculture system designer seeking to exploit an existing structure, predicting the loads imposed on the structure by the pen system is of prime importance.

This presentation describes the use of scale models and wave basins as a means of both predicting loads and understanding the behavior of complex pen systems under simulated environmental exposure.

MODEL TESTS OF MARICULTURE SYSTEMS

Many of the practices that have been developed for the model testing of ships and structures can be applied directly to mariculture systems. The scaling of geometry, weight, speed, wave heights, and frequencies all follow rules established by Froude. As with most conventional model tests, attention to model details can be important and the use of as large a model as possible is always important. In addition, the netting and tension-member portions of a pen system require the use of modeling practices which have been developed in trawl net testing programs. Netting geometric parameters must be accounted for as well as the elastic moduli of materials used in the netting and load-bearing lines.

Figure 4B.3 is an example of an experimental set-up in a circulating water channel aimed at predicting the resistance of a pen system in a current. It is important to note that the resistance determines the shape and the shape determines the resistance: these are highly non-linear systems. Such a test set-up is also useful in determining netting deformation, water flow, and feed pellet trajectories.

A proper test protocol will call for the introduction of netting of several different blockage ratios. In this way the effects of biofouling on netting can be determined with respect to increased loads and reduced water flow. The latter factor can be important in determining stocking densities.

The performance of a mariculture system in waves can be predicted through the use of a wave basin. Due to the dynamic nature of such tests, the contribution of all elements of the system must be included such as anchor lines. Figure 4B.4 is an example of a test setup in a wave basin of a pen designed for full ocean exposure. In such a test, load cells are places at a variety of locations within the system to determine wave-induced loads and help

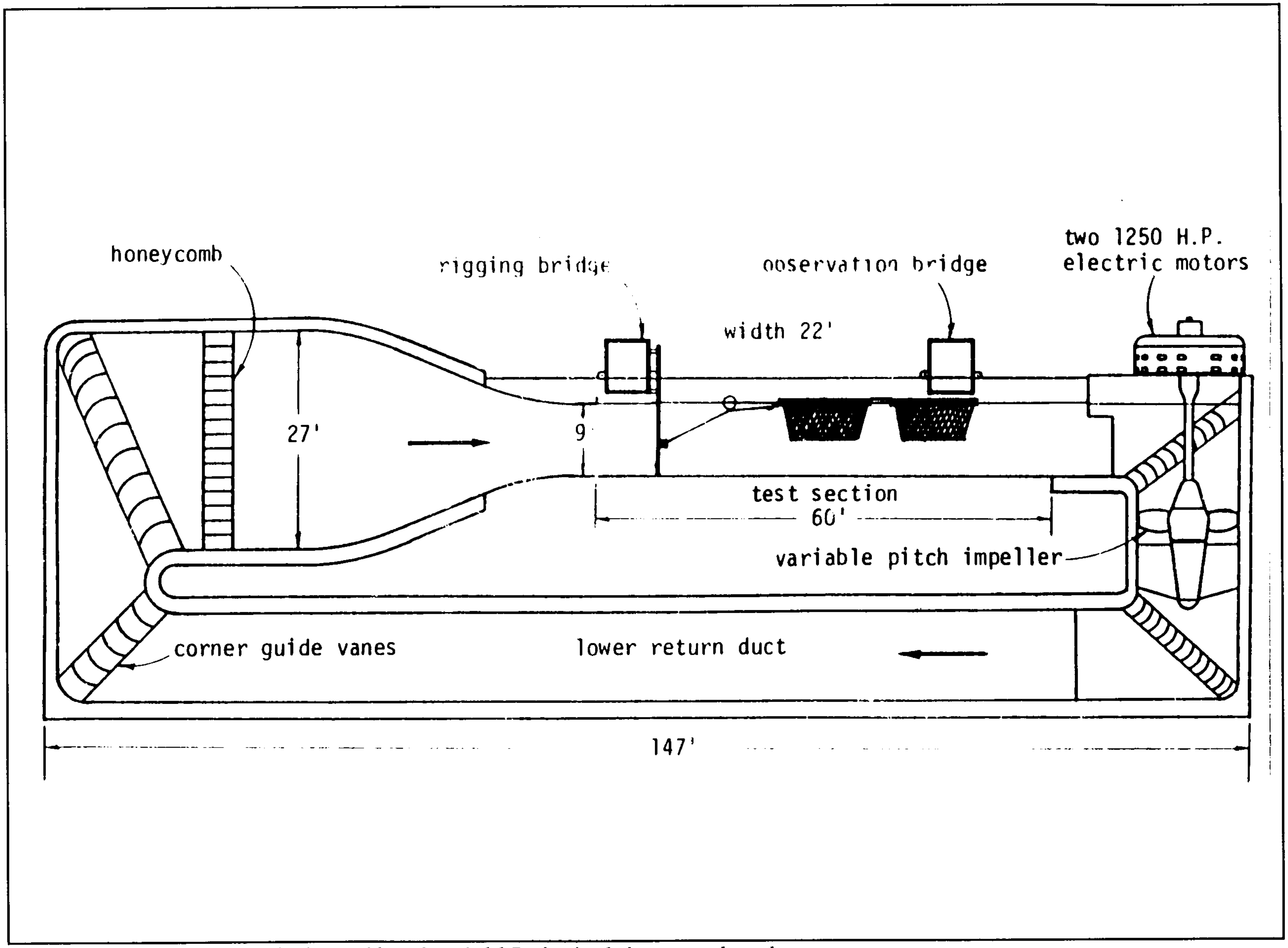

Figure 4B.3. Fish pen tests in the David Taylor Model Basin circulating water channel.

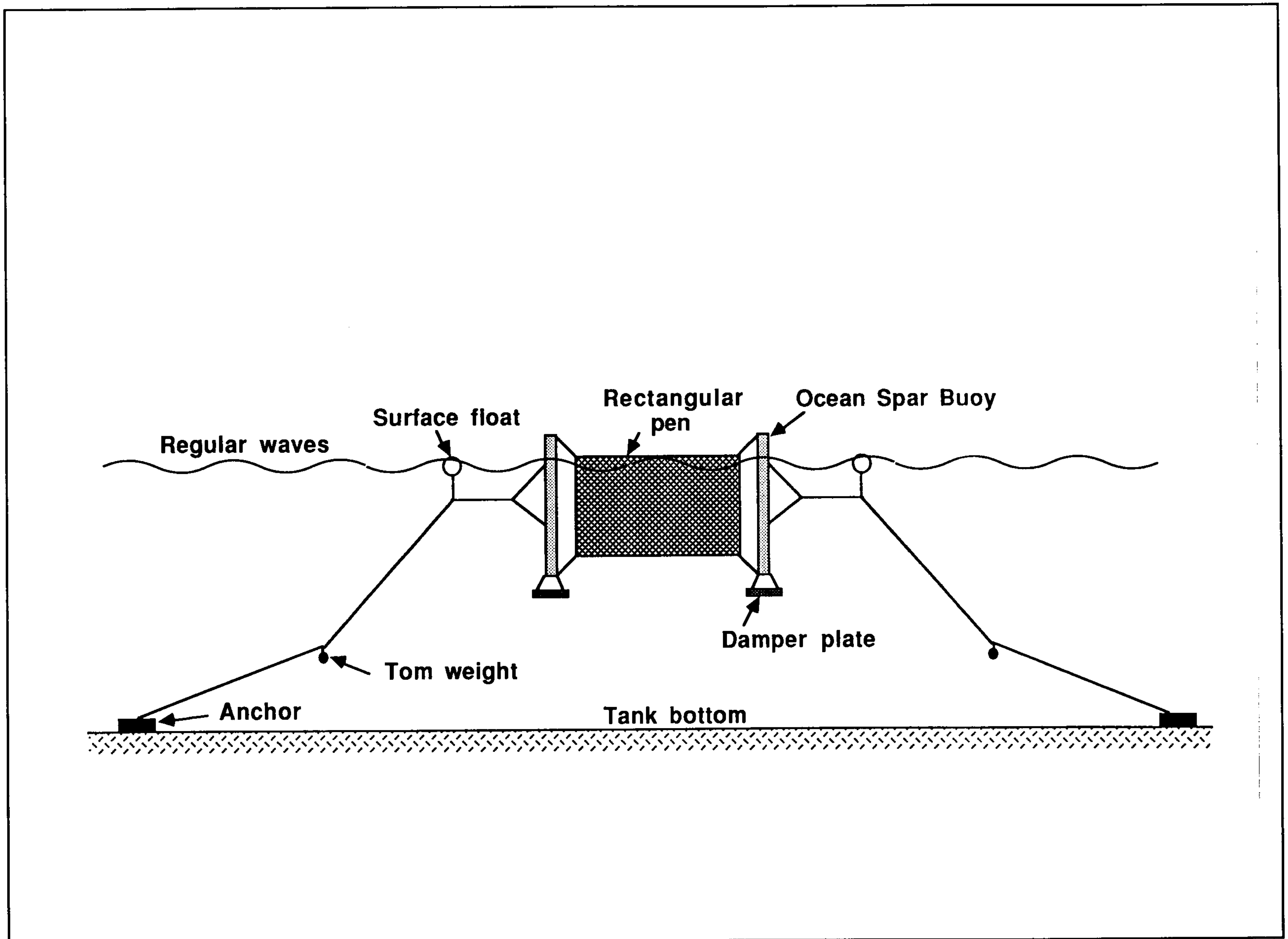

Figure 4B.4. Ocean Spar pen tests in the David Taylor Model Basin maneuvering and seakeeping basin.

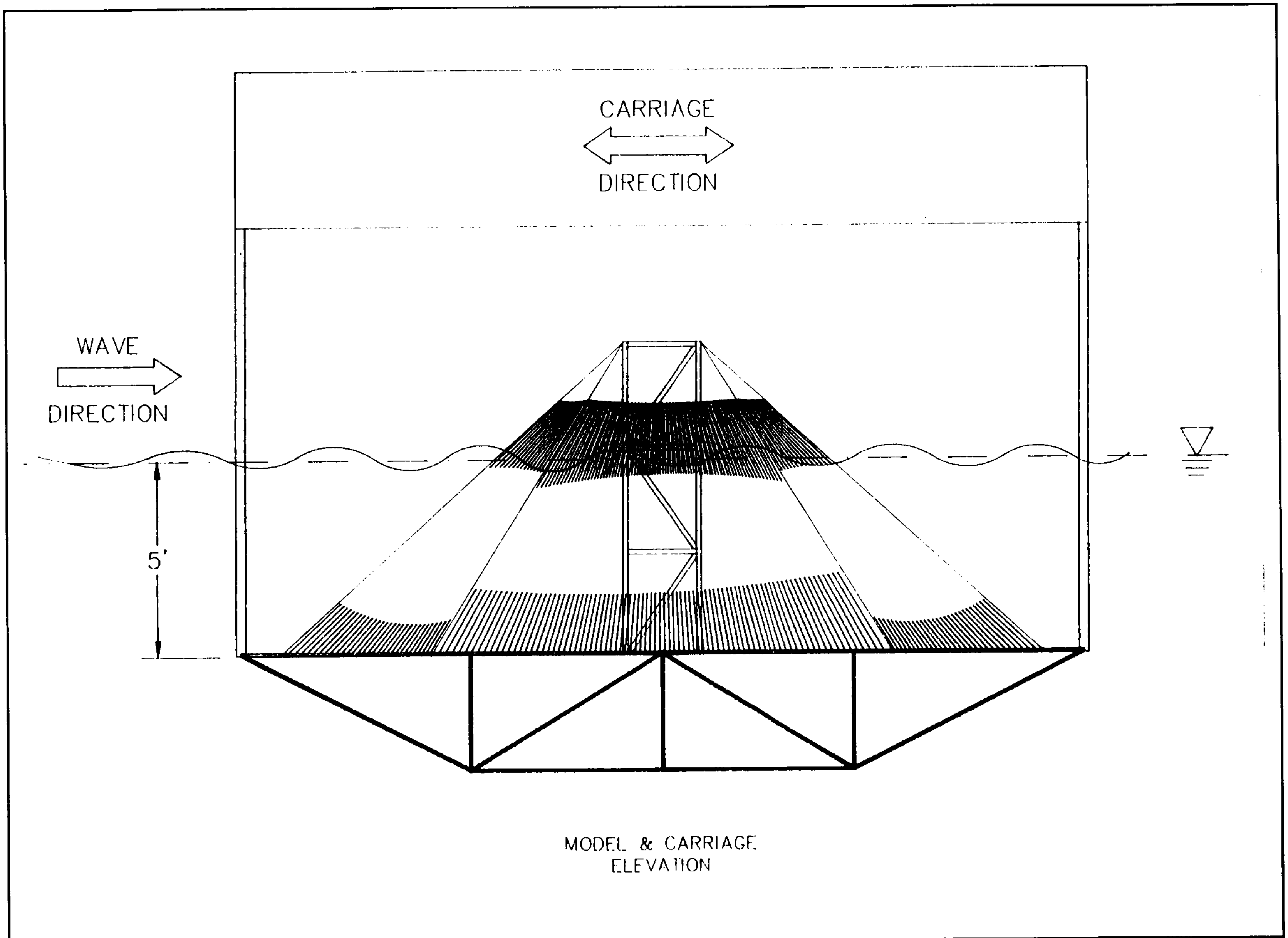

Figure 4B.5. Combined wave and current tests at trhe David Taylor Model Basin maneuvering and seakeeping basin.

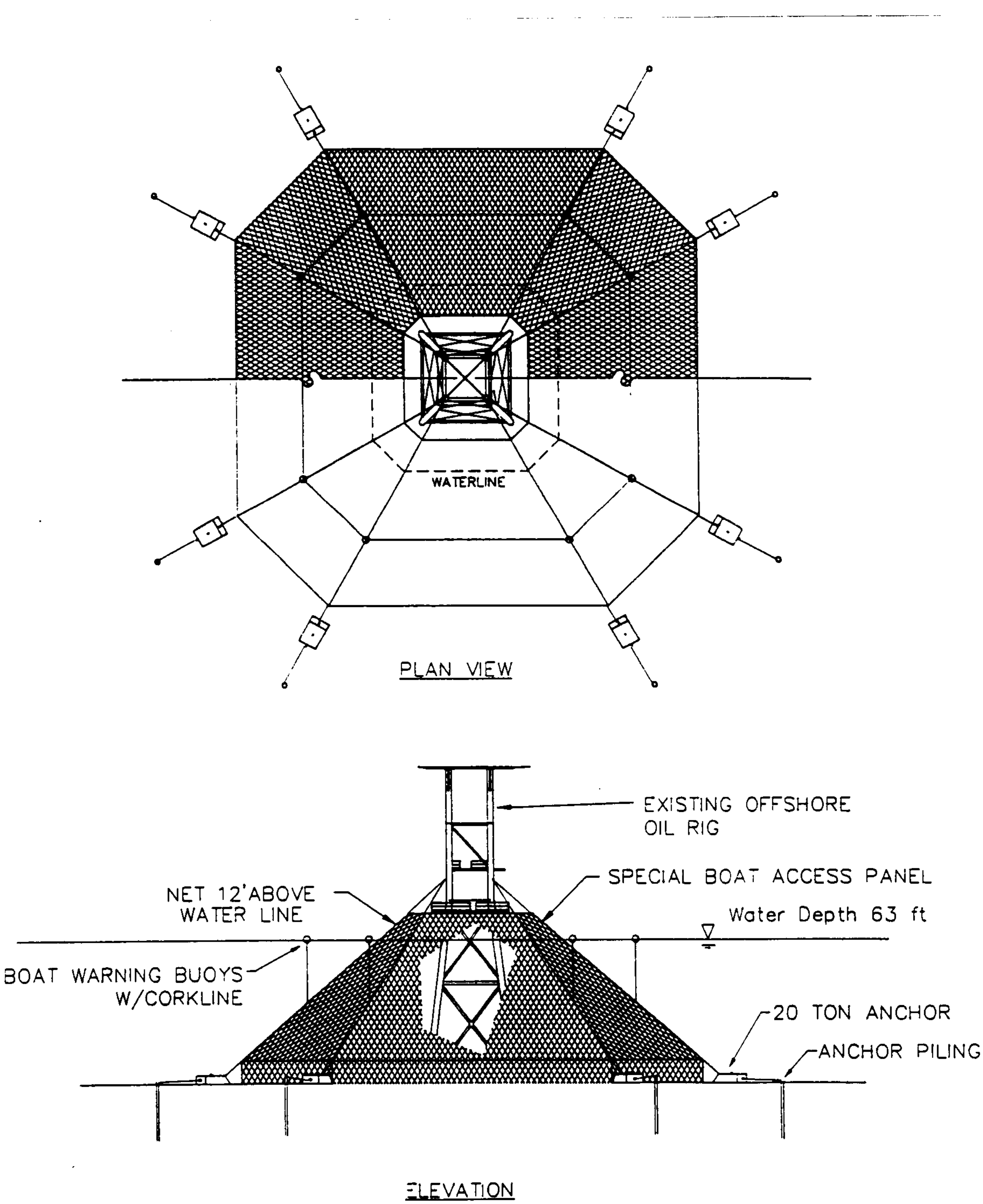

Figure 4B.6. The tent pen mariculture system.

identify areas where cyclic loading and snapping are potential problems. A test regimen of regular waves over a range of frequencies is useful in identifying resonant behaviors and associated peak loads. Breaking waves are useful in understanding the performance of the system under extreme conditions.

In a unique series of tests further described below, the combined effects of current and waves were found to be different than the simple summation of current and wave results determined separately. This is attributable to the non-linearity of these flexible systems and provides a strong argument for doing combined tests. Figure 4B.5 is the experimental set-up for a combined current/wave test where the entire model and a false bottom is suspended below the wave basin carriage to allow its movement through the water.

AN OIL STRUCTURE BASED MARICULTURE SYSTEM

In a collaborative effort by the author and NET Systems of Bainbridge Island, Washington, a mariculture system sited around an oil structure has been designed and evaluated at the model scale. This work, sponsored by an SBIR grant, explored a wide range of system geometries, finally focusing on a concept which offered unique economic appeal.

An important measure of a pen system's merit is the cost of the system versus the enclosed growing volume. A further measure is the amount of growing volume that is away from the air/water interface and the associated wave-induced stress. From a simple geometric perspective the concept of a tent-shaped pen was quickly identified as attractive. An important feature of this concept was the utilization of the structure as the central support for the tent pen. It was critical, therefore, to determine the loads that would be generated by such an installation since that would ultimately determine the size and economy of the approach.

A candidate design using a 45√ angle for the netting was used as the basis for model testing. A 1/10 scale model of such a tent pen system surrounding a structure in 50 feet of water was evaluated. Figure 4B.6 shows the model configuration. Model wave frequencies ranged from 0.3 to 0.7 Hz in 0.1 Hz intervals. Currents (carriage speeds) of 0.3, 0.5, 0.7, and 1.0 were used. These ranges correspond to ocean wave frequencies from 0.095 to 0.22 Hz. or wave periods from 10.5 to 4.5 seconds. The corresponding full-scale currents range from 0.95 to 3.16 knots.

Measurements of anchor loads and structure attachment loads were made at selected locations within the system. Load data was measured using small strain gage load cells and recorded on a PC-based data acquisition system. Angle measurements of structure attachment lines were made manually during each run. Data was analyzed and presented in terms of load verses speed or wave frequency. Wave data was normalized to a model wave height of one foot and presented in terms of both average values and amplitudes.

From the model data, full-scale load predictions can be made. Tension members of the systems can be determined and anchors and attachment padeyes sized. In addition, structural attachment loads and their angles can be combined to determine the resultant load on the structure and its foundation pilings. Through these techniques it was determined that, depending on the adequacy of the candidate structure, the tent pen concept was both economically attractive and feasible from an engineering standpoint.

The ultimate success of an offshore mariculture operation will depend on its ability to compete with existing sheltered-water operations and wild harvest fisheries. Offshore sites offer economies of scale but introduce challenges to the designer. Through the use of logical design, performance prediction through model tests, and the specification of components adequate for the task, a tent pen system has been introduced which will cost between $7 and $9 per cubic meter, including installation but exclusive of structure costs. This compared favorably with today's protected-water systems which are priced at $10 to $20 per cubic meter.

Industry partners are currently being sought for the further development of the tent pen design. Systems can be engineered for structures in water depths from 40 to 100 feet. Interested parties should contact the author or Gary Loverich at Net Systems.

SESSION 4C

MMS ENVIRONMENTAL STUDIES REPORTS

Session: 4C - MMS ENVIRONMENTAL STUDIES REPORTS

Co-Chairs: Dr. Pasquale Roscigno and Ms. Carla M. Langley

Date: November 17, 1994

Presentation	Author/Affiliation
Introduction to Reports from MMS Environmental Studies Program	Dr. Pasquale F. Roscigno Ms. Carla M. Langley Environmental Studies Section U.S. Minerals Management Service Gulf of Mexico OCS Region
Environmental and Economic Assessment of Discharges from Gulf of Mexico Region Oil and Gas Operations	Dr. David A. Gettleson Dr. Alan D. Hart Mr. Bruce D. Graham Continental Shelf Associates, Inc. Jupiter, Florida
USDOE Study: Human Health and Ecological Risk Assessments for Produced Water Discharges	Ms. Anne F. Meinhold Dr. Seymour Holtzman Mr. Michael DePhillips Dr. Leonard D. Hamilton Biomedical and Environmental Assessment Group Analytical Sciences Division Department of Applied Science Brookhaven National Laboratory
Fisheries Impacts of Explosives Used in Platform Salvage	Mr. Gregg Gitschlag Galveston Laboratory Southeast Fisheries Center
An Assessment of Effects and Remediation of Oil Spills in the Gulf of Mexico and Caribbean	Dr. Edward Proffitt Louisiana Environmental Research Center McNeese State University
Benthic-Pelagic Coupling in the Gulf of Mexico: Implications for the Fate of Organic Matter on the Continental Shelf	Dr. Robert R. Twilley University of Southwestern Louisiana Dr. Brent A. McKee Louisiana Universities Marine Center

INTRODUCTION TO REPORTS FROM MMS ENVIRONMENTAL STUDIES PROGRAM

Dr. Pasquale F. Roscigno
Ms. Carla M. Langley
Environmental Studies Section
U.S. Minerals Management Service
Gulf of Mexico OCS Region

This session reflects the diversity of topics and interests that are of concern to MMS in the Gulf of Mexico Region. The range of topics extends from human health effects from platform discharges to the benthic-pelagic coupling of organic matter. These environmental studies are attempts to address the many challenges confronting MMS' mission to develop our non-renewable natural resources in an environmentally sound manner.

All of these studies look at different aspects of oil and gas operations and attempts to examine the extent of the impact and offers recommendations on mitigating the impacts. While these impacts have different scales and probability of occurrence, they are concerned with an activity, or consequence of an activity, that is characteristic of OCS oil and gas operations. The information produced from these studies can provide managers and operators with timely information which can be used to operate the facilities and to protect the environment in a better manner.

Dr. Pasquale F. Roscigno is a program manager in the MMS Environmental Studies Section in New Orleans. Previously he held several positions in the Department of the Interior's Fish and Wildlife Service.

Ms. Carla M. Langley is an environmental scientist in the MMS Environmental Studies Section in New Orleans where she oversees publications coordination and information transfer. She is a graduate of the University of New Orleans in Louisiana.

ENVIRONMENTAL AND ECONOMIC ASSESSMENT OF DISCHARGES FROM GULF OF MEXICO REGION OIL AND GAS OPERATIONS

Dr. David A. Gettleson
Dr. Alan D. Hart
Mr. Bruce D. Graham
Continental Shelf Associates, Inc.
Jupiter, Florida

OVERVIEW

In June 1992, the U.S. Department of Energy (DOE) contracted with Continental Shelf Associates, Inc. (CSA) and its team of subcontractors and independent consultants to conduct the multi-year study entitled *Environmental and Economic Assessment of Discharges from Gulf of Mexico Region Oil and Gas Operations*. CSA's subcontractors include Arthur D. Little (ADL), Battelle Ocean Sciences, Core Laboratories, Florida Institute of Technology (FIT), ICF Resources Incorporated (ICF), and Steimle and Associates, Inc. (SAI); independent consultants include Drs. Bruce Honeyman and Wayne Isphording. This research effort is being supported under DOE Contract Number DE-AC22-92MT92001. This presentation outlines the technical approach being used to meet DOE study objectives and summarizes the current status of each technical task.

GENERAL TECHNICAL APPROACH

The study is designed to increase the present state of scientific knowledge concerning the following topics:

- The fate and environmental effects of pollutants found in produced water;
- The economic impacts of current and potential future regulations on offshore oil and gas producers of the Gulf of Mexico region; and
- The catch, consumption, and human use patterns of seafood species collected from coastal and offshore waters of the Gulf of Mexico.

The research implemented to address these topics will allow for creation of data bases pertaining to:

- The fate and environmental effects of naturally occurring radioactive materials (NORM), trace metals, and organics in water, sediment, and biota near several offshore oil and gas facilities;
- The characteristics of produced water and produced sand discharges as they pertain to NORM, trace metals, and organics variably found in association with these discharges;
- The recovery of three terminated produced water discharge sites located in wetland and high energy open bay environments of coastal Louisiana;
- The economic and energy supply impacts of existing and anticipated Federal and State offshore and coastal discharge regulations; and
- The catch, consumption, and human use patterns of seafood species collected from coastal and offshore waters.

Guidance and expert technical input has also been provided by the DOE Contracting Officer's Representative, members of the scientific community, other agencies, and experts on the program team to further refine various aspects of the program, particularly the field component. Based on DOE's data needs, an eight-task research plan was implemented in mid-1992.

SUMMARY AND STATUS OF TECHNICAL TASKS

Task 1: Organize and Coordinate a Scientific Review Committee

The objective of this task is to organize and coordinate a Scientific Review Committee (SRC), whose main purpose is to review and critically evaluate all aspects of the research program. The SRC was established in July 1992. A total of 25 members comprise the SRC, representing industry groups, the scientific community, and the government sector (Federal and state agencies). As one of their first official duties, the SRC reviewed and commented upon the Sampling and Analysis Plan (Task 2), submitted in August 1992. SRC comments were pertinent to a series of topics, including 1) data needs for the human health and ecological risk assessments, both of which will be completed separately by Brookhaven National Laboratory; and 2) suggested revisions to study design. The SRC also supported enhanced coordination between CSA, DOE, and other Federal agencies or interests.

Task 2: Preparation of the Sampling and Analysis Plan

The objective of this task is to develop a Sampling and Analysis Plan which describes the research to be conducted in Task 3 (Environmental Field Sampling and Analysis of NORM, Heavy Metals, and Organics), Task 4 (Monitoring of the Recovery of Impacted Wetland and Open Bay Produced Water Discharge Sites in Coastal Louisiana), and Task 5 (Assessment of Economic Impacts of Offshore and Coastal Discharge Requirements on Present and Future Operations in the Gulf of Mexico Region). The draft Sampling and Analysis Plan was issued in August 1992 and reviewed by the SRC. Based on SRC comments, as well as comments and recommendations from DOE and other agencies and individuals, further revisions to the Sampling and Analysis Plan have been completed and integrated into the study design.

Task 3: Environmental Field Sampling and Analysis of NORM, Heavy Metals, and Organics

The objective of this task is to gather data necessary to characterize the extent of radionuclide contamination in water, sediment, and biota at produced water and produced sand discharge points. Heavy metals and petroleum hydrocarbon data are also being collected. NORM, heavy metal, and petroleum hydrocarbon data are to be used to evaluate the risks associated with produced water and produced sand discharges to human health and the environment. This risk assessment process involves following the discharge of pollutants from the source through its transport in the receiving environment, including indigenous fauna and humans.

Eight platform sites and six reference sites (Table 4C.1) located in OCS waters off Texas and Louisiana were selected following a rigorous review of 53 candidate offshore facilities. Task 3 sampling was initiated in June 1993 and continued into the summer months. The numbers and types of samples collected at primary and secondary platform sites and reference sites are summarized in Table 4C.2. A matrix summary of the analyses performed on these samples is provided in Table 4C.3. Radionuclides of interest include Ra^{226}, Ra^{228}, Pb^{210}, Po^{210}, and Th^{228}, while a total of 14 metals, three petroleum hydrocarbon classes (VOA, SHC, PAH), and six other elements are also to be determined in effluent, water, sediments, and tissues according to the analyses outlined in Table 4C.3. All analyses will be completed in 1994 with a report to follow in 1995. An additional element of this task involves the pollutant removal efficiency of produced sand washing technologies. Samples of produced sand are being analyzed for NORM, heavy metal, and petroleum hydrocarbons both before and after treatment by mechanical/chemical washing devices.

Task 4: Monitoring of the Recovery of Impacted Wetland and Open Bay Produced Water Discharge Sites in Coastal Louisiana

The objectives of this task are to 1) identify and characterize the rates of ecological recovery at terminated produced water discharge sites located in select coastal wetlands and open bay environments of Louisiana; and 2) study the geochemical mobility of radionuclides, heavy metals, and organics in sediment and water. In addition, samples of water, sediment and commercially- and recreationally-important fish and shellfish tissues have been or will be taken in the vicinity of terminated discharges and analyzed for radionuclide content; results of these analyses will be used to support a separate health and environmental risk assessment for radionuclides discharged in produced water and sand.

Oil and gas facilities located in wetland and bay environments of Texas and Louisiana were screened as potential sampling locations using similar methods to those employed in establishing Task 3 sampling sites. Candidate facilities included those which had proposed the termination of their respective produced water discharges coincident with the current program schedule. A review of facility-specific produced water discharge data was also completed. Based on these evaluations, three sites in coastal Louisiana (i.e., one canal site, two open water bay sites) were selected for sampling (Table 4C.4). The numbers and types of samples collected at each coastal site are summarized in Table 4C.5. A matrix summary of the analyses being performed is provided in Table 4C.6. Pre-termination sampling was completed in spring 1993 at Delacroix Island and Bay de Chene, and in fall 1993 at Four Isle Dome. Two post-termination surveys have been conducted at Delacroix Island (fall 1993 and spring 1994) and Bay de Chene (spring and fall 1994). The first post-termination survey at Bay de Chene was delayed due to a delay in the termination schedule. No post-termination surveys have been conducted at Four Isle Dome as the discharge has not been terminated. A final survey (spring 1995) is planned with a report to follow in late 1995/early 1996.

Task 5: Assessment of Economic Impacts of Offshore and Coastal Discharge Requirements on Present and Future Operations in the Gulf of Mexico Region

The objective of this task is to assess the economic and energy supply impacts of recent effluent limitation guidelines and New Source Performance Standards (NSPS) on oil and gas operations in offshore and coastal areas, both alone and in comparison to other regulatory requirements at the State and Federal level. These impacts are to be assessed and presented in terms of the cost to the petroleum industry, current offshore oil and gas production which could be abandoned, future potentially recoverable oil and gas reserves that could become uneconomic, and future leasing in the Gulf of Mexico that could be diminished. A draft report will be submitted to DOE in January 1995.

Task 6: Synthesis of Gulf of Mexico Region Consumption and Use Patterns

The objective of this task is to gather and assemble information regarding the seafood catch, consumption, and use patterns for the Gulf of Mexico region. In meeting this objective, descriptive field surveys (e.g., via interviews, questionnaires) and a detailed review of pertinent general literature and government and research data are being conducted to develop the database. A draft report will be submitted to DOE in January 1995.

Task 7: Technology Transfer Plan

The objective of this task is facilitate dissemination of the information collected during this study. To this end, the program has adopted a three-tiered approach to make data available quickly and in a useable form. The three primary elements of technology transfer include 1) preparation of short, succinct progress reports or public abstracts; 2) presentation of progress reports and study results at MMS

Table 4C.1. Platform and reference sites, Task 3.

	Water Depth (feet)	NORM Loading ^{226}Ra & ^{228}Ra ($\mu Ci/day$)
Primary Platform Sites		
South Marsh Island 130B	215	1,411
South Marsh Island 236A	20	1,758
Vermilion 214A	127	1,022
High Island 595CF	400	1,280
Secondary Platform Sites		
Eugene Island 313A	236	75
High Island 382F	341	345
High Island 323A	235	38
Matagorda Island 703A	167	6
Reference Sites (platform - no produced water discharge)		
South Marsh Island 229C	18	---
Vermilion 298 and 305 (Sonnier Bank)	66	---
Reference Sites (non-platform)		
West Cameron 448	120	---
South Marsh Island 195	210	---
Galveston 90	132	---
Galveston 204	210	---

Table 4C.2. Types of samples and data, Task 3.

Primary Platform Sites

Produced Water
- initial collection (6 collections)
- monthly for 6 months

Produced Sand
- 3 replicates

Hydrography and Currents
- profiles and continuous

Discharge Plume Water
- 3 replicates at 5 distances—5, 10, 30, 50, and 100 m

Sediments
- 25 stations (replicates at selected stations)

Pore Water
- 3 stations

Biological Tissues
- 1 invertebrate biofouling species
- 2 invertebrate soft bottom species
- 4 fish species

Harvestable Biota
- 3 trawls

Secondary Platform Sites

Produced Water
- 1 collection of 3 replicates

Biological Tissues
- 1 invertebrate biofouling species
- 2 invertebrate soft bottom species
- 4 fish species

Reference Sites (non-platform)

Ambient Water
- 1 collection of 3 replicates

Sediments
- 1 station with 3 replicates

Reference Sites (platform - no produced water discharge)

Ambient Water
- 1 collection of 3 replicates

Biological Tissues
- 1 invertebrate biofouling species
- 2 invertebrate soft bottom species
- 4 fish species

Table 4C.3. Analyses, Task 3.

	Produced Water	Produced Sand	Discharge Plume	Ambient Water	Sediments	Pore Water	Biological Tissues
Radionuclides							
Ra^{226}	X	X	X	X	X	X	X
Ra^{228}	X	X	X	X	X	X	X
Pb^{210}	X	X	X	X	X	X	X
Po^{210}	X	---	---	---	---	---	---
Th^{228}	X	---	---	---	---	---	---
Metals							
Al	---	X	---	---	X	---	---
As	X	X	---	X	X	---	X
Ba	X	X	---	X	X	---	X
Cd	X	X	---	X	X	---	X
Cr	---	X	---	---	X	---	X
Cu	X	X	---	X	X	---	X
Fe	X	X	---	X	X	---	X
Pb	X	X	---	X	X	---	X
Mn	X	X	---	X	X	---	X
Hg	X	X	---	X	X	---	X
Mo	X	X	---	X	X	---	X
Ni	X	X	---	X	X	---	X
V	X	X	---	X	X	---	X
Zn	X	X	---	X	X	---	X
Hydrocarbons							
VOA	X	---	X	X	---	---	---
SHC	X	X	---	---	X	---	---
PAH	X	X	---	X	X	---	X
Other Elements							
Calcium	---	---	---	---	X	---	---
Chloride	X	---	---	X	---	---	---
DOC	X	---	---	X	---	---	---
Sulfate	X	---	---	---	---	---	---
Grain Size	---	X	---	---	X	---	---
TOC	---	X	---	---	X	---	--

Table 4C.4. Study sites and sampling, Task 4.

Site	Termination of Discharge	Environment	Radionuclide Ra^{226} and Ra^{228} (pCi/l)		Discharge (bbl/day)
Delacroix Island Tank Battery #1	May 1993	Saline, Open-Water	273	---	1,397
Bay de Chene	October 1993	Saline, Open-Water	106	---	4,016
Four Isle Dome		Canal	295	448	1,340

Table 4C.5. Types of samples and data, Task 4.

Produced Water
- pre-termination survey only

Sediments
- 10-17 surficial sediment stations (7 stations with 3 replicates)
- 3 deep sediment stations (pre-termination and second post-termination surveys only, three replicates at 20 to 25 and 35 to 40 cm depths)

Pore Water

- 3 stations (pre-termination and second post-termination surveys only, three replicates at 0 to 5, 20 to 25, and 35 to 40 cm depths)

Biological Tissues

- 3 stations (pre-termination and second post-termination surveys only)
- 3-5 species (fish, shrimp, and crab)

Macroinfauna

- 10-17 stations (6 replicates collected with 3 replicates analyzed)

Harvestable Finfish and Shellfish

- gill net, cast net, and trawl (if possible)
- crab traps
- oysters (presence/absence within 500 m of discharge)

Table 4C.6. Analyses, Task 4.

	Produced Water[1]	Surficial Sediments (SS[2])	Surficial Sediments (SS[3])	Deep Sediments[2]	Pore Water[2] 0-5 cm	Pore Water[2] 20-25 and 35-40 cm	Biological Tissues[2]
Radionuclides							
Ra^{226}	X	X	X	X	X	X	X**
Ra^{228}	X	X	X	X	X	X	X**
Pb^{210}	X	---	---	---	---	---	---
Po^{210}	X	---	---	---	---	---	---
Th^{228}	X	---	---	---	---	---	---
Metals							
Al	---	X	X	---	---	---	---
As	X	X	X	---	X	---	---
Ba	X	X	X	---	X	---	---
Cd	X	X	X	---	X	---	---
Cr	---	X	X	---	---	---	---
Cu	X	X	X	---	X	---	---
Fe	X	X	X	---	X	---	---
Pb	X	X	X	---	X	---	---
Mn	X	X	X	---	X	---	---
Hg	X	X	X	---	X	---	---
Mo	X	X	X	---	X	---	---
Ni	X	X	X	---	X	---	---
V	X	X	X	---	X	---	---
Zn	X	X	X	---	X	---	---
Hydrocarbons							
VOA	X	X*	---	---	---	---	---
SHC	X	X	X	---	---	---	---
PAH	X	X	X	X	X	---	---
Other Elements							
Calcium	---	X	X	---	---	---	---
Chloride	X	---	---	X	X	X	---
DOC	X	---	---	X	X	X	---
Si	---	---	---	---	---	---	---
Sulfate	X	---	---	X	X	---	---
Grain Size	---	X	X	---	---	---	---
TOC	---	X	X	X	---	---	---

* - Only at discharge during pre-termination survey
** - Pending available funds
1 - Pre-termination survey
2 - Pre-termination and second post-termination surveys
3 - First and third post-termination surveys

Information Transfer Meetings (ITM); and 3) presentation of study results at scientific conferences and preparation of study results for publication in peer-reviewed literature.

Task 8: Project Management and Deliverables Preparation

The objective of this task is to ensure proper project management, including routine oversight of CSA and subcontractor staff, strict adherence to established quality assurance and quality control procedures and protocols, and timely and thorough preparation of technically sound deliverables. Given the modified technical approach realized since June 1992, revised management and cost plans and milestone schedule have been developed. An expanded quality assurance/quality control program specific to radioactive nuclides has also been developed.

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Bruce Graham is a Marine Biologist/Senior Staff Scientist at Continental Shelf Associates, Inc. (CSA) located in Jupiter, Florida. He has 10 years' experience with major research programs for federal, state, and industrial clients and has served as Project Manager and/or Chief Scientist on numerous marine sampling projects. He has been involved in various projects including oil and gas lease block photodocumentation, dredge disposal monitoring, beach restoration, power plant effluents, and oil and gas biological monitoring. Mr Graham received his M.S. degree in biological sciences from Florida Institute of Technology in 1983.

USDOE STUDY: HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENTS FOR PRODUCED WATER DISCHARGES

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INTRODUCTION

Produced water generated during the production of oil and gas can contain high concentrations of radionuclides, organics and heavy metals. There are concerns about potential human health and ecological impacts from the discharge of these contaminants to the Gulf of Mexico.

Data collected in the United States Department of Energy (USDOE) field study (Gettleson *et al.* 1994) are being used in a series of human health and ecological risk assessments. These assessments will support scientifically-based regulation and risk management.

This presentation summarizes risk assessments performed for produced water discharges; describes how uncertainties in these assessments are guiding data collection efforts in the USDOE field study; and outlines ongoing risk assessment studies.

In these studies, risk assessment is treated as an iterative process. An initial screening-level assessment is performed to identify important contaminants, transport and exposure pathways, and parameters. These intermediate results are used to guide data collection efforts and refinements to the analysis. At this stage in the analysis, risk is described in terms of probabilities; the uncertainties in each measured or modeled parameter are considered explicitly.

PHASE I - COASTAL RISK ASSESSMENT

A screening-level assessment of health and environmental risks associated with the discharge of radium in produced water to coastal Louisiana was performed for the American Petroleum Institute (Hamilton *et al.* 1992). This Phase I screening-level analysis was based on simple models and conservative, worst-case assumptions. The analysis concluded that no detectable impacts to fishes or shellfish would result from the discharge of radium in produced waters. The study also small risks to human health, but possible important risks (individual lifetime fatal cancer risk greater than 1 x 10^{-4}) for an individual ingesting a large amount of seafood harvested near a produced water discharge point over a lifetime. Estimated population risks were similar to those expected for background radium concentrations in the Gulf of Mexico.

PHASE II - OFFSHORE RISK ASSESSMENT

This human health risk assessment was supported by USDOE and focused on radium in offshore oil field discharges to the Gulf of Mexico (Meinhold *et al.* 1993). The subpopulation most at risk from radium discharged offshore is recreational fishermen and their families. The exposure route of greatest concern is the ingestion of radium in fishes caught near the platforms.

The analysis was less dependent on simplistic and conservative assumptions than the Phase I coastal risk assessment and used Monte Carlo methods and distributions of parameters to produce a probabilistic analysis of risk.

Two approaches were used: direct assessment and predictive modeling analysis. Direct assessment was based on measured concentrations of radium in edible fish near three shallow offshore platforms and is assumed to represent a "worst-case" analysis. Predictive modeling analysis estimated risks associated with representative offshore platforms.

Radium in Water and Fish

In the direct assessment, uniform distributions of radium concentrations in fish were based on field data (Continental Shelf Associates 1992; Steimle & Associates 1992) for three shallow (17, 19 and 22 m depth) offshore platforms in the Gulf of Mexico (Table 4C.7).

For the predictive analysis, a data base for 125 produced water platforms in the Gulf of Mexico

Table 4C.7. Uniform distributions of radium concentrations used in direct risk assessment for the Eugene Island, Ship Shoal and South Timbalier platforms (Continental Shelf Associates 1992; Steimle & Associates 1992).

Platform	**Ra-226 (pCi/g)**		**Ra-228 (pCi/g)**	
	mean	range	mean	range
Eugene Island	0.08	0 - 0.16*	0.365	0 - 0.73*
Ship Shoal	0.135	0 - 0.27*	0.89	0 - 1.78
South Timbalier	0.005**	0 - 0.01	1.35	0 - 2.7
Background	0.005	0 - 0.01	0.005	0 - 0.01

* maximum value based on 1/2 a reported "less than quantitation limit" value.

** no Ra-226 was detected in fishes at South Timbalier, distribution used is assumed background distribution.

(Stephenson and Supernaw 1990; USEPA 1993) was used to describe the range of discharge rates and radium discharge concentrations in the Gulf of Mexico. The Offshore Operators Committee (OOC) model (Brandsma 1983) was used to estimate the average dilution achieved within a 50 m radius for outfalls in 67 m of water, discharging 5,000, 15,000 and 25,000 bbl/d. Model results were used to derive an empirical relationship between discharge rate (bbl/d) and average dilution.

In the predictive assessment, a distribution of radium concentration factors was used to estimate the range of radium concentrations in fishes. These concentration factors were derived from a field study conducted near coastal discharges in the Gulf of Mexico (Continental Shelf Associates 1991). Figure 4C.1 shows the predicted distribution of Ra-226 concentrations in fishes living in the plume.

Exposure Parameters and Risk Factors

Fish intake rates for recreational fishermen and their families were derived from data collected by the National Marine Fisheries Service (NMFS 1991).

The parameters and distributions used in the estimation of intake rates for recreational fishermen are given in Table 4C.8. Figure 4C.2 shows the distribution of the calculated intake rates for recreational fishermen.

Lognormal distributions of the risk factors for Ra-226 and Ra-228 (individual lifetime fatal cancer risk per pCi/day) were derived from values developed by the United States Environmental Protection Agency (USEPA; Federal Register 1991).

Results

In the direct risk assessment, median individual lifetime fatal cancer risks to recreational fishermen ranged from 2.8×10^{-6} to 7.0×10^{-6}, and the upper 95% confidence limit ranged from 1.2×10^{-4} to 4.0×10^{-4}. Individual lifetime risks associated with background radium concentrations in fishes were approximately one order of magnitude smaller. Figure 4C.3 shows the predicted individual lifetime fatal cancer risk distribution for the platform with the highest median individual lifetime fatal cancer risk (South Timbalier, median: 7.0×10^{-6}).

In the predictive risk assessment, the median incremental individual lifetime fatal cancer risk for the ingestion of fishes living in the plume was 1.7×10^{-7} and the upper 95% confidence limit was 2.0×10^{-6}. The risk distribution calculated for ingestion of fish living in the total cylinder of water surrounding the platform had a median value of 6.5×10^{-10}.

Table 4C.8. Summary of parameters used to estimate the rate of ingestion for fishes caught near offshore platforms (means and standard deviations are arithmetic).

PARAMETER	DISTRIBUTION DESCRIPTION
No. of Fish Caught	lognormal, mean: 5.4, sd: 9.2, range: 0.011-116
Weight of Fish (kg)	lognormal, mean: 1.9, sd: 3.0, range: 0.1-24.6
No. Days Fished (d/yr)	lognormal, mean: 19.5, sd: 29.6, range: 1-251
Edible Fraction	0.3
Family Size	data for southern U.S. from USDOC (1989)
Maximum Ingestion Rate (g/d)	150

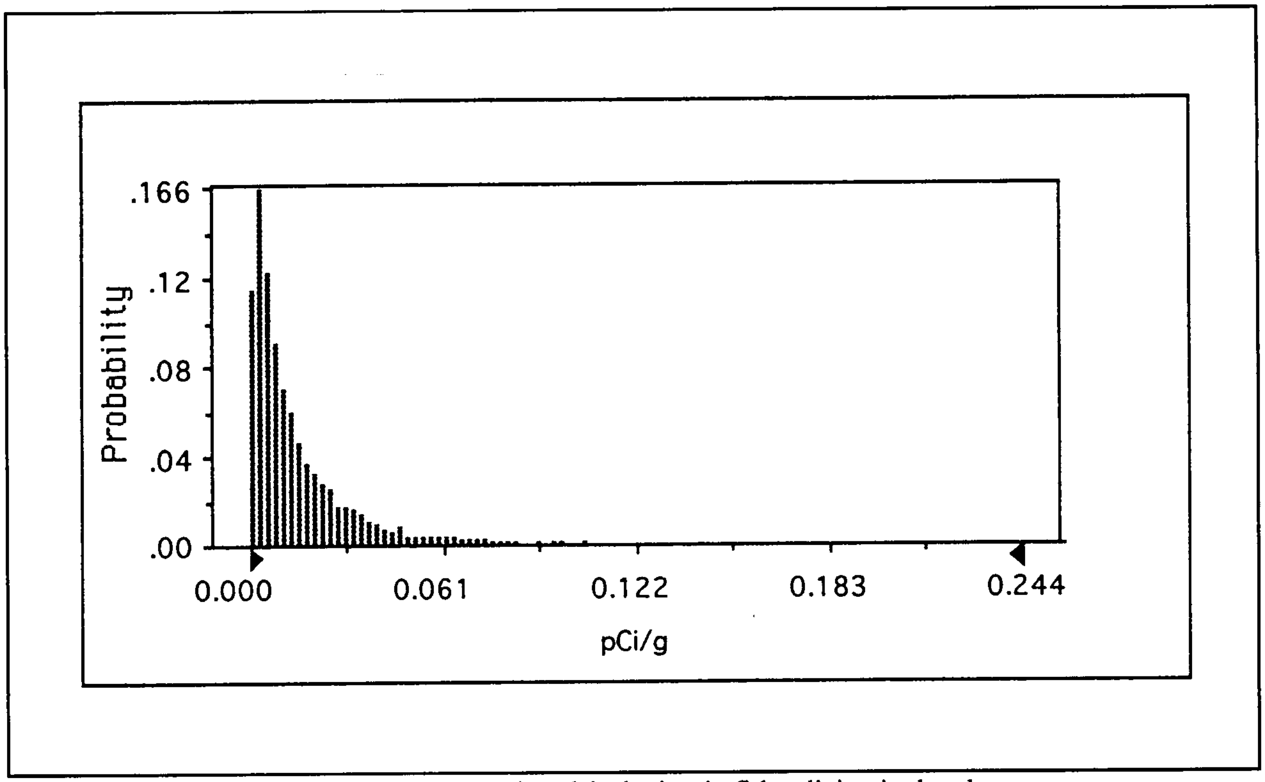

Figure 4C.1. Predicted Ra-226 concentration deistrbution in fishes living in the plume.

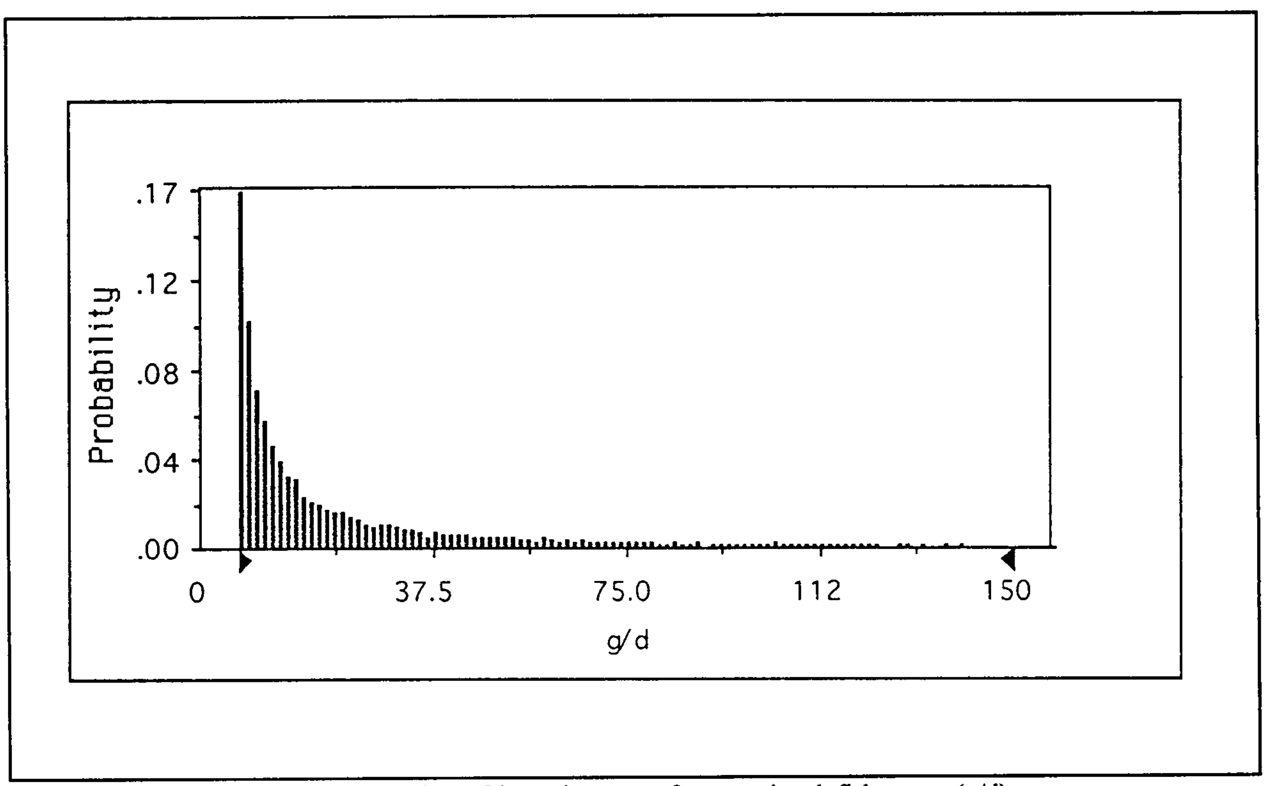

Figure 4C.2. Calculated distribution of ingestion rates for recretional fishermen (g/d).

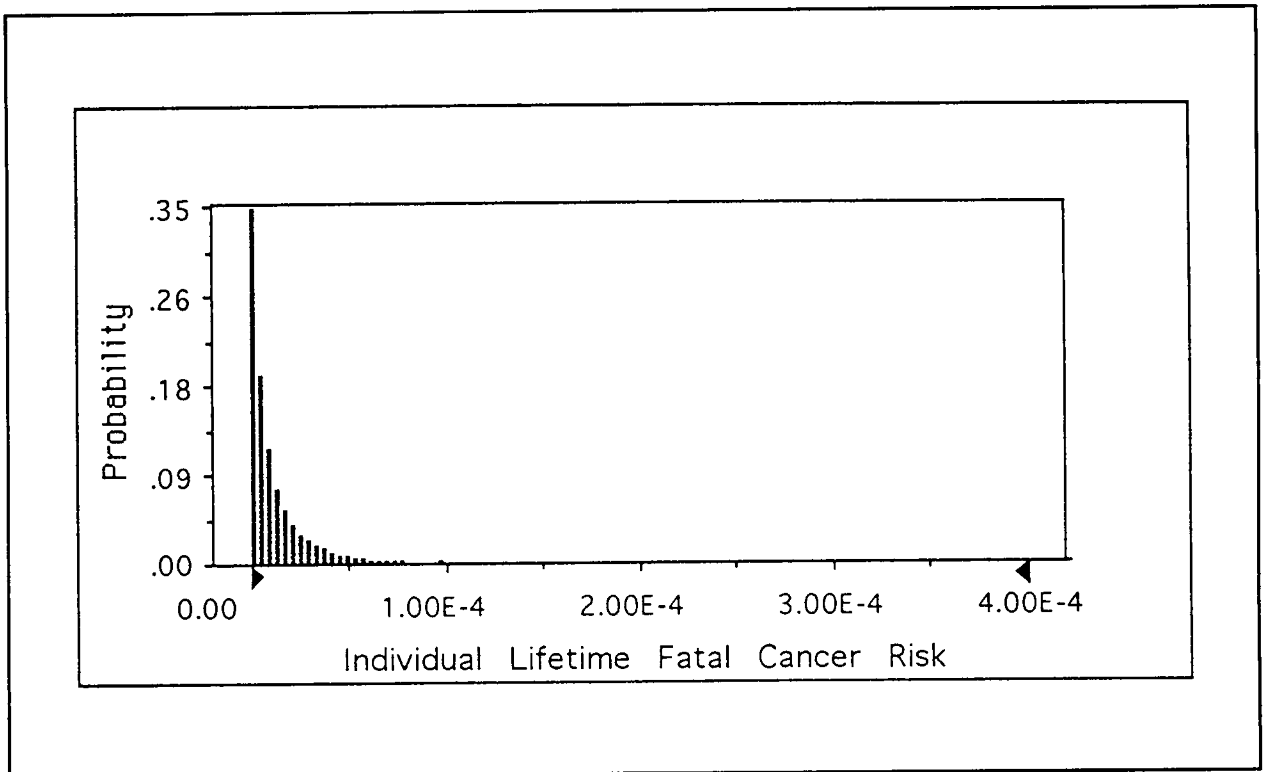

Figure 4C.3. Predicted individual lifetime fatal cancer risk distribution for recretional fishermen at South Timbalier.

The results of the predictive assessment represent estimates of the risk distribution for deep water offshore platforms in Louisiana. These estimates are smaller than the risks that were estimated in the direct risk assessment because of the following: 1) the platforms studied in the direct assessment were in shallower water and larger impacts are expected; and 2) the direct analysis was based on field data that required conservative assumptions to allow the use of values that were coded as "less than" the quantitation limit.

UNCERTAINTIES AND THE USDOE FIELD STUDY

An uncertainty/sensitivity analysis was performed to assess the importance of major uncertainties to the final risk estimates and to guide further research and data collection efforts. The most important contributors to uncertainty in the final risk estimates are 1) the parameters that contribute to the estimate of the radium concentration in fish; and 2) the amount of fish caught near produced water discharges that is then ingested by recreational fishermen.

Data collection in the USDOE field study is guided by the need to reduce these important uncertainties. This field study will improve the data base for human health and environmental risk assessments by 1) reducing the quantitation limit for radium measurements in water and edible seafood; 2) increasing the number of replicate samples; 3) defining background concentrations in water and biota; and 4) surveying seafood consumption patterns of recreational fishermen.

DATA FOR HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENTS

Current work is aimed at reviewing and synthesizing data for use in human health and ecological risk assessments for radionuclides, metals and organics in produced water discharged to coastal and offshore Louisiana. Data collection and review are focused on three areas that will support the planned risk assessments: 1) data describing ingestion rates for recreational fishermen; 2) dose-response relationships for human health risk assessment; and 3) data to support quantitative and qualitative ecological risk assessments.

Ingestion Rates for Recreational Fishermen

The USDOE field study includes a survey of recreational and commercial fishermen in Louisiana and Texas. The survey and associated statistical analyses are being done by Steimle and Associates, Inc. Results from this study will be used to develop distributions of the amount of fish caught near coastal and offshore platforms that is ingested by recreational fishermen.

Dose-response for Human Health Risk

For contaminants of potential concern, USEPA slope factors and reference doses will be documented and reviewed to identify excessive conservatisms. Where appropriate, more realistic and up-to-date dose-response relationships and uncertainty distributions will be developed from the available literature.

Ecological Risk

The current emphasis in this area is to develop a review and synthesis of the available data to support both quantitative and qualitative ecological risk assessments. The emphasis is on data relating to impacts on the Gulf of Mexico.

This data synthesis and review is focused on several kinds of information:

- studies of produced water toxicity;
- USEPA water quality criteria and toxicity studies for individual contaminants;
- sediment quality criteria and toxicity studies;
- dosimetry for radionuclides;
- effects on benthic communities;
- histopathologic and genotoxic effects in fish;
- commercially important fisheries; and
- endangered species and sensitive ecosystems.

ONGOING AND FUTURE RISK ASSESSMENTS

Risk assessments planned for 1995 and 1996 include an assessment of the human health and environmental impacts associated with the continuing discharge of produced water to Louisiana open bays, and offshore. An analysis based on field studies of the recovery of several sites is also planned to estimate the risk reduction achieved through the elimination of produced water discharges to coastal Louisiana.

These assessments will be supported by data collected in the USDOE field study and by the previously described data review. The first assessment performed will be for the continuing discharge of produced water to Louisiana open bays. Initial steps in this assessment include: 1) describe available discharge data and discharging platforms; 2) estimate environmental concentrations of metals, radionuclides and organics; and 3) perform a conservative screening analysis (both human health and ecological) to identify important contaminants, pathways and endpoints. For important contaminants and pathways, a more detailed probabilistic assessment will be performed.

ACKNOWLEDGEMENTS

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Mr. Michael DePhillips has been working as an Associate Environmental Scientist at Brookhaven National Laboratory for the past four years, researching and assessing a variety of environmental issues with regard to energy production, policy and regulation. Mr. DePhillips received a B.A. in political science and an M.S. in environmental sciences from the State University of New York at Stony Brook.

Dr. Leonard Hamilton was head of the Biomedical and Environmental Assessment Group at Brookhaven National Laboratory for 20 years, and is Professor of Medicine at the State University of New York at Stony Brook, and World Health Organization focal point on Energy and Health. His major area of research interest is environmental risks. Dr. Hamilton, a physician, received his D.M. from

Oxford University and his Ph.D. in experimental pathology from Cambridge University.

FISHERIES IMPACTS OF EXPLOSIVES USED IN PLATFORM SALVAGE

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INTRODUCTION

This report describes preliminary results of the fish kill resulting from the explosive removal of three platforms between August 1993 and August 1994. A typical platform is constructed with three components: an upper deck above the water line, a jacket resembling an oil derrick in appearance which sits on the sea floor, and long pilings inside each hollow corner of the jacket driven into the sea floor down to 30 meters (100 ft) or more. Most platform removals begin when the upper deck is cut off with torches and lifted onto a materials barge. Explosives are then lowered into the hollow legs of the jacket to a minimum depth of five meters (15 ft) which is a requirement of Minerals Management Service. Explosives are detonated to sever the pilings which are then pulled with a large crane. The jacket is lifted out of the water and loaded onto a materials barge for shipment back to shore or to an artificial reef dump site. One inevitable result of underwater explosives is a negative impact on marine life in the immediate area.

OBJECTIVES

The objectives of the study include

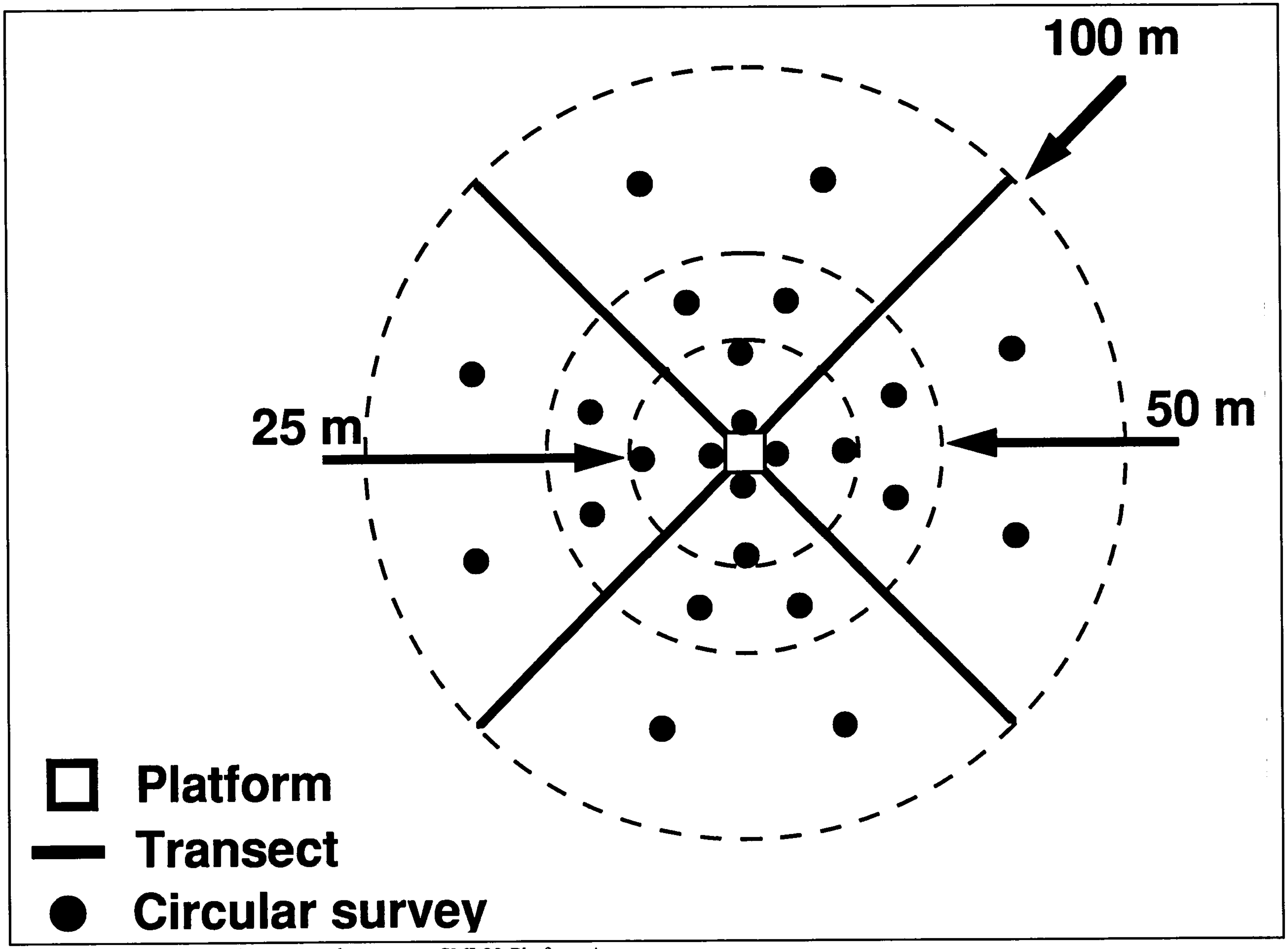
1. Estimating the number of fish at risk at study platforms.
2. Estimating the mortality of fish at study platforms.
3. Estimating the total at-risk fish population in the Gulf of Mexico.
4. Estimating the effects on the productivity of at-risk populations (especially red snapper).
5. Compare these effects with those from other sources of mortality.
6. Evaluate mitigation strategies for impacts on reproduction.
7. Assess need for additional sampling in order to improve the precision of the determinations of the impacts.

This report focuses on the second of these objectives: the estimation of finfish mortality after explosions.

METHODS

Several sampling procedures were employed to collect data for assessing finfish mortality. First, we collected all dead fish floating at the surface after the explosion. Field crews operating from two inflatable Zodiacs picked up fish with dip nets. The fish were transferred from the Zodiacs to utility vessel where fish were measured and identified to species. Selected species were also weighed. A sample of dead fish that settled to the sea bottom was collected using three techniques. The first utilized frame nets placed beneath the platform. These nets were constructed of trawl mesh secured to 3 x 3 meter (10 x 10 ft) galvanized pipe frames. Approximately 20-30% of the footprint area immediately under the structure was sampled with this technique. Transect lines were used to sample the open water area around the platform. SCUBA divers collected fish in defined corridors on either side of transect lines radiating 100 meters (328 ft) out from the structure. Frame nets similar to those placed beneath the platform were also used to sample the open water area at the first study site. At subsequent sites these nets were replaced with circular surveys in which divers collected fish within 6.7 meter (22 ft) diameter circles within a 100 meter (328 ft) radius of the platform (Figure 4C.4). This provided a larger survey area than the frame nets and reduced sampling time.

A straightforward approach was used to analyze the data. The area within 100 meters (328 ft) of the platform was subdivided into geometric regions similar to those delineated in Figure 4C.4 by concentric circles and transect lines. The number of fish present in a sample was divided by the sample area to obtain fish density. The total area of each geometric region was then multiplied by fish density of the samples to estimate the number of fish killed within that region. This procedure was applied independently to data from transect lines, circular surveys, and frame nets.



4C.4. Transect and circular survey placement at SMI 23 Platform A.

RESULTS

During the past two field seasons three explosive platform removals were monitored to assess impacts on finfish. These included a 24-pile platform in 14 meters (45 feet) of water in West Delta Block 30 located about 3 km (6 nm) from the Louisiana coast near Grand Isle. Two four-pile platforms were also studied, one in South Marsh Island Block 23 in 17 meters (55 ft) of water and another in Ship Shoal Block 158 in 25 meters (82 ft) of water. The 24-pile structure was 39 years old and was in very poor condition with holes rusted through some of the structural members. The four-pile platforms were 12 and 33 years old. At the 24-pile platform, 291 kg (640 lb) of explosives were detonated 6-9 meters (20-30 feet) below the mudline on the first of 3 detonation events. Intensive sampling was only conducted after the first series of detonations although observers estimated the surface fish kill resulting from the two subsequent detonation events. Intensive sampling was conducted at the two four-pile structures which were removed with single blast events involving 159 and 73 kg (350 and 160 lb) of explosives each.

Results from all three removals combined showed the vast majority (617) of fish mortalities were collected within 25 meters (82 ft) of the platform with 57 fish taken from 25-50 meters (82-164 ft) and six fish from 50-100 meters (164-328 ft).

At the first four-pile platform (SS 158 Platform C) studied 109 fish were collected at the surface, 162 in frame nets under the platform, 44 from transects, and 111 from circular surveys for a total of 426 fish. Of these 33 were red snapper and 22 were other snapper species. The estimated fish kill under the platform was 540. Estimates for open water areas obtained from transect and circular surveys were comparable at approximately 4,400 and 3,900, respectively. The total estimated fish kill ranged from 4,600-5,000.

The total fish kill at the second four-pile platform (SMI 23 Platform A) was nearly identical at 4,800-5,000 fish, but the distribution by sampling gear was quite different. Nearly 1,300 fish were collected at the surface compared with 109 at the previous four-pile platform. Over 700 of these were red snapper. One hundred eighteen were taken under the platform, 201 from transects, and 210 from circular surveys for a total of approximately 1800 fish. Of these nearly 800 were red snapper and 59 were other species of snapper. There was great similarity in open water estimates of fish mortality derived from transect (3,100) and circular surveys (3,000).

At the 24-pile platform a total of 641 fish were collected. None of them were red snapper. Eighty were other species of snapper, primarily gray snapper. The total estimated fish kill was 1,300-1,800 for the first of three detonation events. The combined surface kill at these subsequent blasts was visually estimated at about twice that of the surface kill after the first blast. Post-detonation conditions were much different at this location. Divers observed hundreds of live fish after the first detonation at this structure but reported virtually no live fish swimming in the water column after the explosions at the two four-pile platforms.

Estimated fish kill was categorized by species for each structure removal. At the Ship Shoal platform 59% of estimated mortalities were spadefish, 23% were blue runner, 8% were sheepshead, and 6% were red snapper. Total mortality of red snapper was estimated at approximately 300 at this site. At the second four-pile platform spadefish was again the dominant species killed (46%) followed by red snapper (26%), blue runner (11%), sheepshead (7%), and a few other species. An estimated 1300 red snapper were killed. Sheepshead (59%) topped the list at the 24-pile platform followed by spadefish (25%), gray snapper (14%) and blue runner (1%).

Length-frequency distributions for red snapper were very different at the two four-pile platforms. The vast majority (94%) of the 33 red snapper were larger than 35 cm in total length at the Ship Shoal site while most (89%) of the 795 collected at the South Marsh Island platform measured less than 40 cm. One explanation for this difference relates to the history of the latter structure. This four-pile platform was previously part of a larger complex consisting of another four-pile and six-pile platform connected by catwalks. Eleven months earlier these two structures were removed using over 318 kg (700 lb) of explosives. It is hypothesized that these initial explosions decimated the snapper population and the remaining platform was repopulated with small snapper over the past 11 months.

Another area of interest was to determine if there was a consistent ratio between the number of dead fish that sank to the sea floor versus the number that floated to the surface after explosions. Such a ratio would be very useful because it is relatively easy and inexpensive to get accurate estimates of the surface fish kill but much more difficult to estimate fish mortalities on the sea bottom. The resulting ratios were 3, 3.5 and 40 which did not indicate a simple, consistent relationship between floaters and sinkers.

Predicting the fish kill at platforms is a complex issue. Any factor influencing the presence of fish at platforms will also affect the fish kill at platforms. A partial list of potential factors includes water depth, salinity, temperature, dissolved oxygen, season, structure size, structure age, number of nearby structures, amount of explosives, time (days) between blast events, and depth below mudline at which explosive charge is placed.

SUMMARY

The species most impacted by underwater explosions at platforms included, in descending order, spadefish, sheepshead, red snapper, and blue runner. The platforms studied were in relatively shallow water ranging from 14-25 meters (45-82 feet) because of their accessibility to divers for sampling the sea floor. It is expected that removals in deeper water will have a greater impact on red snapper than the shallow water removals studied thus far.

Gregg Gitschlag has worked for NOAA's Southeast Fisheries Center, Galveston Laboratory, for the past 16 years as an oceanographer and fishery biologist. His research interests include sea turtle behavior and migration as well as recreational and commercial impacts on red snapper. Mr. Gitschlag completed his B.S. in zoology at the University of Michigan and his M.S. in biological oceanography at Florida State University.

AN ASSSSSMENT OF EFFECTS AND REMEDIATION OF OIL SPILLS IN THE GULF OF MEXICO AND CARIBBEAN

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Louisiana Environmental Research Center
McNeese State University

INTRODUCTION

In July of 1994, a two-day symposium entitled *Gulf of Mexico and Caribbean Oil Spills in Coastal Ecosystems: Assessing Effects, Natural Recovery, and Progress in Remediation Research* was held in New Orleans, LA. The meeting was sponsored by the U.S. Minerals Management Service, the Louisiana Environmental Research Center at McNeese State University, and the Spill Remediation Research Consortium.

The meeting agenda included the following sessions:

1. Experiments and case studies on the effects of oil spills on seagrass, tidal marsh, and mangrove ecosystems.
2. Remediation techniques: reviews and current research.
3. Overview of bioremediation studies in the Gulf of Mexico.
4. Continued overview of bioremediation studies in the Gulf of Mexico.
5. Discussion and planning: recommending the best approaches for the study of the effects and remediation of oil spills in coastal ecosystems.

In sessions one-four invited speakers presented case studies, on-going or just beginning research, and reviews on various topics related to effects of spills and such remediation techniques as dispersants, microbial inoculants, *in-situ* burns (at sea and in marshes), microbial stimulation via nutrient addition, and a critique of various methods used in upland remediation. In Session 5 speakers and meeting attendees broke into groups (marshes, mangroves, seagrasses, and dispersants) to discuss ways to more effectively assess the effects of oil pollution in the different ecosystems, remediation techniques that appeared promising for various systems, and needs for future research. Each group had a leader (one of the invited speakers) and an assistant who served as note-taker so that discussion highlights could be incorporated into the proceedings of the meeting.

The proceedings of the meeting will include text of papers presented and summaries of notes taken during the discussion groups. The proceedings, E. Proffitt and P. Roscigno (eds.), will be published by MMS and should be available by the summer of 1995.

The list of papers presented at the meeting is presented below. Written papers will be included in the proceedings provided these are submitted to the proceedings editors by February 1995.

Experiments and case studies on the effects of oil spills on sea grass, tidal marsh, and mangrove ecosystems

Experimental Analysis of the Effects of Oil on Mangrove Seedlings and Saplings - C. E. Proffitt and Donna J. Devlin. Louisiana Environmental Research Center, McNeese State University.

The 1993 Tampa Bay Spill: Preliminary Assessment of Natural Resources - Jane Urquhart-Donnelly and George Henderson, Florida Marine Research Institute.

The 1993 Tampa Bay Spill: Tracking the Fate of Oil - Richard Pierce[1], Ted S. Van Vleet[2], Dana L. Wetzel[2], , P.M. Sherblom[1], and M. Henry[2]. 1 Mote Marine Lab (Sarasota, FL), 2 Dept. of Marine Science, University of South Florida (St. Petersburg, Florida).

Effects of Oil on Salt Marshes - James Webb, Texas A&M University at Galveston.

The Panama Spill: Effects of Oil and Natural Recovery: Seagrass Communities - Michael Marshall, Mote Marine Laboratory

The Panama Spill: Effects and Natural Recovery: Mangroves - Sally Levings, Coastal Zone Analysis, Inc.

Genetic Degradation of Mangroves a Consequence of Petroleum? - Edward Klekowski[1] and Jorge Coredor[2], 1 Univ. of Mass and 2 University of Puerto Rico.

Remediation techniques: Reviews and current research

Evaluating Remediation Performance: Statistical and Analytical Needs - James Catallo, Louisiana State University.

Dispersants: Current Toxicology Research - Carol Daniels, U.S. Environmental Protection Agency.

Critique of Upland Soil Remediation Techniques and their Application to Marine Spill Situations - Paul Kostechi, University of Massachusetts, Amherst.

Cleanup Techniques in Marshes: The Fine Line Between Help and Hindrance - Ms. Rebecca Hoff, NOAA.

An Overview of Bioremediation Studies in the Gulf of Mexico

Fate of Oil in Salt Marsh Sediments and Stabilization of Oil Residue - Edward Overton, Louisiana State University.

Microbial Inoculants for Oil Bioremediation Evaluated Using Salt Marsh Mesocosms - Richard Weaver, B Crites, S. Neralla, A. Wright, and J. Webb, Texas A&M University (College Station) and Texas A&M University at Galveston.

Mitigating an Oil Spill in Timbalier Bay, LA: NOAA's Damage Assessment and Restoration Program in Action -T. Osborn, E. Zobrist, R.D. Hartman, B. Julius, and M. Newell.

Enhancement of Growth of the Marsh Natural Microbial Community - Ralph Portier, Louisiana State University.

A Preliminary Assessment of the Toxicity of Bioremediation Agents on Salt Marsh Mesocosms: Vegetation - Irving A. Mendelsshon, Louisiana State University.

Effects on the Marsh Infaunal Community - Nancy N. Rabalais, Louisiana Universities Marine Consortium.

Use of *In Situ* Burning as an Oil Spill Remediation Technique - Gus Stacey, Marine Spill Response Corp.

Evaluation of Burning as an Oil Spill clean-up Technique in a High Marsh Community Along the South Texas Coast - Beau Hardegree, D. W. Hicks, and J.W. Tunnell, Jr., Center for Coastal Studies, Texas A&M University-Corpus Christi.

Two additional meetings on this general theme are in the planning stages. These meetings will entail "working groups" to follow up on the ideas and recommendations from the symposium. It is anticipated that each working group will produce a technical report that more clearly documents problems and best known solutions as well as needs for future research. The first of these workshops will be held in the summer of 1995 on the campus of McNeese State University in Lake Charles, Louisiana. The site and date for the second workshop have yet to be picked. Interested parties can contact the author for further information.

Dr. Edward Proffitt is Associate Professor of Environmental Research and Director of the Louisiana Environmental Research Center at McNeese State University. His research interests include plant and animal ecology of mangrove, salt marsh, and shallow benthic systems. Dr. Proffitt received his B.S. (biology) from the University of Miami, a M.S. (botanical thesis) from East Carolina University, and a Ph.D. (marine invertebrate zoology dissertation) from the University of South Florida. He organized and conducted the symposium discussed in this paper.

BENTHIC-PELAGIC COUPLING IN THE GULF OF MEXICO: IMPLICATIONS FOR THE FATE OF ORGANIC MATTER ON THE CONTINENTAL SHELF

Dr. Robert R. Twilley
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Dr. Brent A. McKee
Louisiana Universities Marine Center

INTRODUCTION

The interrelationships among rates of material cycling through both benthic and water-column communities play an important role in the ultimate fate of inorganic nutrients and organic matter within land margin ecosystems (Nixon 1981, Glibert 1982, Harrison *et al.* 1983, Kemp and Boynton 1984, Aller *et al.* 1985). The coupling of benthic and pelagic processes contributes to elevated rates of primary productivity in land margin ecosystems by sequestering nutrients in the coastal zone (Zeitzschel 1980, Boynton *et al.* 1982, Fisher *et al.* 1982, Klump and Martens 1983, Boynton and Kemp 1985). Rates of *in situ* nutrient remineralization may be equivalent to allochthonous inputs of inorganic and organic nutrients (Fisher *et al.* 1982, Nixon and Pilsen 1983, Pennock 1987). Over short time scales, nitrogen remineralization from the sediments and water column may provide a significant proportion of the nitrogen required to support primary production. However, nitrogen that is reduced to nitrogen gas in sediments is excluded from use in the biotic cycle and no longer contributes to the carbon cycle (Twilley and Kemp 1986, Seitzinger 1988). Over longer time periods, the balance between sediment deposition and remineralization rates determines the burial and loss of organic nutrients from the ecosystem (McKee *et al.* 1983, DeMaster *et al.* 1985). Quantifying the time and spatial scales of these major water column and sediment processes that influence the availability of nitrogen and fate of carbon (eg. mineralization, denitrification, and burial) are therefore essential to understanding the utilization of organic matter in the Louisiana shelf ecosystem (Dagg *et al.* 1991).

The major emphasis of this proposed project is to determine the role of water column and benthic processes in affecting the fate of carbon and nitrogen in a river dominated shelf ecosystem. The goal of these studies is to understand the coupling of the fifth largest river system in the world to coastal margin ecosystems in the Mississippi River Bight. Proposed products in the form of a technical summary include manuscripts describing the input, deposition, and regeneration of nitrogen and carbon in the seabed and water column in the plume region of the southwest discharge of the Mississippi River to the continental shelf. This continental shelf region of the Gulf of Mexico is a rich reserve of gas and oil exploration. I will focus this presentation on one of the research products from this MMS study that describes sedimentation and carbon burial in the sediments of the Mississippi River Bight.

Nutrient concentration and production/sediment trap data indicate that nutrient inputs stimulate high rates of primary production and that these nutrients are quickly sequestered into organic matter in the water-column. Individual studies indicate that the fate of this organic matter appears to vary, at times fluxing to the sediments and undergoing remineralization or transport, while at other times appearing to be efficiently grazed and remineralized in the water column. Previous studies of deposition suggest that the proximal region of the Mississippi River plume is a zone of extreme input of allochthonous particulate material to the seabed. The fate of this organic matter is largely unknown in the Mississippi River Bight, as well as for other deltaic continental shelves. The objective of this presentation is to determine area weighted carbon storage of sediments in this region of the Gulf of Mexico, and document the contribution of terrigenous particulate organic carbon to this carbon sink. We will compare these results with other deltaic shelf ecosystems to evaluate the importance of these coastal margins to global carbon cycle.

METHODS AND RESULTS

This study utilized naturally occurring (^{234}Th and ^{210}Pb) radionuclides to determine rates of deposition and sedimentation. These radionuclides are very particle-reactive (i.e., rapidly sorbed onto particle surfaces) and have proven to be very useful as particle tracers (Broecker *et al.* 1973; Santschi *et al.* 1980). Because of natural radioactive decay, these radionuclides are particularly useful in examining rates of sedimentary processes at two time scales based on their half-lives. ^{234}Th (24 day half-life) is used to examine processes that occur on a time scale of days to months (e.g., sediment deposition related to flood and storm events), while ^{210}Pb (22 year half-life) is used to examine processes that integrate over a period of 10 to 100 years (e.g., sediment accumulation during the past century).

Box core samples were collected from 42 stations in the Mississippi River plume region (Figure 4C.5). Additional cores were collected from selected stations within this grid after high and low discharge periods for measurements of ^{234}Th. Large diameter (16.5 cm) subcores were taken from box cores at each sampling station. Each core was carefully extruded and simultaneously subsectioned at precise 0.5-1.0 cm intervals. Yield tracers (^{232}U/^{228}Th, ^{208}Po) were added to the dried core samples, then leached with a combination HNO_3, HCl and $HClO_4$ solution. Thorium and uranium are isolated and purified via ion exchange methods, plated onto stainless steel planchets and counted on a low-background beta detection system (McKee *et al.* 1986). ^{210}Po is spontaneously deposited onto silver planchets and ^{210}Pb is measured via the polonium method (Nittrouer *et al.* 1979). The deposition and accumulation (burial) of carbon, nitrogen and phosphorus in bottom sediments was calculated from the following equation (Hatton *et al.* 1983): A = Cd x R x D x 10^4 (g m^{-2} yr^{-1}); where A is the rate of nutrient deposition or burial, Cd is the dry mass nutrient concentration, D is bulk density, and R is the sedimentation rate (determined by ^{234}Th or ^{210}Pb).

The plume region of river-dominated land margin ecosystems are sites of high sedimentation of allochthonous carbon, nitrogen and phosphorus. However, nutrient retention may vary within the plume region, particularly during high flow, depending on differences in depth and circulation. A common observation in river-dominated environments is that most of the sediment discharge is initially deposited near the river mouth; sedimentation rates decrease with increasing distance from the river (DeMaster *et al.* 1985; Nittrouer *et al.* 1987). Deposition rates calculated from samples collected in April of three consecutive years range from 69 to 436 gdw m^{-2} d^{-1} near the mouth (station B50) of southwest pass. This interannual variation

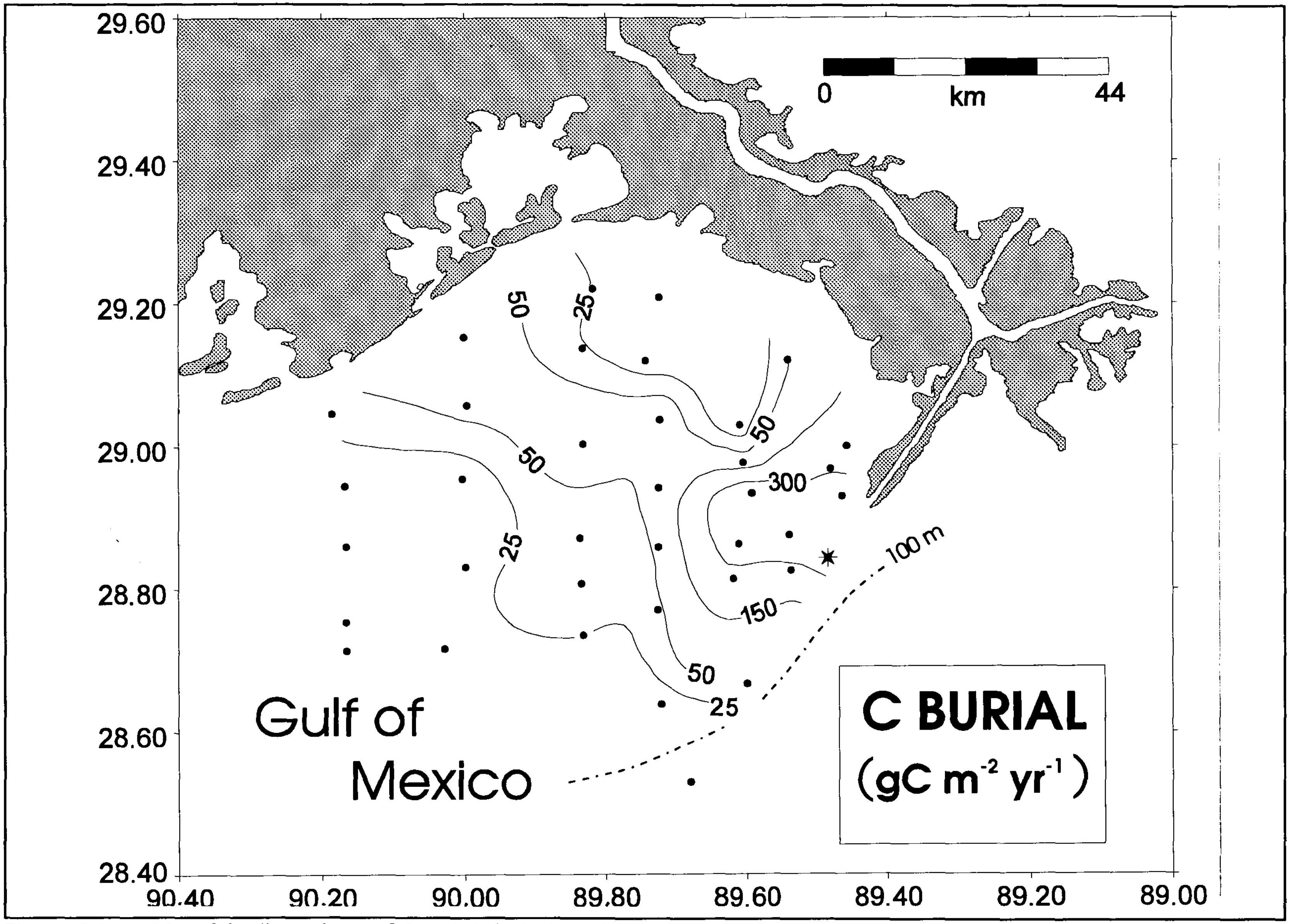

Figure 4C.5. Map of the dispersal area of the Mississippi River Bight showing location of box cores used to estimate carbon accumulation is shelf sediments. Contour lines represent the rates of carbon burial in gC m^{-2} yr^{-1}.

reflects differences in cumulative discharge during the three to four months prior to sampling. Rates of deposition for similar discharge periods were generally less at downfield stations. During the low flow period, river discharge decreases by about 85%, resulting in reduced riverine input to the shelf.

The corresponding supply of POC to this site was 1.6 to 8.7 gC m-2 d-1, based on sediment deposition rates and riverine POC contents of 1.97 to 2.41%. On a seasonal time scale, the organic carbon content of sediments stored at B50 (asterisk in Figure 4C.5) ranged from 1.36 to 1.61% and the resulting organic carbon deposition rates (1.1 to 6.3) were 28-34% less than the riverine carbon supply. Thus, approximately 30% of the terrestrial carbon was remineralized within four months. However, deposition rates (100-day time scale) within the plume region of the Mississippi River (Figure 4C.5) are 5-10 times greater than the sediment accumulation rates (100-year time scale) determined using ^{210}Pb. The contrast in fate of materials deposited to the seabed based on relative rates of deposition and burial indicate that a substantial portion of these materials may be redistributed. Redistribution may occur from the shelf to shelf slope, or to more distal parts of the dispersal system along the shelf. Redistribution of materials delivered during high river flow leads to a more uniform distribution of particulates throughout the dispersal system.

Coastal and shelf sediments may be considered large reservoirs of deposited nutrients that are not regenerated to the water column. The relative magnitude of burial is controlled by the quantity and quality of particulate material supplied to bottom sediments (Zeitzschel 1980; Klump and Martens 1983). The annual sediment discharge estimate for the Mississippi River is averaged over the last 100 years taking into account the effects of reservoirs constructed in the Mississippi River watershed (pre- and post- 1963 annual estimates) and considering 30% of the river discharges through southwest pass (Malcolm and Durum 1976). Riverine inputs of carbon are calculated based on 2.0% content of sediment load (Trefry *et al.* 1991). The annual input of sediment and carbon (7.14×10^{13} and 0.114×10^{13}, respectively) were divided by study area to determine loading in units of g m^{-2} yr^{-1} . About 50% of the sediment input from the river can be accounted for by the accumulation of sediment in the study area of the Louisiana shelf. Rates of carbon burial in the study area ranged from 1 to 494 gC m^{-2} yr^{-1}, with higher rates of carbon burial occurring in the proximal regions of the dispersal area (Figure 4C.5). We have divided the study area into 5 regions based on organic carbon burial (Figure 4C.5) with rates ranging from >300 gC m^{-2} yr^{-1} to < 25 gC m^{-2} yr^{-1}. The area weighted organic carbon burial rate is 64 gC m^{-2} yr^{-1} for the study area. We have estimated the percentage of the buried organic carbon that is of terrigenous origin based on natural isotope studies. Overall, about 40% of the organic carbon preserved in the study area is allochthonous in origin (Hedges and Parker 1976), resulting in 26 gC m^{-2} yr^{-1} of riverine POC buried on the shelf (Figure 4C.6). Therefore, 67% of the particulate organic carbon supplied by the river over the past century has been remineralized, resulting in the burial of only 33% of the terrestrial supply.

SUMMARY

The interrelationships among rates of material cycling through both benthic and water-column communities play an important role in the ultimate fate of inorganic nutrients and organic matter within land margin ecosystems (Fig 4C.7). The coupling of benthic and pelagic processes contributes to elevated rates of primary productivity in land margin ecosystems by recycling nutrients in the coastal zone. High concentrations of suspended sediments and nutrients introduced from the river are quickly deposited to the seabed in the near proximal zone of the plume region. Autotrophic production in this zone is limited by turbidity and remineralization in the water column is minor compared to the loading of organic nutrients. This zone is represented by high deposition rates to the seabed, particularly from March to July, but dependent on the timing of maximum river discharge. Estimates of burial range from 1-2 cm/yr, compared to deposition rates of 1-4 cm/month. This difference suggests that a large percentage of this allochthonous material, both sediment and nutrients, is redistributed to other areas of the shelf.

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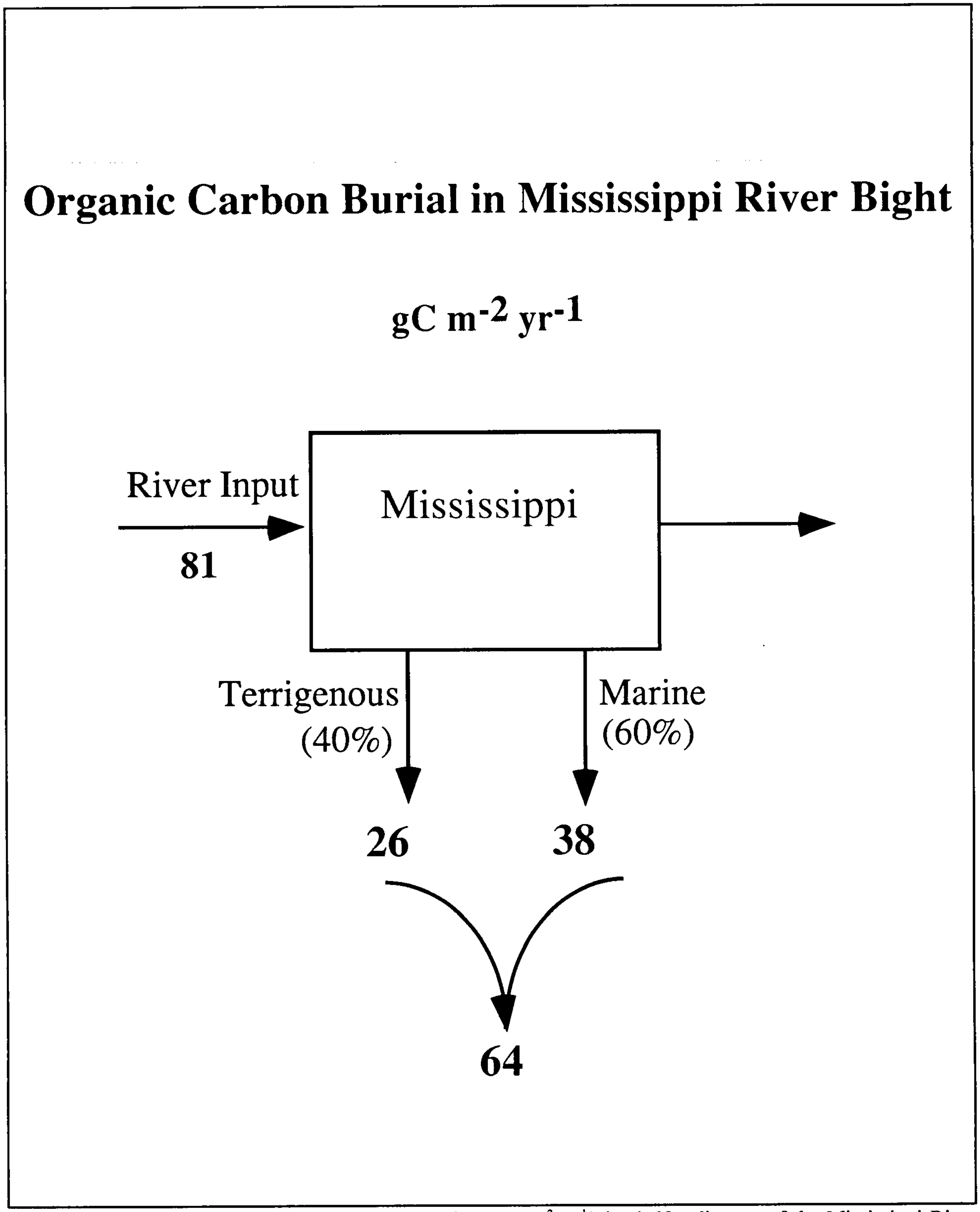

Figure 4C.6. Mass balance of carbon accumulation (gC m^{-2} yr^{1}) in shelf sediments of the Mississippi River Bight including the riverine input, and the relative contribution of terrigenous and marine carbon to total accumulation rates.

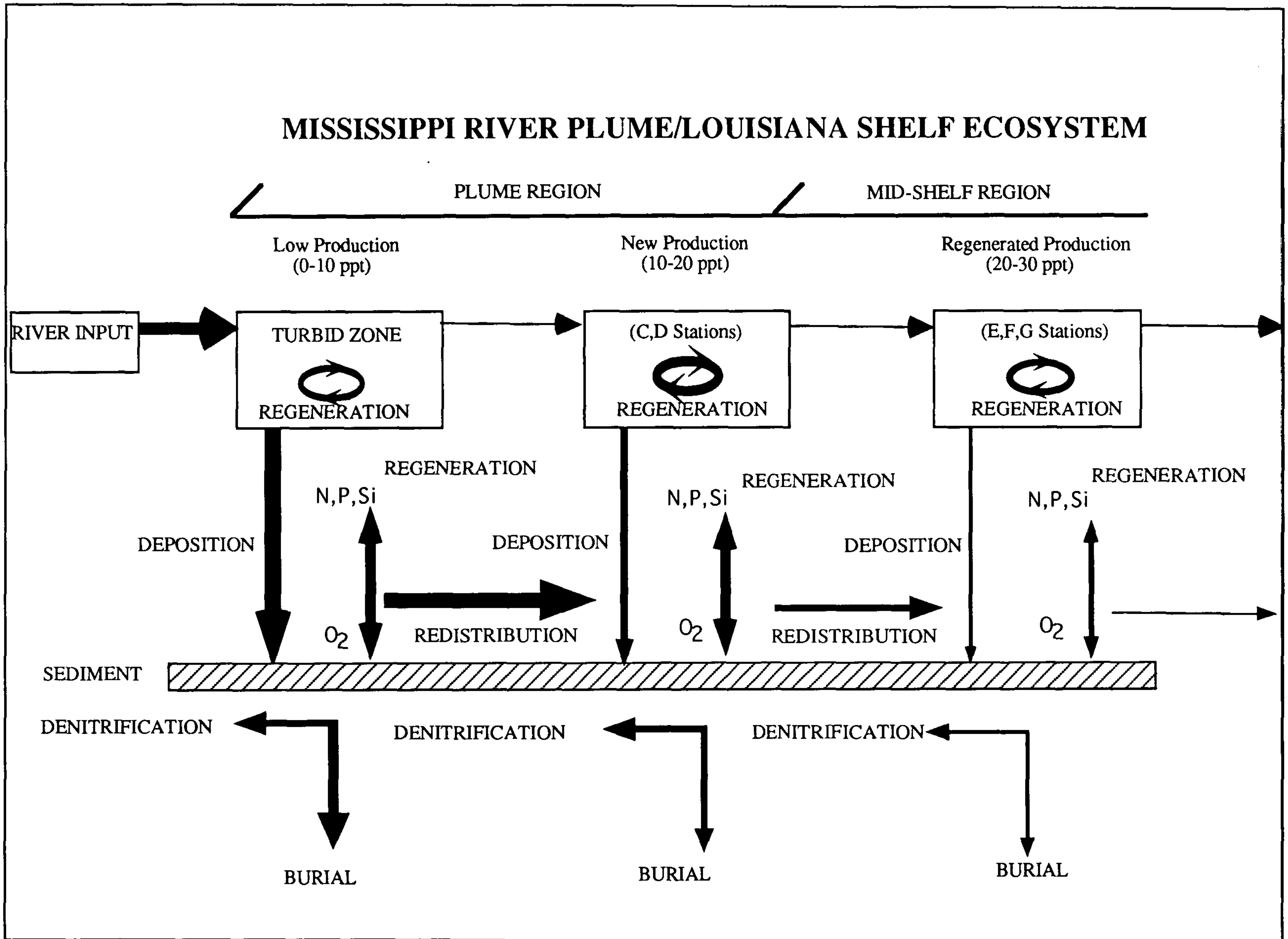

Figure 4C.7. Conceptual model of the fate of organic matter in the plume and mid-shelf region of the Louisiana shelf ecosystem.

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Dr. Robert R. Twilley has been on the faculty in the Department of Biology at University of Southwestern Louisiana for eight years where he is presently Associate Professor. His area of research interest is the biogeochemistry of coastal ecosystems, particularly tropical and subtropical regions. Dr. Twilley received his B.S. and M.S. degrees from East Carolina University in biology, and his Ph.D. from the University of Florida in botany and system ecology. He worked for five years in coastal ecology at University of Maryland Horn Point Environmental Laboratory.

Dr. Brent A. McKee is Associate Scientist with the Louisiana Universities Marine Center where he has been working for seven years. Dr. McKee also has academic appointments at University of Southwestern Louisiana (Department of Biology) and Louisiana State University (Department of Geology). His research interest is the geochemical properties of major river interactions with continental shelf environments. Dr. McKee received his Ed.B. from the University of North Carolina-Chapel Hill, and B.A., M.S. and Ph.D. from North Carolina State University in marine geochemistry.

SESSION 4D

DISTRIBUTION AND ABUNDANCE OF CETACEANS, PART I

Session: 4D - DISTRIBUTION AND ABUNDANCE OF CETACEANS, PART I

Co-Chairs: Dr. Robert Avent and Dr. Randall Davis

Date: November 17, 1994

Presentation	Author/Affiliation
Introduction and Overview of the GulfCet Program: Distribution and Abundance of Marine Mammals in the North-Central and Western Gulf of Mexico	Dr. Randall Davis Texas A&M University at Galveston
Historical Overview of Cetaceans in the Gulf of Mexico: A Synopsis	Mr. Thomas A. Jefferson Texas A&M University
GulfCet Aerial and Ship Surveys: Survey Design, Methods, and Preliminary Results	Dr. Keith Mullin Mr. Larry Hansen National Marine Fisheries Service Southeast Fisheries Science Centers Mr. Thomas A. Jefferson Texas A&M University
Estimating the Abundance of Sperm Whales Using Passive Sonar	Dr. Robert H. Benson Dr. William E. Evans Dr. J. C. Norris Texas A&M University
Behavior of Cetaceans Relative to Census Vessels in the Northwestern Gulf of Mexico, 1992-1994	Dr. Bernd Würsig Mr. Spencer Lynn Texas A&M University at Galveston

INTRODUCTION AND OVERVIEW OF THE GULFCET PROGRAM: DISTRIBUTION AND ABUNDANCE OF MARINE MAMMALS IN THE NORTH-CENTRAL AND WESTERN GULF OF MEXICO

Dr. Randall Davis
Texas A&M University at Galveston

The Minerals Management Service (MMS) has the responsibility to assure that oil and gas operations on the Outer Continental Shelf Leases in the Gulf of Mexico are conducted in a manner that reduces risks to the marine environment. To meet their responsibilities under the Marine Mammal Protection Act of 1972 and the Endangered Species Act of 1973, the MMS must understand the effects of oil and gas operations on marine mammals. The purpose of the GulfCet study is to determine the distribution and abundance of cetaceans in the areas potentially affected by future oil and gas activities along the continental slope in the north-central and western Gulf of Mexico. The GulfCet Program is a 3.25-year project that commenced on 1 October 1991 and will end in the spring of 1995. The study is restricted to the area bounded by the Florida-Alabama border, the Texas-Mexico border, and the 100 and 2,000 m isobaths. The major part of the GulfCet Program's field research consists of seasonal, line transect surveys to determine the distribution and abundance of cetaceans in the study area. Three types of surveys are being conducted: 1) visual surveys from an aircraft, 2) visual surveys from a ship, and 3) acoustic surveys using a linear hydrophone array towed behind the visual survey ship. The hydrographic portion of the program was designed to sample the meso-to-large scale features in the Gulf of Mexico. Stennis Space Center is providing remote sensing and geographic information system support for the GulfCet project. Finally, tagging and tracking of sperm whales using satellite telemetry was attempted.

Dr. Randall W. Davis is a Professor and Head of the Marine Biology Department at Texas A&M University at Galveston. His research interests are the diving physiology of marine mammals, the rehabilitation of oiled wildlife, and the conservation of endangered and threatened species. He received his B.S. in biology from University of California, Riverside and his Ph.D. in physiology from the University of California, San Diego.

HISTORICAL OVERVIEW OF CETACEANS IN THE GULF OF MEXICO: A SYNOPSIS

Mr. Thomas A. Jefferson
Texas A&M University

This paper reviews and summarizes what is known of the distribution and seasonal occurrence of offshore cetaceans in the Gulf of Mexico. Offshore cetaceans are defined here to include all those members of the order Cetacea found in the Gulf of Mexico, with the exception of the bottlenose dolphin (*Tursiops truncatus*). This species is not included because it is primarily a coastal species (although there are an increasing number of outer continental shelf and slope records), and its distribution in the Gulf has been comparatively well-studied. The analyses in this paper are based on all available records, published and unpublished, except those resulting from the GulfCet program, which form a continuous, homogeneous database based on systematic surveys.

MATERIALS AND METHODS

Sources of Data

All available records of strandings, sightings, and captures of cetaceans from the waters of the Gulf of Mexico were compiled. The records from the GulfCet project are not analyzed here, except for those that have previously been published: Fraser's dolphins (Leatherwood *et al.* 1993), melon-headed whales (Mullin *et al.* 1994a), and Clymene dolphins (Mullin *et al.* 1994b). A total of 1,223 records were available for this analysis.

Verification of Species Identification

For each record, the species identification was questioned, and an attempt made to verify it. Verification could come in one of several ways: location of photographs, drawings, or detailed descriptions of the animals demonstrating diagnostic features; examination of voucher materials, such as skulls collected from specimens stranded or captured; identifications made by highly-trained observers; or identifications made by relatively inexperienced observers, but of highly distinctive species. Of the total of 1,223 records, 1,044 were considered to be verified, 104 were questionable, and 75 could only be identified to genus.

RESULTS

Baleen Whales

There are only two confirmed records of northern right whales (*Eubalaena glacialis*) in the Gulf of Mexico, a spring sighting off Florida and a winter stranding in Texas. It is concluded that the northern right whale is not a normal inhabitant of the Gulf of Mexico.

All five species of rorquals (genus *Balaenoptera*) have been recorded from the Gulf of Mexico, although mostly from strandings for most species. The only species that is represented by a substantial number of sightings is the Bryde's whale (*B. edeni*). This is the most common baleen whale in the Gulf, and is probably the only species that normally occurs there.

There are seven Gulf of Mexico records of humpback whales (*Megaptera novaeangliae*) that have been considered reliable. It seems likely that some humpbacks stray into the Gulf of Mexico during the breeding season or on their return migration northward from the Caribbean.

Sperm Whale

There are numerous records of sperm whales (*Physeter macrocephalus*) in the Gulf of Mexico (189 reliable records), more than for any other species of offshore cetacean, except the Atlantic spotted dolphin. It appears likely that there is a resident population of sperm whales in the Gulf of Mexico. There is no doubt that sperm whales are, by far, the most common large whales in the Gulf, and that they can be found there are at any time of year.

Pygmy and Dwarf Sperm Whales

Both species of the genus *Kogia* have been recorded in the Gulf of Mexico. Despite the small number of sightings for both species, strandings indicate that they may not necessarily be rare in the Gulf.

Beaked Whales

Cuvier's beaked whale is probably the most common beaked whale in the Gulf of Mexico. Gervais' beaked whale (*Mesoplodon europaeus*) is probably the most common mesoplodont in these waters; however, this conclusion must be considered tentative. There are only three confirmed records of Blainville's beaked whale (*M. densirostris*) from the Gulf. Sowerby's beaked whale (*M. bidens*) is represented in the Gulf of Mexico by only a single record, a stranding in Florida, and is considered extralimital.

"Blackfish"

From the small number of records and repeated resightings of individuals, it seems likely that there are a small number of pods of killer whales (*Orcinus orca*) that use the offshore waters of the Gulf of Mexico as all or part of their normal range.

Based on historical records, the short-finned pilot whale (*Globicephala macrorhynchus*) would be considered to be one of the most common offshore cetaceans in the Gulf of Mexico. However, recent aerial and shipboard surveys in the northern Gulf of Mexico have not borne out the conclusion that pilot whales are common in the Gulf; they have only occasionally been sighted.

There are a small number of records of false killer whales (*Pseudorca crassidens*), pygmy killer whales (*Feresa attenuata*), and melon-headed whales (*Peponocephala electra*) in the Gulf of Mexico, suggesting that none of these species is very abundant in this body of water.

Small Delphinids

Eight species of offshore dolphins have been recorded from the Gulf of Mexico. Other than the bottlenose dolphin, the Atlantic spotted dolphin (*Stenella frontalis*) is the only species that regularly occurs over the continental shelf. There are more records (194) of Atlantic spotted dolphins than there are for any other species of offshore cetacean in the Gulf.

Risso's dolphins (*Grampus griseus*) have been commonly recorded in some continental slope areas of the northern Gulf of Mexico, and there is no doubt that this species is more commonly than previously-believed.

Rough-toothed dolphins (*Steno bredanensis*) and Fraser's dolphins (*Lagenodelphis hosei*) have both been recorded from the Gulf in relatively small numbers. Neither of these species appears to be highly abundant in the Gulf.

Common dolphins (*Delphinus delphis* and *D. capensis*) have been reported from the Gulf of Mexico in previous years. However, many of these records appear to be cases of mistaken identity, and all of the remaining records are highly questionable. It is concluded that there is currently no solid evidence that common dolphins occur in the Gulf of Mexico.

Besides the continental slope species, *Stenella frontalis*, the other four species of the genus *Stenella* have been recorded from the Gulf as well. The pantropical spotted dolphin (*S. attenuata*) is highly abundant, and appears to be the most common small cetacean in deep waters throughout the Gulf of Mexico. Striped dolphins (*S. coeruleoalba*) and Clymene dolphins (*S. clymene*) are moderately common in the Gulf, and the spinner dolphin (*S. longirostris*) is represented by the fewest records, indicating that it is the least common of the *Stenella* species in this body of water.

CONCLUSION

Although our knowledge is still rudimentary, a great deal has been learned in the past decade, and the pace of this rise in knowledge is still increasing. This has come about only through the hard work and dedication of a small group of interested individuals. Recent increases in funding for studies of offshore cetaceans of the Gulf of Mexico have allowed us to add greatly to the efforts of those early workers who painstakingly documented strandings and occasional sightings of these relatively poorly-known animals. Only with continued funding and dedicated study, can we provide the information on the biology of these animals that is needed to protect them from human-caused threats, and thus ensure their continued existence in the Gulf of Mexico.

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GULFCET AERIAL AND SHIP SURVEYS SURVEY DESIGN, METHODS, AND PRELIMINARY RESULTS

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The objectives of aerial and ship surveys were to provide data for estimating the relative abundance of cetaceans, and for correlating their distributions with oceanographic features in the GulfCet study area. The GulfCet study area, about 210,000 km^2, was bounded by the Florida-Alabama line, the U.S.-Mexico border, and the 100 m and 2,000 m isobaths. While ship surveys covered the entire study area, aerial surveys extended only to the 1,000 m isobath west of 90° W and covered a total area of 85,850 km^2. Line transect sampling methods were used. Aerial surveys were conducted from a Twin Otter modified with large bubble windows. Ship surveys were conducted from NOAA Ship *Oregon II* and R/V *Pelican*. Shipboard observers searched for cetaceans using 25X150 binoculars. Eight seasonal aerial surveys were conducted from Summer 1992 to Spring 1994. Each season, 74 transects with a total length of about 6,300 km were surveyed. Ship surveys were conducted from the *Oregon II* during Spring 1992, 1993 and 1994 and Winter 1993, averaged 30 days each, and surveyed a total of 16,100 km; and from the *Pelican* during seven seasonal surveys that averaged 12 days each from Spring 1992 to Winter 1993 and surveyed a total of about 6,000 km.

Eighteen cetacean species were sighted in 404 groups during aerial surveys. The overall abundances (and CV, the coefficient of variation) of all cetaceans in the aerial survey study area was 16,986 animals (14%). Cetacean abundance varied seasonally: Summer, 14,959 (24%); Fall, 6,051 (32%); Winter, 21,894 (27%); and Spring, 19,215 (24%). The overall abundances and CV of the most commonly sighted species were: bottlenose dolphin, 2,890 (20%); pantropical spotted dolphin, 5,251 (22%); Risso's dolphin, 1,214 (24%); dwarf/pygmy sperm whale, 176 (30%); and sperm whale, 87 (27%). Except for the sperm whale, the seasonal abundances of most species were generally similar for Summer, Winter and Spring, but were much lower for Fall. Average groups sizes were less than three animals/group for physeterids (e.g., sperm whale) and ziphiids, 50-100 for fast, small oceanic dolphins (e.g., spinner dolphin), and 10-20 for small whales and larger dolphins (e.g., Risso's dolphin). The mean depth of species sightings ranged from less than 300 m (e.g., bottlenose dolphins and Atlantic spotted dolphins) to greater than 100 m (e.g., pantropical spotted dolphin).

During the ship surveys, about 300 cetacean groups were sighted in the GulfCet aerial survey study area. The species sighted from the ships, the relative proportion of groups of each species, and their mean group sizes were similar to those sighted from the aircraft. In the entire GulfCet study area, the overall abundances and CV of the most commonly sighted species from the ships were: bottlenose dolphin, 2,761 animals (31%); pantropical spotted dolphin, 11,950 (23%); Risso's dolphin, 1,658 (26%); dwarf sperm whale, 198 (37%); sperm whale, 321 (37%), Atlantic spotted dolphins, 1,718 (47%), and striped dolphin, 3,816 (55%).

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ESTIMATING THE ABUNDANCE OF SPERM WHALES USING PASSIVE SONAR

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Conventional methods of estimating the abundance of cetaceans have focused on both aerial and shipboard surveys using line transect methods (Gates 1969, Burnham *et al.* 1980, and Buckland *et al.* 1993). Although these approaches are highly valuable, they exhibit important limitations. For example, shipboard and aerial surveys are only conducted during daylight and are effected by weather and sea state. Additionally, only animals at or near the surface are counted.

Acoustic surveys using passive sonar methods offer the possibility of extending activities throughout the night, detecting animals far below the surface, and operating in marginal weather. Furthermore, a physical record of the acoustic survey is provided in the form of audio tape recordings. Owing to these advantages, we have undertaken the development of new procedures for conducting passive sonar surveys of sperm whales, *Physeter macrocephalus,* with the objective of estimating population density and abundance.

The work described here was completed using a towed linear hydrophone array. The array is made up of three sections; a deck cable, a tow cable, and a wet section that contains the active elements. The active section of the array is composed of fore and aft high frequency elements with depth and temperature sensors, and a middle low-frequency section. There are 195 hydrophones organized into 18 groups. These groups are tuned to six different frequency bands. There are eight low-frequency groups tuned to 30 Hz, one group tuned to 480 Hz, one group tuned to 3.84 kHz, and fore and aft groups tuned to 5, 10, and 15 kHz (Thomas *et al.* 1986). Data were collected during a cruise aboard the University of Texas RV *Longhorn* and during six cruises aboard the LUMCON RV *Pelican.* The array and study area in the North-Central and Western Gulf of Mexico are described in detail in the GulfCet Interim Report (Fargion and Davis 1994).

Standard line transect methods require the measurement of perpendicular distances (or angles and radial distances) from the trackline of the vessel to the position of the target animals. Perpendicular distances to vocalizing sperm whales cannot be determined with sufficient accuracy using a towed linear array. Consequently, we have developed alternative methods to allow the estimation of population density in our study area.

The hydrophone array was calibrated by projecting various acoustic signals (including recordings of sperm whale clicks) from measured distances broadside to the array. Distances between the array and the projector were determined by using two GPS receivers; one at the projector and one aboard the RV *Pelican.* The projector was a calibrated type F56 transducer leased from the Naval Research Laboratory at Orlando, FL. Additionally, the transducer source level was measured during operations using a calibrated B&K SPL meter. Sperm whale recordings were projected at 171 dB re 1 μP, the published source level for sperm whale clicks (Levenson 1974). Under the noise conditions present during the calibration of the array, a transmission loss model was developed in the form: $TL = 20 \log r + ar$ where r is the range to the source and a is an attenuation coefficient. Fifty random samples of background noise from cruises two through seven were measured to adjust the loss model to the averaged conditions over the entire data collection phase of the project. It was determined that a sperm whale signal of at least 67 dB re 1 μP must be present (on average) at the array in order for the animal to be detected. Based on the transmission loss model, the average maximum detection range for sperm whales was determined to be 11.125 km (6 nm)

The total number of "on effort" sperm whale groups encountered during the cruises was calculated to be 63. Contacts separated by at least 11.125 km were considered to be separate groups. In a few cases, signals from separate groups overlapped but these were resolved by looking at the arrival times of the clicks in the fore and aft sections of the array. Under the assumption that all whales heard were within 11.125 km from the array, a rough density estimate could be calculated by dividing the number of groups encountered by the product of the "on effort" distance times twice the maximum detection distance. The problem with this rough calculation is that several factors associated with the psychoacoustics of listening to a "boring" noise background limits the ability of humans to make detections when the signal to noise ratio is small. This is analogous to the problem of determining the detection function in standard line transect methods. In other words, some of the whales' signals that could have been heard by the acoustic crew were likely missed owing to lack of concentration and the fatigue of long shifts at the headphones. To correct for this error, we required knowledge of the shape of the sperm whale acoustic detection function that had not previously been determined.

Using the digital audio workstation at the Center for Bioacoustics, at Texas A&M University in College Station, we created an audio tape recording to simulate the experience of listening to the hydrophone array described above. We recorded 43 minutes of background noise (without detectable sperm whale clicks) from one of the cruises. We digitally mixed 34 sequences of sperm whale clicks into the background at random spacing in time. The levels of clicks were adjusted to simulate a random distribution of animals along a simulated transect line. A computer program was written to allow listeners to press the spacebar on the keyboard when they heard a sequence of clicks. When the spacebar was depressed, the elapsed time written to a computer disk file. After two training sessions, twenty-four participants completed the experiment of listening to the 43-minute tape and coding sperm whale contacts. From these data (Figure 4D.1) a model for the psychoacoustic sperm whale detection function was developed. As expected, participants had little trouble detecting clicks with marginal or higher signal to noise ratios. A rapid drop off in the ability to detect clicks occurs only after the signal to noise ratio became very small. This suggests that very few contacts out to the maximum detection range were missed during hundreds of hours of listening. Based on the model described here, we predict that only 3.7 percent of the detectable sperm whale clicks were missed and the density estimate should be multiplied by a correction factor of 1.039.

Based on the work to date, we estimate the density of sperm whale groups in the study area to be 2.56 X 10^{-4} groups/km^2. For perspective, this means that one sperm whale group should be found in a square with a side of 62.49 km. From visual observations and considerations of the clustering rule stated above, we estimate that the average group size is 7.3 individuals per group. With a defined study area of 154,621 km^2, a group density of 2.56 X 10^{-4} groups/km^2, and a group size of 7.3, we estimate the abundance of sperm whales in the study area to be 289 individuals. We are presently calculating the estimated variance associated with this abundance estimate and this will appear in the draft final GulfCet technical report expected to be completed by spring of 1995

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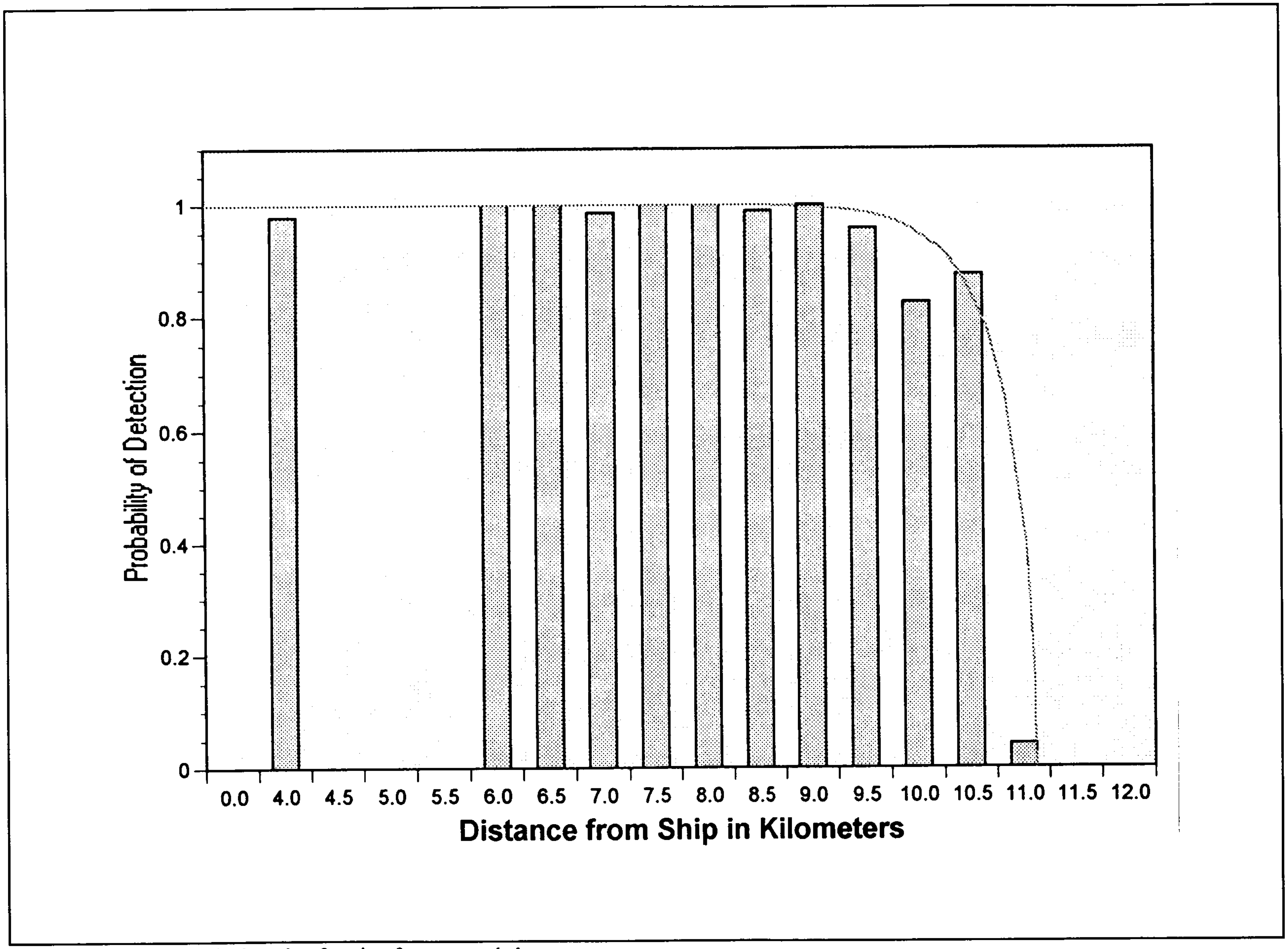

Figure 4D.1. Acoustic detection function for sperm whales.

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BEHAVIOR OF CETACEANS RELATIVE TO CENSUS VESSELS IN THE NORTHWESTERN GULF OF MEXICO, 1992-1994

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INTRODUCTION

There is great variability in morphology, group sizes, and behavior of the approximately 20 cetaceans that are commonly found in the northwestern Gulf of Mexico (Jefferson *et al.* 1993). The ranges are from small delphinids of 2.5 meters to the sperm whales, at over 15 meters; from groups of single individuals to groups of hundreds; and from those animals that habitually approach boats and even bowride to those that ignore or avoid vessels (Leatherwood and Reeves, 1983, provide an excellent summary). It is intuitively obvious that differing characteristics can result in differing abilities to detect, identify, and accurately count animals; but descriptive characteristics of detection variables, especially those stemming from different behaviors, have been given only rarely (Barlow, in press).

There are often differences in the distances at which cetaceans are first seen, first identified, and most accurately counted. These differences in distances are determined by morphology and behavior, and also by the variability of weather, or sighting, conditions. For example, sperm whales can often be seen, identified, and counted quite a bit over one kilometer distant from the survey vessel, and often in rather inclement weather. Ziphiids or *Kogia* sp., on the other hand, may or may not be seen at distance, and their often cryptic behavioral nature of avoiding or at least ignoring a vessel may preclude identification. A major difficulty in the present study was our inability to deviate consistently from course once a distant marine mammal group was sighted. This restriction, due to overall survey time available, precluded identification and counting of many sighted animals, and thus decreased the overall data base.

By and large, most marine mammal surveys have not taken into account variabilities in morphology and behavior related to sighting conditions. Weather has been addressed, and on-transect animals are counted only with certain weather conditions, such as Beaufort Sea State 3 or less (for example, Barlow and Lee 1994). However, we know from personal experience that there are strong differences in initial sightability of at least smaller cetaceans between Beaufort Sea State 0-1, and 2-3. A particularly dramatic example confronted us on 23 August, 1994, when we experienced Beaufort Sea State 0-1 for three hours in the afternoon. During that time, we saw at least five small cetacean groups greater than five kilometers from the vessel, with some of these probable resights as we meandered back and forth (for sperm whale acoustic tracking and photographic recognition studies) in the area. Before and after these excellent sighting conditions, when sea state was greater than 2, we saw no small odontocetes in the same area, despite the same vigilance of observation. We are convinced, although it is difficult to put onto numerical basis, that the change in sea state caused our change in sightability of at least some of these more distant cetaceans.

The present brief analysis does not attempt to augment discussion of the complex issues of weather-related (as well as observer-related) differences in sightability (See Breese and Tershy 1993, for a laudable example). We do, however, address differences in sightability and identifiability of species or species groups according to their morphology and behavior.

METHODS

We searched for cetaceans from the upper decks of the vessels *Oregon* II, 32 m, 10.1 m above sea level; *Longhorn*, 32 m, 7.7 m above sea level; and *Pelican*, 32 m, 8.9 m above sea level. Methods are given in Mullin, *et al.*, this session. Notes on apparent responsiveness of each sighting were transferred to a separate data file. Behavioral reactions could not be determined for many sightings. But for those for which adequate behavioral notes were made, categories of avoidance (-), no reaction (0), approach to vessel (+), and bowriding (b) were given. It was often very difficult to categorize potential reaction to disturbance, and our analyses only included clear reactions, for which the authors could unequivocally assign behavioral response. A (-) assignation was earned when an individual or group moved away from the vessel or appeared to dive in response to the vessel, in either case making it more difficult to identify the animal(s) than with a neutral or positive response. A (0) designation means that the animal(s) showed no apparent response relative to the approach or pass-by of the vessel. This is to be distinguished from the many cases during which we could not tell whether or not there was a response; none of these cases are presented. A (+) indicates that the animal(s) approached the vessel during at least some time of their observation, and it is likely that a positive mark would have enhanced identifiability if the animals were seen at distance. However, a (+) response was earned even if the animals were not identified because of the positive response; only their actions were of importance. Finally, a (b) for bowriding is an extreme case of (+) response; all such animals encountered during regular daylight on-transect watches were identified.

Some species were pooled according to the criteria and justification for pooling for estimates of abundance. We believe that for heuristic comparisons of the estimates and our behavioral data base, the same pooling regime should be followed. Briefly, we pooled 1) *Kogia* sp. and ziphiids, 2) Small delphinids, 3) and 4) Bottlenose Dolphins/ Atlantic Spotted Dolphins; 5) Larger delphinids, and 6) Sperm Whales. However, we also discuss separate species or species groups within pooled groupings as these relate to differences in morphology, behavior, and hence potential sightability. Due to a presently small data base of behavioral reactions, we made no formal attempts to separate reactions relative to the three observation vessels. However, our judgment was that differences among vessels, if they exist, were much smaller than differences among species and species groups. Because of the broad categorizations of behavioral reactions described above, analyses of differences were by simple chi-square, and Fisher's tests of comparisons of initial sighting distances.

RESULTS

Distance estimates were described for 655 sightings for which the cetaceans were identified to species or species group (Figure 4D.2). Initial sighting distance was 2.3 $\pm$ s.d. 1.77 km (n=655), with mean sightings as close as 1.6 $\pm$ s.d. 1.50 km (n= 384) for *Tursiops*, 1.6 $\pm$ 1.33 km (n=46) for *Ziphius* sp., and as far as 4.2 $\pm$ s.d. 1.46 km (n=6) for *Orcinus.* A summary for all species is found in Figure 4D.3.

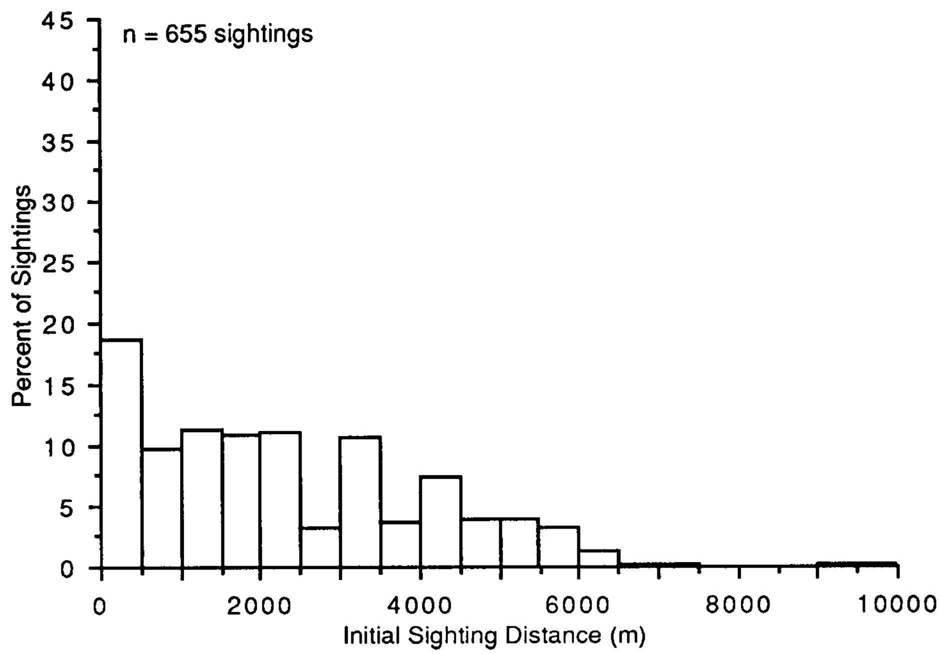

Figure 4D.2. Initial distance of all sightings.

Group 1. *Kogia* sp. and Ziphiids

This group of cetaceans was first sighted at a mean of 1.7 ± s.d. 1.28 km (n=86, Figure 4D.4). Eleven of 15 sightings (73%) involved animals reacting negatively to the vessel by orienting away; in no instance did members of this group appear to react positively to the vessel. None bowrode (Table 4D.1). The designation of "cryptic" is certainly correct. It is unknown how many *Kogia* sp. and ziphiids were unseen, unidentified, and uncounted because of their crypsis.

Group 2. Small Delphinids

This group of delphinids, mainly of the continental slope, for which we obtained reaction information consisted of pantropical spotted dolphins (*Stenella attenuata*), Clymene dolphins (*S. clymene*), striped dolphins (*S. coeruleoalba*), spinner dolphins (*S. longirostris*), melon-headed whales (*Peponocephala electra*), rough toothed dolphins (*Steno bredanensis*), and two groups of Fraser's dolphins (*Lagenodelphis hosei*).

Initial sighting distance of this group was 2.4 ± s.d. 1.83 km (n= 264, Figure 4D.4). All Stenellids except for *S. coeruleoalba* habitually approached the vessel and rode the bow, at 83% for *S. attenuata*, 14 of 14 sightings (100%) of *S. longirostris*, and 22 of 24 sightings (92%) of *S. clymene* (Table 4D.2). The overall reaction for *S. coeruleoalba* was dramatically different, however, with only 14 of 27 sighted groups (52%) riding the bow, and 9 of the 13 (-) reactions of the entire continental slope small delphinid group exhibited by this species (Table 4D.2). Positive reactions and bowriding combined occurred for 90% of group 2.

Groups 3 and 4. Bottlenose Dolphins/Atlantic Spotted Dolphins

The two species of dolphins that occur over the broad continental shelf of the present study area have similar sighting characteristics and at times school together. They were first seen at 1.6 ± s.d. 1.58 km (n=138, Figures 4D.3 and 4D.4) distance; and, overall, members of 79% (a similar 77% for *Tursiops* and 85% for *Stenella frontalis*) of sighted groups

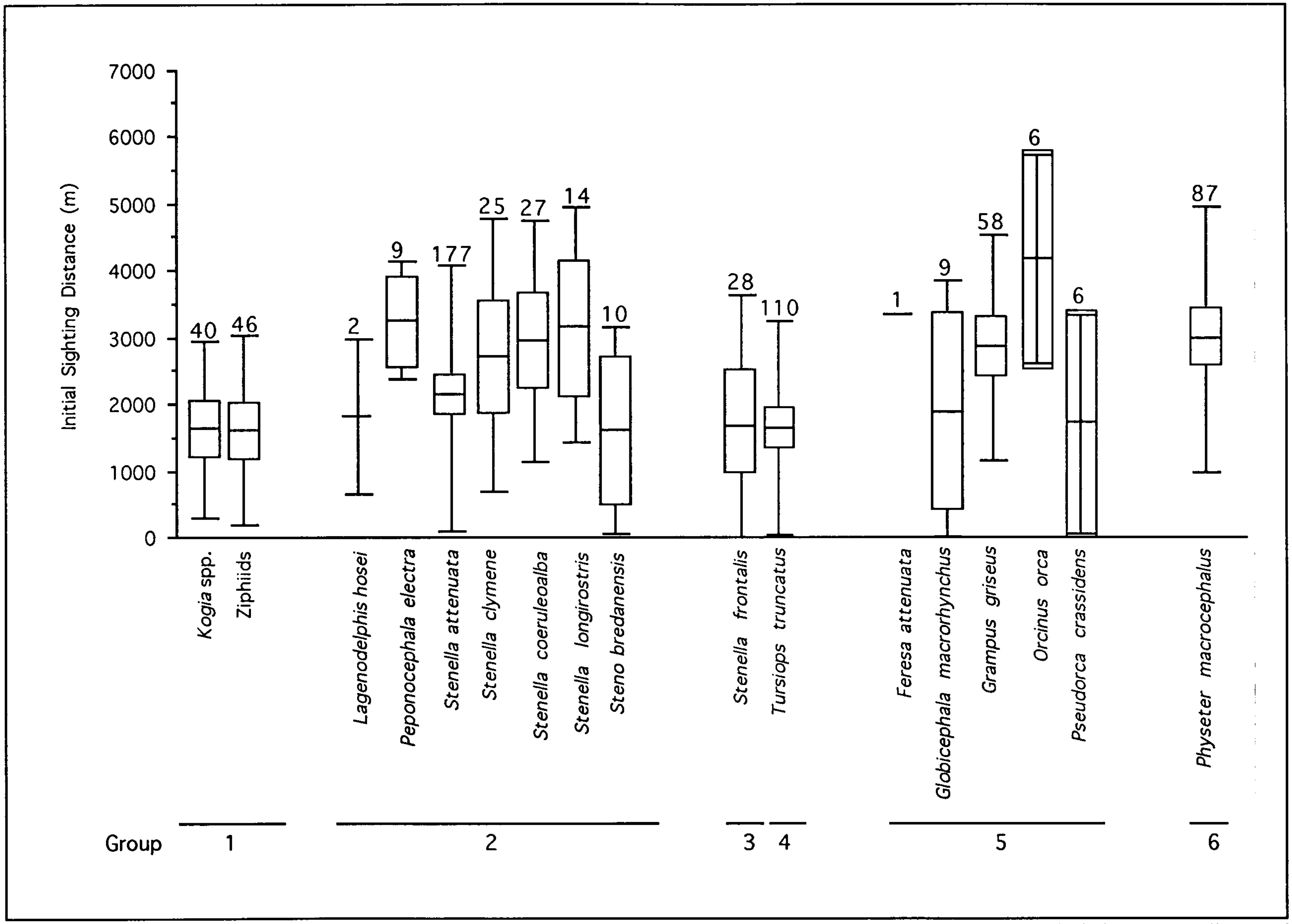

Figure 4D.3. Initial sighting distances by individual species, and six pooled groups; with means as central line, standard deviation as outer lines, and 95% confidence intervals as boxes; and sample sizes.

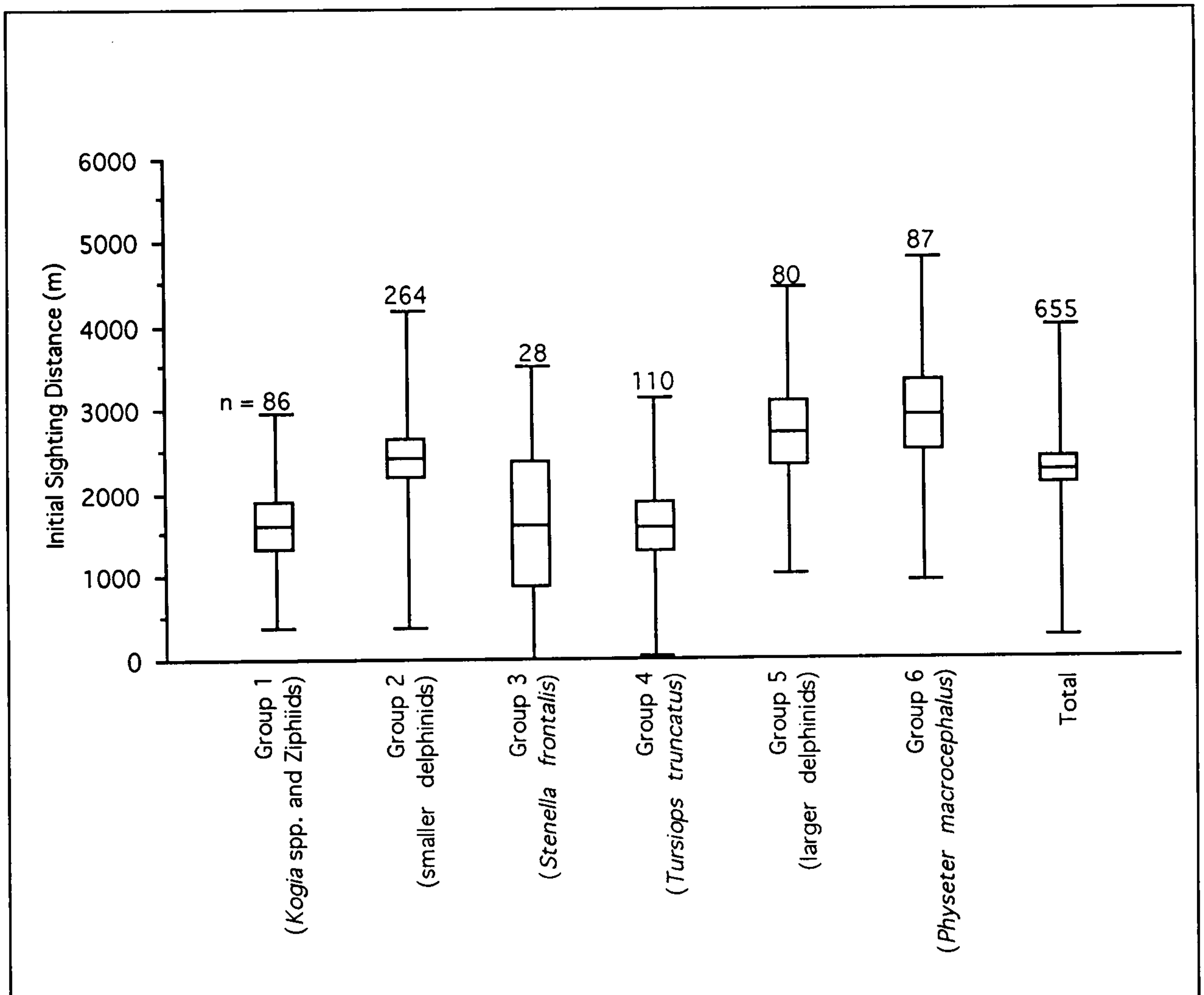

Figure 4D.4. Initial sighting distances by six pooled groups. Data presentation as in Figure 4D.3.

came to the ship and rode the bow pressure wave for at least one minute, and—at times—for over one-half hour (Table 4D.3). Fourteen of 88 behavioral descriptions of *Tursiops* and two of 22 of *S. frontalis* were classed as (0) reaction, and none were classed as (-) throughout the study (Table 4D.3). Overall, positive reactions and bowriding combined occurred for 86% of this group.

Group 5. Large Delphinids and Small Whales

This group consisted of short-finned pilot whales (*Globicephala macrorhynchus*), Risso's dolphins (*Grampus griseus*), false killer whales (*Pseudorca crassidens*), killer whales (*Orcinus orca*), and the smallest member of the group, the pygmy killer whale (*Feresa attenuata*). The mean distance of first sighting was 2.7 ± s.d. 1.65 km (n=80, Figure 4D.4), with killer whales sighted at greater distance, of 4.1 ± s.d. 1.46 km (n=6), than any other species (Figure 4D.3). Pilot whales and Risso's dolphins exhibited the least attraction to the vessel, with only one of six in the former and 12 of 30 in the latter species moving towards the vessel or bowriding (Table 4D.4).

Group 6. Sperm Whale

Sperm whales were sighted at an average distance of 3.0 ± s.d. 1.86 km (n=87, Figures 4D.3 and 4D.4).

Table 4D.1. Behavioral reactions* of Group 1 relative to the census vessel.

	Reaction					
Species	(-)	(0)	(+)	(b)	%(b)	Total
Kogia spp.	6	1	0	0	0	7
Ziphiids	5	3	0	0	0	8
Total	11	4	0	0	-	15

* (-) indicates animal orienting away from vessel or abrupt diving
(0) indicates no reaction
(+) indicates approach
(b) indicates bowriding
%(b) = percentage of bowriding per total reactions

Table 4D.2. Behavioral reactions of Group 2 (smaller delphinids) relative to the census vessel. Reaction designations as in Table 4D.1.

	Reaction					
Species	(-)	(0)	(+)	(b)	%(b)	Total
Lagenodelphis hosei	1	0	0	1	50%	2
Peponocephala electra	1	1	2	3	43%	7
Stenella attenuata	1	9	18	137	83%	165
S. coeruleoalba	9	2	2	14	52%	27
S. longirostris	0	0	0	14	100%	14
S. clymene	1	0	1	22	92%	24
Steno bredanensis	0	0	2	6	75%	8
Total	13	12	25	197	-	247

Table 4D.3. Behavioral reactions of Groups 3 and 4 relative to the census vessel. Reaction designations as in Table 4D.1.

Species	Reaction (-)	(0)	(+)	(b)	%(b)	Total
Stenella frontalis (Group 3)	0	2	2	22	85%	26
Tursiops truncatus (Group 4)	0	14	6	38	77%	88
Total	0	16	8	90	-	114

Generally, sperm whale reaction was not described in the sighting notes, but our overall impression was that reactions tended to be non-existent for all but approaches to within several hundred meters. Eleven of 15 sightings with behavioral notes were labeled as (0) reaction; none as (+) reaction; and 4 as (-), consisting of the whales diving abruptly in apparent response to the vessel, all within 200m.

Sperm whales were unlikely to be mis-identified even at several kilometers distance, due to their characteristic bushy, single-spouted, blow at the very front of the head; and due to their unique head-to-dorsal-hump surface profile. However, sperm whales dive for long times, often greater than one-half hour, and counts of animals in an area are therefore difficult.

Table 4D.4. Behavioral reactions of Group 5 (larger delphinids) relative to the census vessel. Reaction designations as in Table 4D.1.

Species	Reaction (-)	(0)	(+)	(b)	%(b)	Total
Feresa attenuata	1	0	0	0		1
Globicephala macrorhynchus	1	4	0	1	17%	6
Grampus griseus	5	13	7	5	17%	30
Orcinus orca	0	2	0	4	67%	6
Pseudorca crassidens	0	1	1	3	60%	5
Total	7	20	8	13	-	48

Group 7. General Comparisons

Overall, killer whales were initially sighted at greatest distance from the census vessels (n=6, see above). Despite the low sample size, this distance was significantly greater than for all other animals, except for melon-headed whales (at 3.2 ± s.d. 0.83 km, n=9; Fisher's PLSD, p<0.0001 for all comparisons). The cryptic *Kogia* sp. and ziphiids, group 1, were not sighted at distances significantly different from the *Stenella frontalis* and *Tursiops truncatus* groups (groups 3 and 4). These three groups were sighted closer to the ship than the small delphinids, large delphinids, and sperm whales (groups 2, 5, and 6, respectively). There was a slight significant difference between small and large delphinid distances (Fisher's PLSD, p = 0.005), but not between the small delphinids and sperm whales (p = 0.09), and the large delphinids and sperm whales (p = 0.41; Table 4D.5).

Overall, the *Kogia* sp. and ziphiids showed the greatest percentage (79%) of negative (-) reactions, with the large delphinids at 16%, the small delphinids at 5%, and the Atlantic spotted and bottlenose dolphins at 0% each. Risso's dolphins of the large delphinids reacted negatively five of 30 (17%) of the time, and striped dolphins of the small delphinids reacted negatively nine of 14 (64%) of the time. Spinner dolphins, rough-toothed dolphins, bottlenose dolphins, killer whales, and false killer whales never appeared to react negatively towards the vessel. On the other hand, *Kogia* sp., the ziphiids, and the pygmy killer whale (with only one sample for it, however) never showed positive reactions, including bow-riding.

DISCUSSION

Sperm whales are easy to sight and identify, and reactions relative to the vessel may be unimportant in

Table 4D.5. Paired comparisons (Fishers LSD) of initial sighting distances for the six groups. "S" denotes comparisons (P≤0.05).

Comparison	Mean Difference	Critical Difference	P-Value	
Group 1 vs. Group 2	-724.427	414.556	0.0006	S
Group 1 vs. Group 6	-1312.496	507.709	<0.0001	S
Group 1 vs. Group 5	-1096.615	518.633	<0.0001	S
Group 1 vs. Groups 3 & 4	58.121	458.708	0.8036	
Group 2 vs. Group 6	-588.068	412.755	0.0053	S
Group 2 vs. Group 5	-372.187	426.121	0.0868	
Group 2 vs. Groups 3 & 4	782.549	350.729	<0.0001	S
Group 6 vs. Group 5	215.881	517.195	0.4127	
Group 6 vs. Groups 3 & 4	1370.617	457.081	<0.0001	S
Group 5 vs. Groups 3 & 4	1154.736	469.185	<0.0001	

estimating abundance. However, a caveat must be made: it is possible that sperm whales that hear an approaching or passing vessel change their dive times, by remaining submerged longer than they would otherwise, or shortening their surface time in response to the vessel, at some distance from the vessel. Neither of these possibilities is indicated by present information, however, and we assume that behavioral reactions do not consistently cause over or undercounts of sperm whales. It is, however, very likely that whales of a subgroup are undercounted in an area simply because of their normally long submergences, and this surface/dive ratio must be assessed with further work.

Bottlenose dolphins and Atlantic spotted dolphins are relatively easy to sight and identify, in large part because of their habit of approaching vessels. Their behavior patterns relative to vessels are quite similar for the two species, and we conclude that population estimates are not likely to be skewed between the species due to behavioral reactions. However, their proclivity for bow-riding may result in overcounts relative to other less attracted species.

The continental slope small delphinids are probably also rather similar in reaction, except for the striped dolphin and perhaps the lesser seen and known Fraser's dolphins and melon-headed whales. For the striped dolphin, we have strong indication of avoidance reaction, and apparent leaping away from the vessel at distances as far as 3 km. All nine negative reactions that were scored nevertheless resulted in species identifications simply because the dolphins were leaping at distance, and therefore allowed their clearly marked flanks to be seen. We have no numbers on how many times *S. coeruleoalba* avoided the vessels and were thereby not seen or—if seen—not identified to species group or species. It is probable that striped dolphins are undercounted relative to other stenellids.

A similar problem may exist for Fraser's dolphins and melon-headed whales, each of which were only identified two and seven times, respectively. Fraser's dolphins bow-rode once of two times (50%) and melon-headed whales showed positive reaction or bow-rode five of seven times (71%). These data would indicate that positive and other reactions might balance out, but the numbers of identified sightings are simply too small, and the possibility exists that these delphinids are more cryptic than indicated. Further work, including detailed comparisons with aerial surveys, may shed light on this question.

The mid-sized blackfish of the large delphinid group are probably seen with approximately equal frequency, with varied reactions to the vessel. They are also large and identifiable enough to be seen and counted from well over one kilometer. The killer whales are probably "overcounted" relative to others, with killer whales in approximately the same category as the easily-seen sperm whales. On the other side of this scale are the ziphiids and especially *Kogia* sp. Ziphiids are often not identifiable to species, but at least can be placed into the beaked whale category much of the time. *Kogia* are smaller and generally behaviorally cryptic, and we must assume that we seriously undercount these two species of physeterids.

We assume that the noise of the census vessel, both from the engines and propeller cavitation, alert cetaceans to the vessel's presence (Richardson *et al.* 1991). Cetaceans that react positively are probably either curious or are gauging the possibility of riding bow or stern pressure waves of the vessel. The exuberant forward leaps of spotted dolphins, for example, as they race towards the bow, can be described as a play activity which makes these animals very easy to see indeed. Cetaceans also habituate to vessels, and much "ignoring" of our census vessels is probably due to habituation in a propeller-noisy environment such as the northern Gulf of Mexico. It is unclear why some cetaceans, even those not known to have been harassed or killed by humans on any large scale, are habitually or at times evasive. Perhaps the noise of the vessel is disruptive to feeding or resting or other activities.

Distances at which ship noises are heard are variable by ship, weather (sea state and rain) conditions, oceanography, depth of dive of the target species, frequencies of sensitivity, general ambient noise conditions, and angle of species from the bow (Greene 1991, Malme 1991). These variable factors make it very difficult to summarize distances of potential noise influence. However, we know that supply vessels of the approximate sizes of our survey vessels have sound levels in the range from 20 Hz to 1,000 Hz of about 120 to 150 dB re. 1 uPa at a distance of 0.2 km, and about 105 to as high as 125 dB re. 1 uPa at a distance of 9 to 10 km, while underway (Greene 1985, Greene and Moore 1991). The major sensitivities of hearing of the toothed whales of the present study are well above 100 Hz, with the smaller delphinids doing almost all communicating and echolocating well above 1,000 Hz. (Evans 1969, Au 1993).

The sighting and identification of cetaceans can change by weather and variable behavior of species or species groups. However, behavior is even more variable than summarized in this chapter, with potential differences by group size, age and sex, time of day, season, weather, and other factors. For example, we know that spinner dolphins of Hawaii are more shy and cryptic while resting in early morning, and more aerially demonstrative in the afternoon (Würsig *et al.* 1994). Dusky dolphins (*Lagenorhynchus obscurus*) of the southern hemisphere attune their human interactions, including approaches to boats, closely to group size and whether or not they have fed in the previous several hours (Würsig and Würsig 1979). They show marked differences in human interaction responses relative to age and sex, and to seasonality (Würsig *et al.* 1989). Sperm whales and several species of baleen whales may increase their aerial activity prior to and in the initial stages of a drastic weather change (personal observation). It is likely that similar differences exist for the cetaceans of the northwestern Gulf of Mexico, but our behavioral data base, gleaned literally while transiting past the animals, is at present too meager for more definitive statements.

REFERENCES

Not submitted with manuscript.

Dr. Bernd Würsig is a professor at Texas A&M University, and Director of the university's Marine Mammal Research Program. His main interests are in behavioral ecology and social strategies of whales and dolphins, with special emphasis on comparisons among species and habitats. Dr. Würsig's research, much of it in coordination with his graduate students, is centered on the Gulf of Mexico, but also takes him on a regular basis to sites in the Amazon, Costa Rica, Hawaii, the Bahamas, the Arctic, New Zealand, and central China. He is especially interested in attempting to find ways to mitigate ecological problems to near shore and river dolphins.

Spencer Lynn is currently a graduate student of Dr. Bernd Würsig's at the Marine Mammal Research Program of Texas A&M University, Galveston. His work involves photo-identification, behavioral observation, radio-tracking, genetic biopsy sampling, and acoustic recording of free-ranging bottlenose dolphins along the Texas coastline, as part of social affiliation and environmental monitoring studies. Before moving to Galveston in 1991, he assisted in research on the behavior, communication, and cognition of captive bottlenose dolphins in San Francisco, California.

SESSION 5B

MARICULTURE ASSOCIATED WITH OIL AND GAS STRUCTURES, PART II

Session: 5B - MARICULTURE ASSOCIATED WITH OIL AND GAS STRUCTURES, PART II

Co-Chairs: Mr. Villere Reggio and Mr. Dave Moran

Date: November 17, 1994

Presentation	Author/Affiliation
Mariculture Potential, Problems & Perspective Nearshore & Offshore Texas and throughout the Gulf of Mexico	Mr. Tim Moore Texas Aquaculture Association
The Watermark Corporation	Mr. Gregg Creppel The Watermark Corporation
High Seas Mariculture	Mr. Michael C. Kacergis Maryland Shrimp Company, Inc.
Open Ocean Mariculture and the Significance of Petroleum Structures to Fisheries	Mr. Steve Kolian Tulane University

MARICULTURE POTENTIAL, PROBLEMS & PERSPECTIVE NEARSHORE & OFFSHORE TEXAS AND THROUGHOUT THE GULF OF MEXICO

Mr. Tim Moore
Texas Aquaculture Association

Gulf of Mexico offshore aquaculture is defined as the rearing of marine organisms under controlled conditions in the Exclusive Economic Zone (EEZ) of the United States; that is, from the three mile territorial limit of the coastal states to 200 miles from shore. There currently is no federal policy with respect to regulating offshore aquaculture.

While marine aquaculture has focused on the production of fish, shellfish and algae in recent years, it is the raising of aquatic animals for food that has seen the truly explosive growth in the last twenty years, with most of that growth taking place in the last ten years.

Why this sudden interest in mariculture? The global catch of fish in 1990 was less than 100 million metric tons. This quantity is simply not adequate to meet the demand that exists today, let alone the demand that will exist in the future.

And regretfully, the oceans of the world will probably never produce more fish than that 100 million metric tons. If anything, a scenario of less and less appears likely. The Food and Agriculture Organization (FAO) has projected that the industrialized nations of the world will require an additional 22.5 million and the non-industrialized nations another 5.9 million metric tons of fish and seafood products by the year 2000. That's a total of 28.4 million metric tons or nearly 60 billion pounds. If the oceans of the world are not going to produce more seafood in the years immediately ahead, that 60 billion pounds must come from aquaculture worldwide.

As most of you are acutely aware, fish landings from the worlds' oceans have lagged far behind the population growth. So not only are we seeing the absolute demand of those in the market now pulling ahead of the supply but we're seeing an additional gap because population is growing much more rapidly than the industry is able to keep up with.

We can simply no longer catch enough fish or aquatic animals to meet the demand of these products. With the population growth and changing diets of health-conscious consumers, aquaculture facilities have begun to respond by expanding to help fill the gap.

Mariculture dwarfs the expectations for the future. Mariculture promises to become the dominant factor in the world seafood industry in the next twenty years but only if the capital necessary to ensure its growth becomes available.

With all of that as background let's look a little more closely at some of the things occurring in the mariculture world and how they may impact on investments in mariculture.

If current state and federal regulatory trends continue to dominate the environmental agendas, several trends are apparent. We are either going to grow marinefish on shore in systems that are environmentally correct, i.e., those that emphasize water reuse and conservation, minimal impingement and negligible effluent impacts, and build facilities that fully consider competing users of the available resources, or we will grow marinefish offshore in open waters where potential impacts are less controversial and environmental impact statements and routine monitoring are not required.

One thing is certain. World demand for seafood appears insatiable. We know that because what started in just a few countries is now truly worldwide and nearly every nation on earth, industrialized or third-world is not only participating in aquaculture but is increasing their annual production and their number of species produced.

Along with globalization, we are seeing a gradual sorting out and relocation by species of aquaculture production areas. More and more aquaculture activities are closing down in geographic areas which are inhospitable for cultural, climactic or economic reasons and are moving closer and closer to more hospitable sites. Aquaculture now is beginning to migrate to places where greater opportunity for ongoing profitability exists, places with warmer

climate, inexpensive land, abundant water, minimal effluent discharge problems, low labor cost.
The primary reasons for interest in offshore mariculture are

- Existing structures such as drilling platforms can be used during and beyond their capable years of extracting oil and gas from the seabed below as growout sites.

- Most pollution from sewage, pesticides, petroleum spills and industrial wastes that occur in coastal waters can generally be avoided in offshore sites.

- Nutrient loading from waste feed and fecal material can be avoided in offshore areas where water volumes and movements will rapidly disperse the waste products.

- Offshore water quality is traditionally more stable than inshore areas. These very enticing benefits are balanced and possibly overbalanced with serious constraints.

- Offshore facilities must endure the harshness of the Gulf. Structures must be engineered to routinely withstand high winds and wave actions that peak at 15-20 feet.

- Modeling structures for the Gulf of Mexico cannot be modeled in the David Taylor Wave Tank. Engineers that design projects for the Gulf cannot easily go from the toothpick model to a full scale ocean structure. Engineers have not been able to accurately predict the force of X height wave times the current when every ninth wave doubles or even quadruples in force. The base line data does not clearly indicate whether offshore structures like rigs should defy nature or work in some sort of unison with nature in the Gulf environment.

Conventional wisdom says:

- Eliminate anchors from the mooring system of any net pen design. They are expensive, unreliable and could interfere with shrimp trawling operations.

- A reliable automated water flush feed delivery system which can be used on either active, unmanned platforms or non-producing rigs has been developed and tested with success.

- Containment nets should in fact not be netting but rather panels of molded fiberglass with 1-2" square grids standardized for all pens and easily replaced by divers as the material becomes biofouled.

- Annual production for any cage system can be increased utilizing supplementing water circulation via a platform mounted pump during high DO demand (i.e., adult fish, mid-summer).

- Every project that I am aware of in the Gulf of Mexico incorporating mariculture concludes that all viable future facilities must be built as much as 20 feet below the surface in the Gulf of Mexico. Conventional wisdom is that "Hostile Environment" only moderately describes the challenges presented mariculturists in Gulf of Mexico.

If it is true that systems have had more success submerged, and thereby removed from the most extreme wave action, then the ability to raise and lower cages in the water for maintenance and harvest must become key components to any system. One of the most simplified versions utilized an exchange of air and water volume inside an octagon flotation collar attached to the pen.

Submerged structures require automation to surface and harvest, requiring additional cost in construction. It appears beneficial to build pens outside the platform legs to allow for expansion of cage volume to an economically viable size. This outside the leg location eliminates the need for anchors, which have been problematic in many systems. The rigidity of units appears to allow for more simplified and reliable feed delivery system.

Current U.S. and international law and offshore lease agreements require the complete removal within one year of offshore structures at the end of the intended useful life. In testimony to Congress, The Marine Board of the National Research Council projected that by the year 2000, two-thirds of the existing offshore structures will have become commercially unproductive and subject to removal and onshore disposal.

Let's be realistic and look at it from the oil and gas companies' perspective:

In consideration of this time-line utilization of off-shore structures, oil & gas companies find it nearly impossible and downright unattractive to contribute surplus equipment to anyone but an authorized artificial reef program, such as Louisiana's. Of course the same liability concerns combined with engineering and operational issues dissuade oil and gas companies from considering mariculture agreements involving active production structures.

Other limitations to consider:

- Federal oil and gas leases for the OCS do not authorize the conduct of any sort of commercial activities. e.g., no casinos, no restaurants, no vendor warehousing and no mariculture.
- Mariculture is not related to the core business of oil and gas production. Most oil and gas companies continue to divest non- core, non-strategic assets and activities to cope with increasing compliance costs and foreign competition.
- Oil & gas companies are unwilling to increase their exposure to lawsuits stemming from ANY source.
- Safety concerns discourage oil and gas companies from considering mariculture on active structures, and they are legally bound to remove inactive ones.
- Oil and gas companies would never warrant the suitability or serviceability of offshore structures for uses other than their intended use.
- If oil and gas companies were in a position to accommodate mariculture activities on offshore structures they would require the operator to post performance bonds for both installation and removal of equipment, maintain sufficient insurance to cover all foreseeable damages, and ensure that no structural modification could interfere with either normal or emergency oil and gas operations, including evacuations.

These six major constraints must be overcome for ANY oil and gas company to participate in a mariculture project now or in the future.

Offshore production activities require vastly different approaches and technologies from those utilized in coastal or inland waters. Currents in excess of seven knots, wave actions exceeding 15 feet and seasonal hurricanes dictate utilization of materials and engineering approaches that are inherently more expensive than those in protected waters. Information on engineering requirements for such facilities is developing but have not as yet proven economically competitive.

Anti-fouling has not been comprehensively factored into design criteria materials. Fish biology and fish behavior in cage or net culture is only nominally understood.

High-value species must be economically feasible in offshore culture. Species most favored for offshore production include yellowtail snapper, ling and mahi mahi. These species have achieved complete life cycles in captivity, and larval rearing techniques as well as prepared diets continue to improve. By its very nature, offshore cage culture and its appropriate technologies make it a high-risk/high-cost production method. Marginally valued species simply are not cost effective. Some research indicates that until we in the United States adopt an Asian mindset that allows for an $8-9 dollar per pound average price, mariculture production models will fail to be sustainable and profitable.

With the best technologies available to the industry, we must remember that the agriculture policy in this country has always supported a cheap and affordable food policy.

The risk/reward ratios for platform culture have not been fairly assessed. If pricey fish products prove to be the only viable species, we still haven't determined market demand for these products.

As offshore cage culture commercial production of these high-priced fish increases, per unit cost will be driven downward. This forces us to produce more fish in the same systems to maintain profitability.

We know that dolphins (mahi mahi) experience rapid growth on a cut fish and shrimp diet, but there is no known feed ingredient mix of like nutrition currently developed for open sea culture. Mahi Mahi are symptomatic with schooling behavior and experience less than desirable growth conversion rates when the culture environment experiences rapid and fast current flows. Rapid flows force rapid swimming action in the culture species. This action always increases rapid oxygen intake and contributes to oxygen depletion.

We know that in warm water culture, dissolved oxygen levels can and do fluctuate greatly in the hot summer months. We do not know optimal dimensions for cage culture for each species and in what densities.

We do know that with maximum fish biomass there are many situations in the open seas where large fish in the middle of culture cages will demand supplemental aeration. Supplemental aeration requires additional pumps and energy and additional operational costs.

We know that 70% of all saltwater sportfishing trips made by coastal residents beyond three miles from shore made their trips to oil and gas structures. What does this mean for offshore mariculture? It probably means that fully automated, manned platforms will be required for security and economic reasons. Poaching and theft will demand unique and innovative solutions. The fact that these offshore structures lie in public U.S. waters makes them especially vulnerable and accessible. Video surveillance and utilization of alarm systems may be required as effective deterrents. Satellite communications to trigger patrols of the platforms will certainly be a necessary component of security.

We know that the Gulf waters nearshore structures are threatened by increased nitrogen and phosphorus levels and more unstable salinity. Better culture waters appear to be outside the three-mile barrier. Most of the available rigs lie in the waters beyond three miles anyway.

If the most desirable sites are beyond the three-mile boundary, then this culture methodology will develop on the most inaccessible, remote platforms that will require more costly maintenance from shore, more costly ingress and egress with personnel.

On the positive side however, the more remote locations also offer less risk of winterkill, which is greatly reduced further offshore as oceanic water is not subject to rapid temperature change.

We know that at an average cost of $10 to 15 million for existing construction and placement, industry cannot bear the cost of duplicating these structures for growout facilities. Existing structures must be utilized. A short window of opportunity exists for the development of offshore mariculture.

It is highly unlikely that there will ever be coordination of mariculture activities with oil and gas operations on active platforms. However if oil and gas personnel and mariculture activities can utilize boats, helitransport services, decompression chambers, diving activities and the like, favorable cost controls for mariculture activities will be better achieved. Availability of decompression chambers, need for 110' utility boats to ferry out personnel and to deliver the structures themselves, feed, harvest equipment, use of trained divers for structural repairs can exceed $2,000 per day. These technologies do not come without serious ongoing operational costs that cannot easily be borne by mariculture activities alone.

It will not be easy to make this culture concept viable, sustainable or profitable. High quality seafood demand will continue, regulatory pressure will continue to mount for land-based operations, platforms will continue to be chopped up and scrapped or donated to rig-to-reef programs. Mariculture has a short window of opportunity to make best use of these multi-million dollar structures. We need the fish they are capable of producing, we need the jobs they are capable of generating; therefore, we will meet the demand for technology that makes these platforms viable. Profitability may well be the single most limiting factor in the consideration of the ocean giants for mariculture production.

With roughly an eight-year window of opportunity, the most innovative and viable projects will compete for investment and venture capital dollars against other investment alternatives and possibly less risky ventures. Offshore projects will not enjoy a honeymoon with investor attitudes. This culture technique will not be capable of sustaining highly visible public losses and failures without an immediate erosion of investor confidence. We cannot afford to elephant hunt on the high seas. The most visible of projects in the next five years must show positive promising results. This means that collaborative government and private enterprise projects must pave the future. Platform culture will not attract small investors. These projects are for the stout-hearted and will be funded by big business. They will succeed if they are designed around economies of scale or as supplemental income streams to other offshore integrated oil and gas activities.

THE WATERMARK CORPORATION

Mr. Gregg Creppel
Watermark Corporation

Watermark is embarking upon a venture of attempting to couple offshore oil and gas production with operations designed to farm fish and shellfish in the offshore environment on deep water oil and gas platforms. Recognizing that natural resource management, energy production, and food availability will all become critical issues in the coming century, Watermark has developed a plant that will meet these needs (Figures 5B.1 and 5B.2). Oil and gas production and seafood farming are two industries that are viable for development in the Gulf of Mexico immediately and concurrently. Management believes that the success of combining these industries is built upon the premise that diversity in commercial operations will provide a shield from the risks associated with either operation by itself because of the "buffering" that one operation's revenue flow should offer to the other.

Watermark's primary focus is to establish a mariculture (sea farming) operation that will utilize offshore oil and gas production platforms located in the clear, oceanic-quality, deep waters of the Gulf of Mexico, beyond near-shore land runoff and related pollution. Watermark has researched the global state of affairs with regard to inadequate food supplies for future generations and has selected mariculture as a business venture that will contribute to the solving of these global societal problems. Furthermore, Watermark has chosen to conduct this business in a way that can turn the liabilities of off-shore oil and gas platforms into assets. The company will seek to acquire platforms which still have hydrocarbon production in order to receive the benefit of the revenues generated from further oil and gas production. This income can create a positive cash flow for the company during the time in which the mariculture operation is being established and can enhance the overall corporate profitability thereafter.

The demand for seafood significantly exceeds the ability for the countries of the world to supply seafood to consumers. Seafood shortages are related to the decline in natural fishery populations both from over-fishing and environmental degradation. With the anticipated continued decline in natural seafood supplies, mariculture is attracting wide interest from both the business community and governments around the world as a means to supplement dwindling natural fishery supplies and eventually could become a dominant source of seafood.

Mariculture, the farming of marine organisms in a controlled aquatic environment, is an infant science with significant, although untested, potential. Well planned, efficiently managed mariculture operations can achieve goals of environmental protection and natural fishery stock preservation. The farming of marine species can reduce pressures on natural stocks, which in some instances are approaching extinction, and can provide economic stability to fishing communities by providing significant profit-producing food harvests for growing populations world-wide. As mariculture technology continues to develop, including the use of better environments, such as deep ocean water regions, and the continued improvement of caging methods and feeding of culture species, there is no doubt that the proportion of seafood provided through mariculture versus natural fished stocks will continue to increase.

Watermark's goal is to supply a premium-priced species such as pompano to the seafood market. There are many economic advantages to cultivating a delicacy product such as pompano. This product can command a high price, eliminate the vagaries of commodity markets, and control market expansion by supply rather than demand. Presently, the pompano market (about one million pounds annually) is relatively small compared to other fishery products, due to a limited catch by fishermen. The market is also highly elastic and could be greatly expanded with little effect on its price. Pompano has an excellent name and reputation throughout the United States. No efforts have been made, however, to

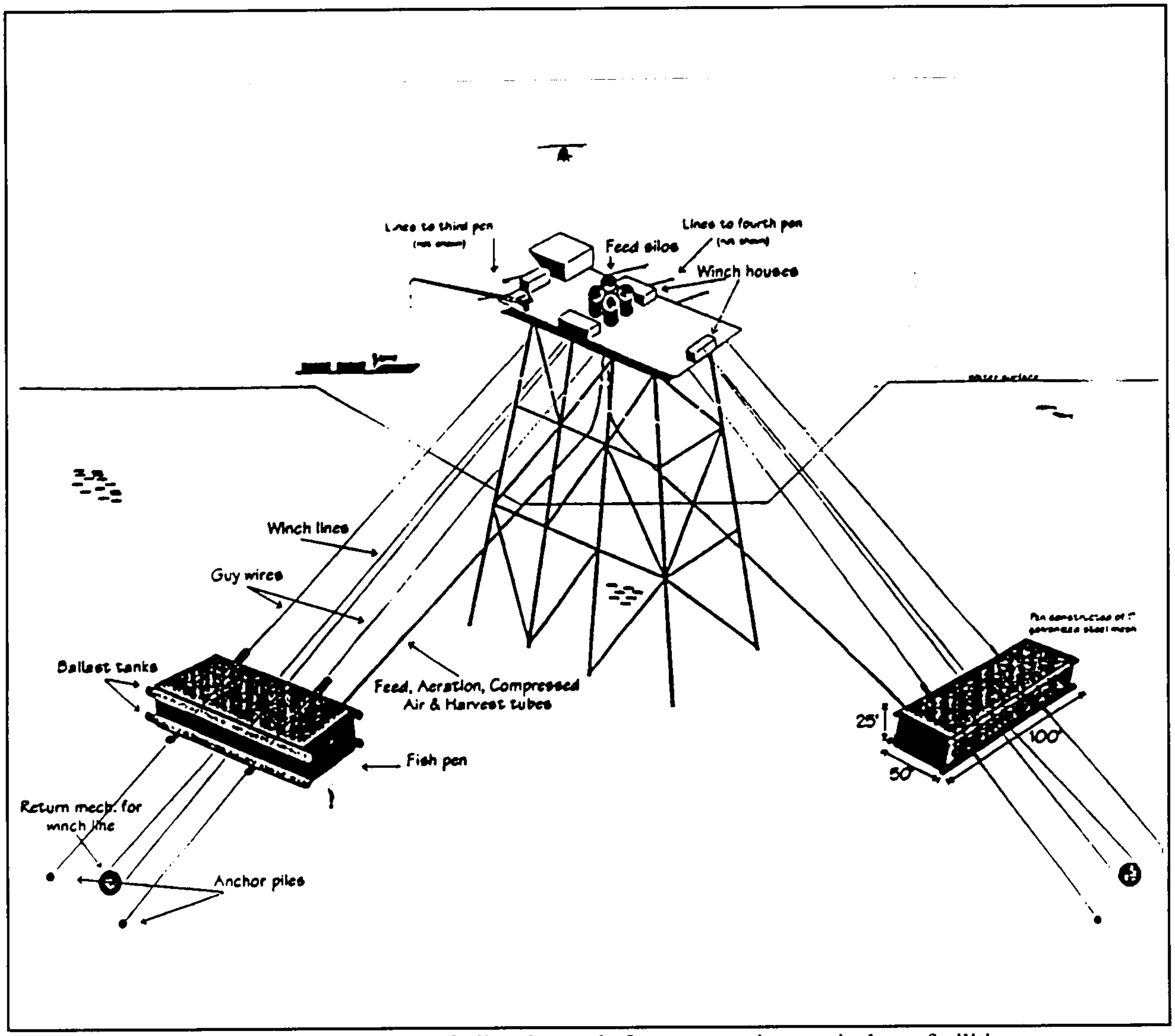

Figure 5B.1. Surface view rendition of oil and gas platform supporting mariculture facilities.

expand the pompano market because of its limited natural supply.

The concept of utilizing offshore oil and gas production platforms for mariculture purposes is not new. It is only now, however, that the environmental, economic, and biotechnological components are coming together to facilitate this industry. The development of this proposed relationship provides a catalyst for a critical evolution in the way natural and man-made resources are utilized, as even the most bountiful of resources are finite.

Watermark envisions rapid horizontal expansion to a number of platform facilities, followed by vertical integration of several of the component services and products involved in mariculture. With as many as 3,800 platforms in the Gulf of Mexico, there is the potential for the company to obtain a substantial number of producing platforms that will serve as mariculture facilities. As Watermark expands, it will also eventually be able to minimize the Company's dependence on commercial purveyors of feed products and processing facilities. This will result in enhanced profitability by incorporating value-added processing at all levels of production as well as through cost reduction.

Oil and gas platforms provide an excellent environment in which to grow enormous quantities of

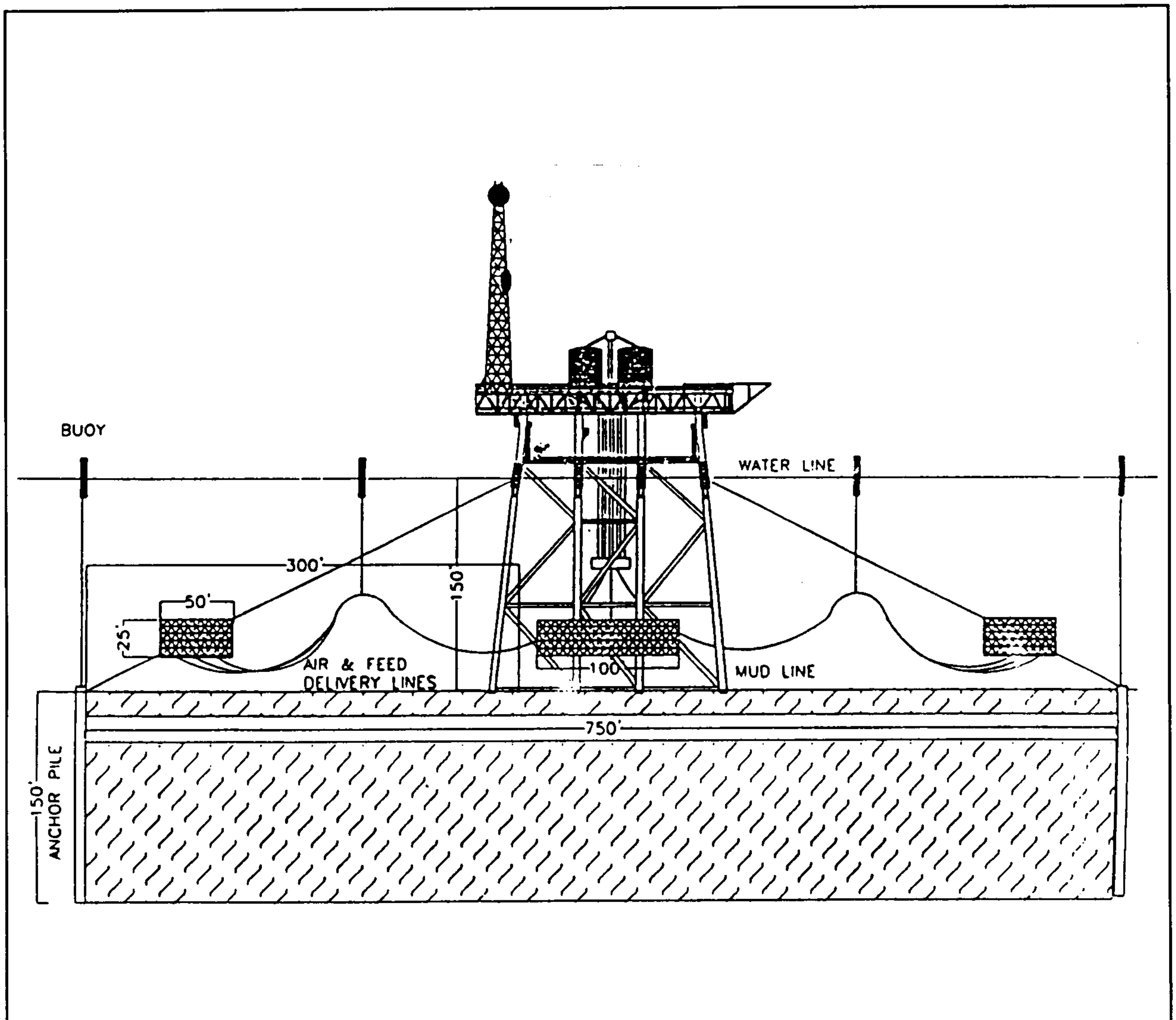

Figure 5B.2. Vertical cross-section rendition of oil and gas platform supporting mariculture facilities that shows the radial dimensions of the complex.

high-value fish and shellfish worth many millions of dollars. The possibilities for growth and profits for Watermark through combining the business of oil and gas production with the business of mariculture are extensive, and Watermark has assembled the right management team with the expertise to get the job done.

HIGH SEAS MARICULTURE

Mr. Michael C. Kacergis
Maryland Shrimp Company Inc.

To most people the word aquaculture is either a foreign term or it invokes images of cutting edge technology and exotic gadgetry for rearing shellfish and finfish. While many believe that aquaculture is a new industry, the reality is that aquaculture dates back to the ancient Romans in the West and the Chinese in the East. Today, worldwide efforts in aquaculture, especially mariculture or marine aquaculture, are expanding as traditional fishery stocks dwindle or collapse.

The U.S. fishing industry is experiencing difficult times, as indicated by these headlines that paint a picture of a recently-unfolding crisis:

Baltimore Sun: "Over Fishing Has Nearly Depleted World's Oceans"
Boston Globe: "Fish: Greed, Pollution, Development Take Toll"
Buffalo News: "The Worldwide Fishing Crisis"
National Fisherman: "Disaster Relief Funding Sought To Keep Northeast Fishermen Afloat"
The Economist: "The Tragedy Of The Oceans" (a possible allusion to G. Hardin's 1968 article, The Tragedy of the Common, Science 162:1243-1248.)

In reality the decline of ground fish populations has been seen over many years. Georges Banks has experienced one remarkable shift in species biomass. Traditionally cod, haddock, and yellow tail flounder dominated this rich fishing ground. Today dogfish (shark) and skate account for 75% of the catch by weight (U.S. Department of Commerce 1992).

In 1988, the United Nations Food and Agricultural Organization (FAO) reported that the world fish production accounted for approximately 98 million metric tons. This figure includes 14 million metric tons from aquacultural production (FAO 1991). According to dollar value statistics from the FAO, as of 1992 the United States ranked as the world's second largest importer of fishery products. Japan ranked first in fish imports. In 1993 U.S. imports of fishery products reached a record $10.6 billion while our exports of fishery products accounted for only $6.9 billion. This resulted in a trade deficit of $3.7 billion (U.S. Department of Commerce, 1994).

In general, the U.S. fishing industry appears plagued by catch reductions and closures due to diminished fish populations. Some examples include the west coast herring roe fishery now reduced from its historical significance to a season lasting all of 42 minutes. The Alaskan halibut fishery is shifting from last year's pair of 24-hour "derbies" to a system of Individual Transferable Quotas (ITQs). (For an overview of ITQs, see D. Shaw. 1994. Halibut: Understanding ITQs: When youy buy, what you'll pay. In Seafood Leader, Vol. 14, pp. 106-114.) For the second time in 28 years Alaska is closing the Bristol Bay king crab fishery. On the east coast the New England Fishery Commission is proposing sweeping closures on Georges Bank to allow haddock stocks to regain strength. And in Gulf of Mexico waters, Florida just passed a referendum that essentially bans nets larger than 500 square feet of mesh from state waters.

There are several measures that may ease fishing pressure and allow fish populations to regain strength. The implementation of bans and area closures represent the harshest restrictions to be endured by the fishing community. Individual transferable quotas, limited entry, area licensing, and sole ownership (Edwards *et al.* 1993) are additional measures that may aid in the recovery of fish populations. Mariculture, a truly renewable industry represents an alternative that would help mitigate heavy fishing pressures currently exerted on our living marine resources. By producing sufficient quantities of domesticated fish species, we would reduce our dependence on natural stocks, allowing them to regain historical levels.

Mariculture would also provide a means to reduce our dependence on imported fishery products. In 1988 seafood product imports accounted for more than 25% of the dollar value of all food and live animal imports combined. The imported seafood products total for 1988, $5.3 billion, was slightly greater than the total imports of meat products and live animals, $5.2 billion (National Research Council 1992). In light of our dependence on imported seafood, the 1994 $3.7 billion deficit, and declining fish populations, it would be prudent to explore the possibilities of large scale mariculture.

In the Gulf of Mexico there exists a unique opportunity to link the oil and gas industries with mariculture operations. The petroleum industry on the Outer Continental Shelf (OCS) began in 1947 when the first well was drilled beyond the sight of land (Emmer *et al.* 1992). Since then the industry has experienced many lucrative years but today it finds itself in an economic slump. A new trend has recently appeared in the OCS where the petroleum industry began removing more production platforms than they were installing. (See Figure 5B.3 for

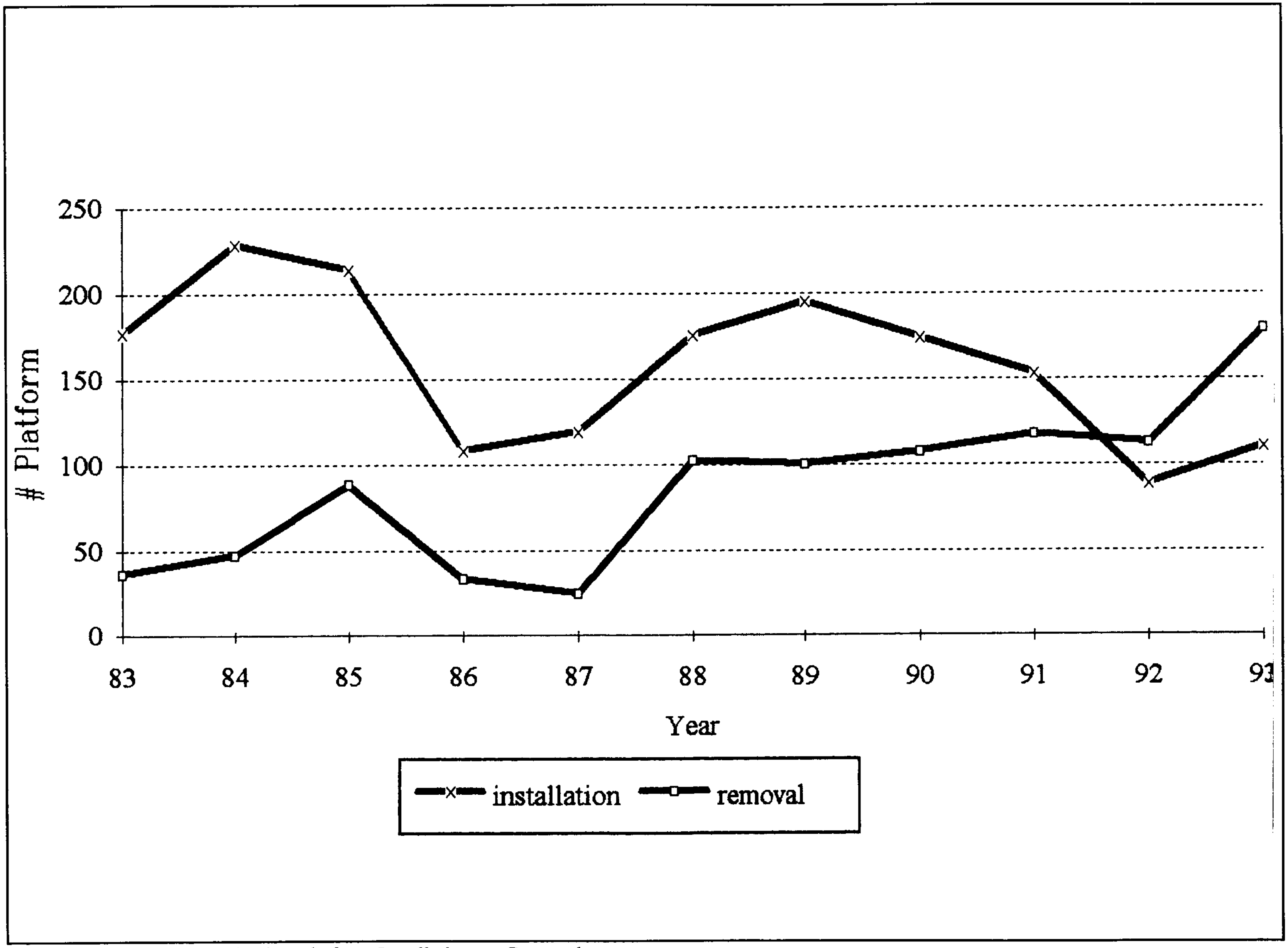

Figure 5B.3. OCS Production Platform Installation vs. Removal.

additional detail.) Since 1987 and 1993 the number of platforms being removed jumped from 24 to 179 respectively. This accounts for an 87% increase in platform removals over only six years (U.S. Department of the Interior 1994). These platforms, which have reached the end of their effective design life are viewed as a liability and not a valuable resource. The largest aspect of the liability is presumably the considerable cost of platform removal. One should note that many of these platforms are situated in waters highly suitable for raising a wide variety of marine finfish and shellfish. As each platform is removed, a potential opportunity to establish a mariculture site in the OCS is lost.

Maryland Shrimp Company (MSC) feels that mariculture can intervene in several ways, providing financial incentives for both platform owners and for the Minerals Management Service. Platform owners will benefit from the additional revenue stream generated by a percentage of the sales of fish. This new revenue stream, which could effectively cover the debt service on the platform could transform a marginally producing platform into a profitable platform. A non-producing platform scheduled for removal would remain on station. This would postpone the costly removal and greatly increase the design life of the platform. Under MSC's program the platform would now serve as a support structure for mariculture operations whereby one platform will be associated with one netpen. Platforms or "Offshore Mariculture Infrastructure Stations" can now serve as housing for netpen attendants, storage for feed, and a site for energy generation required for the daily operation of the netpen. MMS would benefit from a royalty based on a percentage of the fish sales. Maryland Shrimp Company views the role of MMS in OCS mariculture as that of lead agency in regulatory oversight. MMS already regulates gas and oil operations in the Gulf of Mexico and has in place the necessary infrastructure to fill the position of lead agency. This infrastructure includes support systems, transportation, and the generation of data for the Gulf of Mexico.

Netpens will not be attached directly to the platform for both engineering and safety considerations. The only direct connection between the netpen and the platform will be an umbilical that will provide power to both the winching system and surface lighting. In the event of catastrophic failure of the netpen the umbilical will have a breakaway connection, thus allowing the netpen to settle to the bottom and not affecting the structural integrity of the platform. The netpens are designed to allow remote adjustment of their height in the water column. This will permit netpen attendants on site to raise or lower the pen in varying weather conditions.

Maryland Shrimp Company plans to raise a range of economically important finfish species. These species include:

Tuna	(*Thunnus sp.*)
Mahi-mahi	(*Coryphaena sp.*)
Red drum	(*Sciaenops ocellatus*)
Snapper	(*Lutanus sp.*)
Grouper	(*Epinephelus sp., Mycteroperca sp.*)
Tilapia	(*Tilapia sp.*)

All species above were chosen for a variety of reasons. Economically, species appeal as a "white table cloth item" (a term used to describe high value, high priced items in the restaurant trade) implies high economic value on the retail market. This factor alone makes a species highly attractive for domestication. In the case of blue fin tuna, wholesale export prices can command as much as $35.00 per pound. Growth rates and ease in spawning are other important considerations in the choice of a fish species targeted for domestication. Mahi mahi demonstrate high fecundity (many eggs from a single spawn) and tremendous growth rates in captivity where a 1.3 kg fish can be raised from the egg stage in approximately 130 days (Hagwood *et al.* 1981; Kraul 1993).

Even though tilapia is a fine fish for human consumption, this species was chosen for several additional reasons. First, certain species of tilapia are filter feeders which means all their nutritional requirements can be derived from the surrounding water. This significantly reduces the quantity of food required to rear them. Full strength sea water is known to inhibit the spawning of tilapia. Even though there are reproducing populations of tilapia in the coastal brackish waters of Florida, Louisiana, and Texas, we are not aware of any reports of tilapia caught in deep waters of the OCS. In the event of escape, it is unlikely a tilapia would survive long. This species of fish is suited to the relatively shallow protected waters of rivers, ponds or estuaries. Their morphology allows the fish only short bursts of speed which will make them easy prey for the streamlined pelagic predators which roam the Gulf of Mexico. Tilapia will provide both a protein source as feed required by the species of higher economic value as well as high quality white fish fillets for human consumption.

There are several benefits the mariculture industry has to offer. One of the more obvious benefits is the creation of jobs in economically troubled regions. Many positions would be created including netpen attendants, fish processing, and transportation. Maryland Shrimp Company has a standing policy to set starting wages at $11 per hour. Unlike the traditional fisheries, mariculture is a truly renewable industry. Entire generations of fish are reared from larvae to adulthood supplied by eggs of captive brood stock. Another benefit is that fish farming offers relief from the heavy fishing pressures exerted on many fish populations. Markets can be supplied with farmed fish, thus reducing the dependence of wild stocks. Mariculture can also directly replenish depleted populations through a program of stock enhancement. Large quantities of larvae and juvenile fish can be released into specific areas where populations once flourished in the hope that a small percentage will survive to the age of reproduction. Last, unlike traditional fish harvest methods, there is no bycatch associated with mariculture. (Bycatch or incidental-catch is the taking of non-target species. Bycatch is usually discarded into the sea dead.) For a worst case scenario one need only examine the global shrimp industry's bycatch records to view discard rates as high as 1,100% (Warren 1994).

Mariculture in federal waters has its share of difficulties, the largest being regulatory ambiguity specific to ownership of fish within a netpen. For example, the Magnuson Fishery Conservation and Management Act, does not mention aquaculture or mariculture within its text. It does state however, ". . . the United States claims . . . sovereign rights and exclusive management authority over all fish, and all Continental Shelf fishery resources, within the exclusive economic zone." (For additional information, see Magnuson Fishery Conservation and Management Act, section 101.00-627(a).) This gives ownership of fish within a netpen to the Federal Government and eliminates private ownership. The Canadian Aquaculture Act (ascended to 8 December 1988) on the other hand states in section 16(5),

> "All aquacultural produce of the species and strains specified in the aquaculture license, while constrained within the boundaries of the aquaculture site, are the exclusive personal property of the licensee until sold, transferred, or otherwise disposed of by the licensee."

For mariculture to exist in the OCS there must be a legal provision that specifies private ownership to fish within the netpen. Without such a provision, there is little incentive for private industry to invest under such financially risky circumstances.

The oil and gas industry in the Gulf of Mexico's OCS is experiencing a dramatic shift toward increased production platform removals. These platforms should be considered a valuable asset rather than a financial liability. Mariculture offers a renewable industry and alternative revenue stream to the platform owner. By creating an industry in the OCS, mariculture will offer many jobs to communities burdened by high unemployment rates. Mariculture represents a viable alternative to the traditional methods of harvesting marine fish products. Finally, mariculture has the potential to satisfy many of the United States' seafood needs and offers relief to our increasing seafood import deficit.

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OPEN OCEAN MARICULTURE AND THE SIGNIFICANCE OF PETROLEUM STRUCTURES TO FISHERIES

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Discourse begins by introducing an open ocean mariculture concept and then moves on to address two case studies that examine the significance of petroleum structures to the regional fisheries. The mariculture idea, called Hydro Wheel (Figure 5B.4), is to submerge and organize several petroleum structures as artificial reefs inside a planning area. Then process fish above the reef configurations, sending the discards down to the reef fish.

For example, if a trawler came up and unloaded his catch at the processor, the usable portion of the harvest would be channeled to the market and the discards would be sent down to the reef fish. His by-catch would be reduced to 1%, everything would go to the market or be utilized to feed the reef fish below. Commercial and recreational hook and liners would catch fish above the reefs.

More importantly, the fishermen will be doing the work for the fish. Most of his catch will be diffused through a pipe system distributing about 2,000 lbs. of fish offal a day. His trawls, his haul, his diesel engine, will help find the next meal for the fish. Much as in agriculture, where yield can be related to the input of subsidiary energy, i.e. machine, fertilizers, irrigation. Hydro Wheel production will be relative to the amount of food and habitat invested. The proposed system can be a platform for a succession of fisheries management strategies, including crab culture, lobster farming, brooding and stocking, etc. Fishermen will be transferred from predator methods to agrarian methods, lifted from one groove to be set in another.

REEF HABITAT, RED SNAPPER, AND PETROLEUM STRUCTURES: CASE STUDY

The Louisiana continental shelf is home to over 3,000 oil and gas platforms. The base of a platform, called a jacket, forms a profile against ocean currents. Attaching organisms, including hermatypic coral and octocoral, colonize the substrate up and down the steel structures. The 3,000 oil and gas platforms peppered across the shelf constitute 90% of the reef habitat offshore of Louisiana (Scarborough-Bull 1987). Otherwise, there would be virtually no reef habitat. Sedimentation from the Mississippi and the Atchafalaya smothers any natural reef development until a thin archipelago of coral reefs, about 100 miles seaward from the coast (Figure 5B.5).

As the wells dry up, the structures are removed. Every year over 300 acres[3] of high-profile substrate disappears off the continental shelf (MMS platform

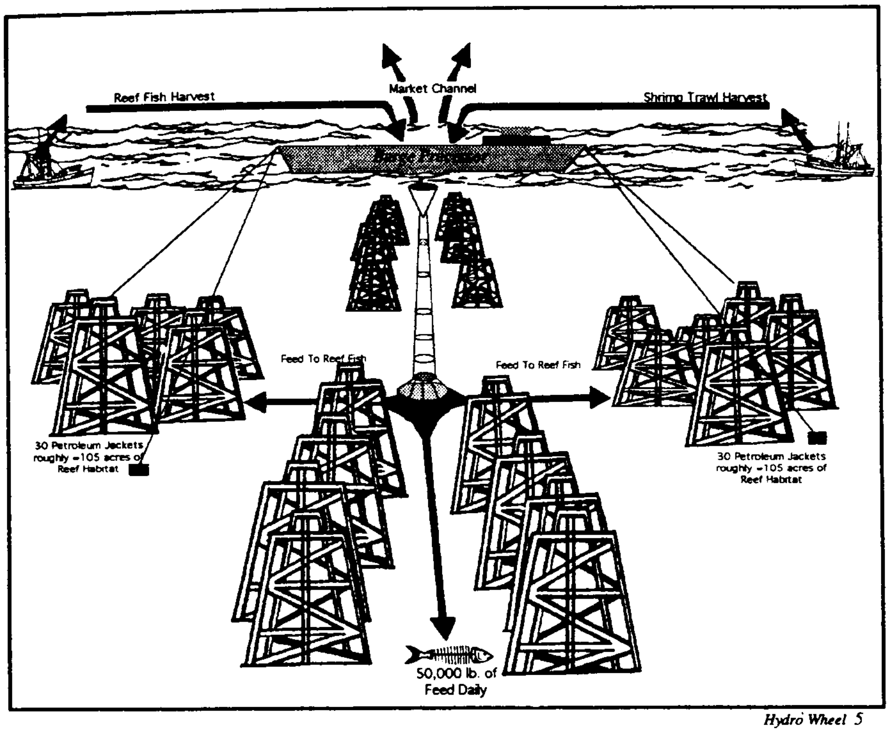

Figure 5B.4 Hydro Wheel concept.

removal schedule 1994). To reef fish such as red snapper, the ferrous profile of an oil and gas platform provides the same functions as the calcium profile of natural coral. They form grazing areas, respite from the current, nursery grounds, and protection from predators. They accommodate feeding mechanisms for numerous species at every trophic level.

Due to their hydraulic morphology, artificial reefs have a much higher (10-15 times) carrying capacity than natural reefs. So the removal of petroleum structures, estimated to be 90% of the reef habitat along the Louisiana continental shelf, may be more significant than the figure above suggest (Figure 5B.6)

Authorities are campaigning for the mandatory use of a Bycatch Reduction Device (BRDs) to protect red snapper from incidental catch by shrimp trawlers. Contrary to popular opinion, the BRDs are not being implemented to protect finfish in general; they will be required to protect red snapper. Ground fish are only being harvested at about 50% of their optimum yield (NMFS 1981).

Red snapper exhibit such a strong fidelity to structure, the developers of BRDs have encountered trouble designing a device that works. Red snapper have been observed to refuse to swim out of a net equipped with a cumbersome BRD (Atrand 1994). In another report, by-catch reduction devices where used on one side of a vessel and a normal net on the other. Researchers found that the nets without a BRD consistently had zero or very few snapper mortalities while the nets equipped with a BRD consistently contained larger snapper mortalities (Lirette 1994). This suggests that snapper are structure oriented.

Most of the red snapper habitat ranges west of the Mississippi right where oil and gas structures compose the majority of reef habitat. If the bulk of the reef habitat disappears, the red snapper populations will decrease proportionally. There are approximately 18,000 licensed commercial shrimp operators in Louisiana alone (LDWF 1989). The BRDs will be enforced upon all the shrimpers in the Gulf of Mexico. Thousands of fishery jobs are in jeopardy due to the declining populations of red snapper.

JAPANESE ARTIFICIAL REEFS AND PETROLEUM JACKETS

Japan has experienced amazing success with their artificial reef program. They have invested $7 billion in their coastal program so far and continue to reinvest year after year (Nagahata 1991). Their aim is self reliance, to transform a national fleet that once pursued fish in distant seas to one that harvests fish in Japanese coastal waters.

Their materials are usually reinforced cement blocks, and they are only about 2 by 2 meters, though some modules reach 10 meters in height (Sonue and Grove 1985). Although they sometimes try other configurations, generally they drop cement blocks and pile them on top of each other (Figure 5B.7). So the end result is not, by any means, as highly developed an engineering design as petroleum structures.

The cost of Japanese installations vary from $60,000 to $16,300,000 (Nagahata 1991). An eight-tier petroleum jacket from a 120-foot depth composes

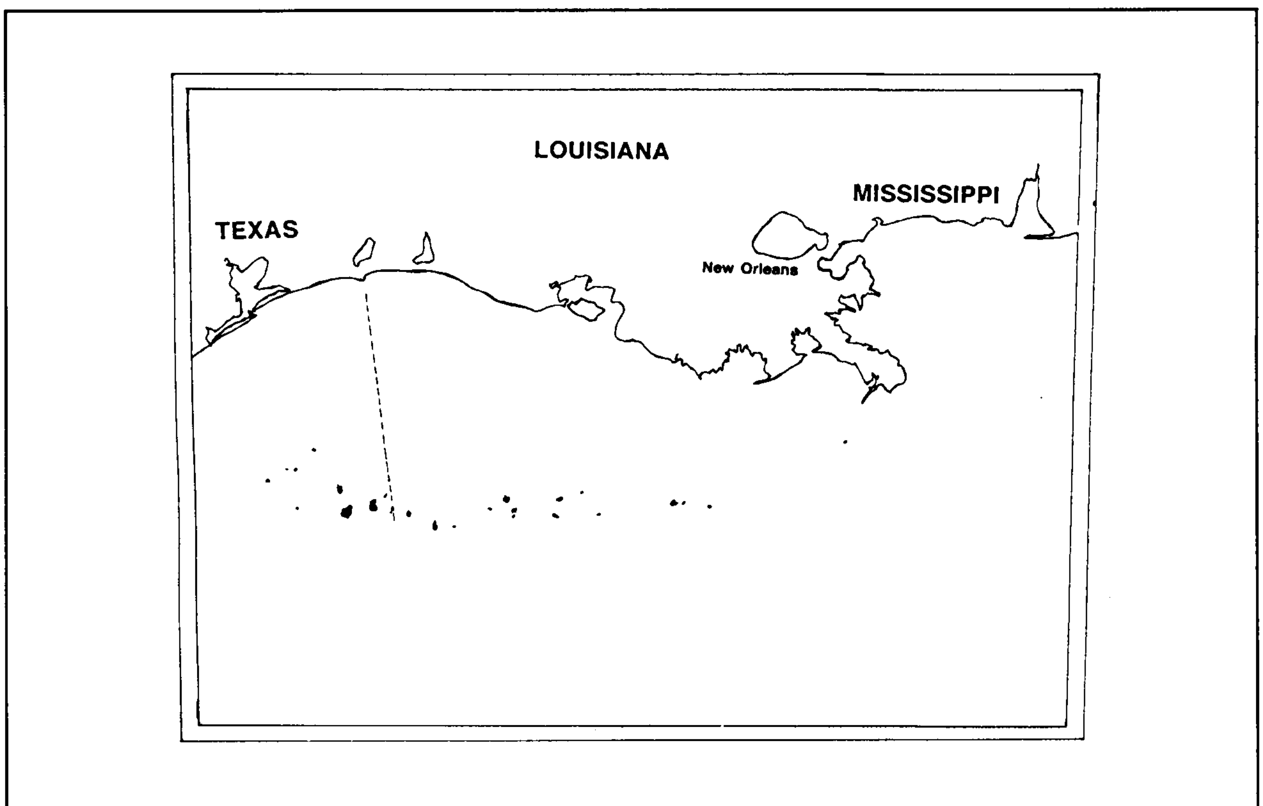

Figure 5B.5. Tributary sedimentation prevents any natural reef development until a thin archipelago of reefs.

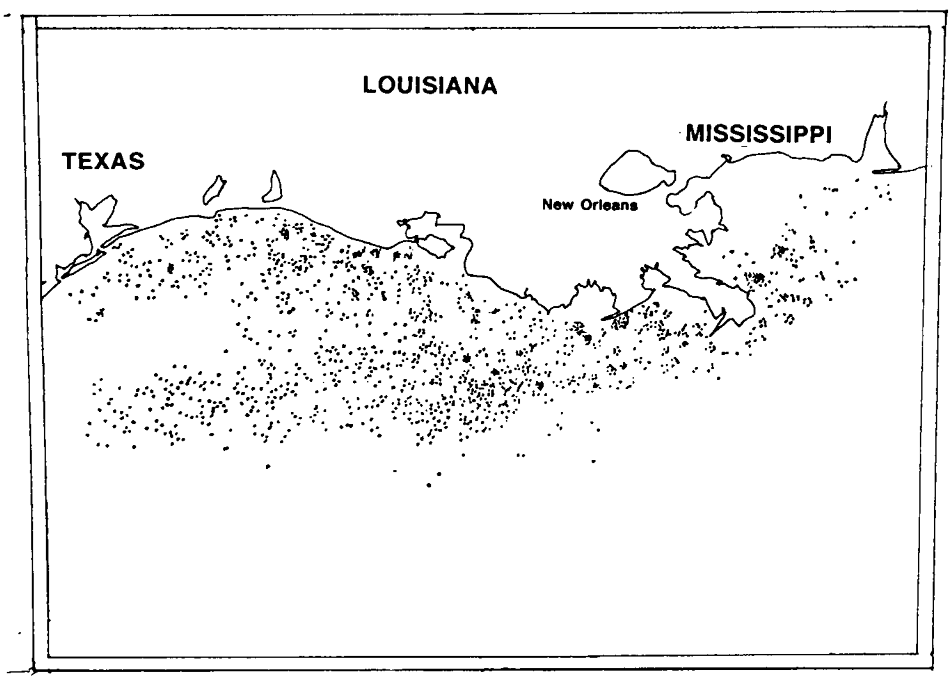

Figure 5B.6. Petroleum structures constitute 90% of the reef habitat along the Louisiana continental shelf.

93,000 m^3 of volume with a footprint of 3,900 $meters^2$ encompassing 3.5 $acres^3$ of substrate surface (Quigel and Thorton 1987) (Figure 5B.8). A comparable Japanese cement reef of that size would cost $10,000,000 to build and install.

Bonsack and Sutherland (1985) showed that Japanese artificial reefs offset their investment dollar in one year. If they spent $10 million to build and install 93,000 m3 of reef habitat, the fishermen would catch $10 million worth of fish over the reef every year. They would spend about $45 billion on cement modules to build the equivalent amount of reef habitat presently available in our petroleum jackets.

CONCLUSION

Man and marine life would mutually benefit by leaving the oil and gas structures in the water, particularly when you consider Japan has spent $7 billion installing artificial reefs and our oil and gas companies will spend over $7 billion to remove them all (Reggio 1989). The obsolete oil and gas platforms could help develop a new fishery approach that eliminates waste and transforms fishermen from predator methods to agrarian methods. It is crucial that parallels be drawn between snapper populations and petroleum structures as well as natural reef habitats and the ferrous profiles supporting the platforms. They constitute 90% of the reef habitat along the Louisiana continental shelf. Over three hundred $acres^3$ are being destroyed every year.

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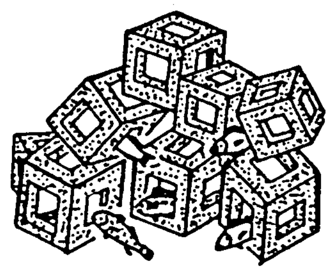

Figure 5B.7. Japanese artificial reefs.

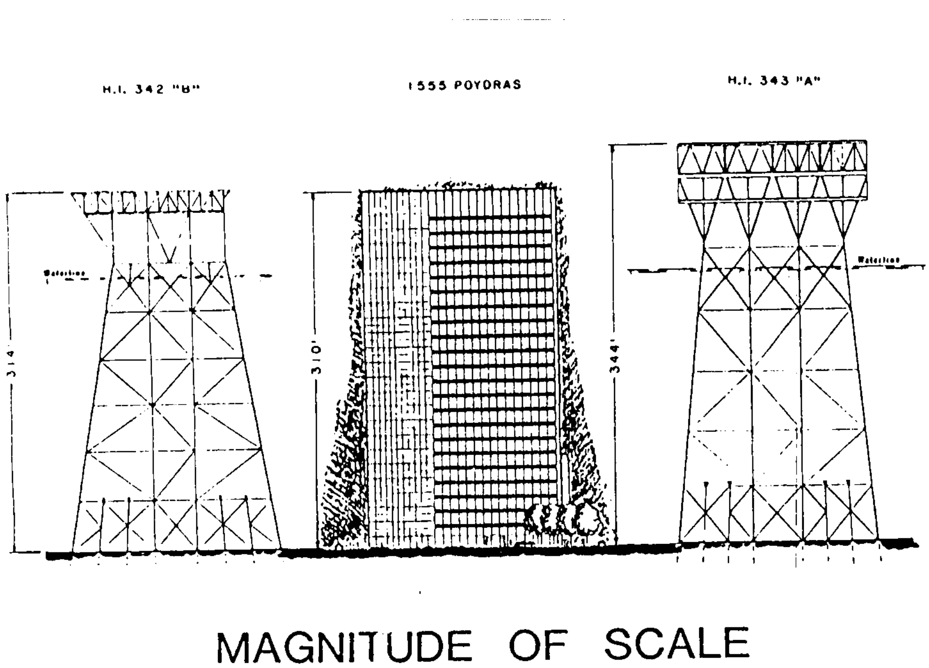

Figure 5B.8. Petroleum platform.

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Mr. Steve Kolian grew up commercial fishing in the Gulf of Mexico from Brownsville to the Dry Tortugas with several years' experience in both the trawling and reef fishery. Mr. Kolian also worked on the railroad on lines across the Canadian Provinces and the U.S. Rockies as a gandy dancer and as part of a section gang. He received his B.A. from Augsburg College and MSPH in Environmental Water Quality at Tulane University.

SESSION 5C

SUBSALT EFFORTS ON THE OUTER CONTINENTAL SHELF

Session: 5C - SUBSALT EFFORTS ON THE OUTER CONTINENTAL SHELF

Co-Chairs: Mr. Jesse Hunt and Mr. Gary Rutherford

Date: November 17, 1994

Presentation	Author/Affiliation
Subsalt Efforts on the Outer Continental Shelf	Mr. Jesse Hunt U.S. Minerals Management Service Gulf of Mexico OCS Region
No manuscript submitted	Dr. Bruno Vandeville University of Texas Bureau of Economic Geology
Uncovering a New Play with Advanced Technologies	Mr. Dick Standaert Oryx Energy
Subsalt Imaging over the Mahogany Salt Sill	Mr. Davis W. Ratcliff Mr. David J. Weber Diamond Geophysical Service Corporation
Mahogany Subsalt Prospect	Mr. Tim A. Wallace Phillips Petroleum
Present and Future Subsalt Exploration	Mr. Kenneth Nadolny Mr. Stefan Rutkowski Mr. Clint Moore Anadarko Petroleum

SUBSALT EFFORTS ON THE OUTER CONTINENTAL SHELF

Mr. Jesse Hunt
U.S. Minerals Management Service
Gulf of Mexico OCS Region

INTRODUCTION

Since the first offshore well in the Gulf of Mexico was drilled using an onshore rig on a wooden platform in the 1940's, hydrocarbon exploration has advanced based on "hot new plays." These plays identified and drilled through the advancement of drilling, seismic and computer technology.

In the early years, with crude seismic technology and very little processing available, only the major salt domes and growth faults were targeted. As seismic technology and processing advanced, "bright spots" as hydrocarbon indicators became the hot new play. The next "hot new play" became the flexure trend along the continental shelf-slope break. With advances in drilling technology, the deep water areas of the Gulf of Mexico were the "hot new play" of the late 1970s and early 1980s, and are still active today. The latest "hot new play," made possible by major advances in computer technology to aid in processing, is potential reservoir quality sands found beneath horizontal sheets of salt.

For years, geophysicists have recognized the existence of large masses of salt beneath the outer continental shelf, but only with recent advances in computer technology and speed have they been able to image beneath the salt to map potential hydrocarbon trapping structures.

In keeping with the purpose of the ITM meetings to foster sharing of information on research, accomplishments and current industry activity and technologies, we felt it was appropriate to include industry subsalt efforts in this year's agenda.

UNCOVERING A NEW PLAY WITH ADVANCED TECHNOLOGIES

Mr. Dick Standaert
Oryx Energy

A new play with great potential is emerging within the Gulf of Mexico. Lying in water depths of 120 feet to more than 3,000 feet, the current subsalt play stretches across more than 36,000 square miles of the Western and Central Gulf of Mexico, with potential hydrocarbon-bearing sediments lying below horizontal salt layers up to 9,000 feet thick.

Since the early 1970s the concept of targetable geologic section in a subsalt position has been recognized because of data acquired in the more ultra-deepwater areas of the Gulf of Mexico OCS and the subsequent leasing activity there. Until recently, subsurface imaging of these sediments had been obscured in the shallower water areas of the Gulf of Mexico by the overlying salt layers, thus preventing any accurate examination of interpretation of the underlying sediments with traditional 2-D seismic data. However, with the development of improved acquisition methods and architectures (larger cable lengths), 3-D seismic processing technologies (*PSDM*), and the new generation of supercomputers, it is now possible to image more properly the sediments and structure below these salts.

But new and improved technologies bring higher costs, larger time requirements to process seismic surveys, and the need to find new steps to help reduce these time requirements and associated costs.

Success within the subsalt could have a significant impact on the Gulf of Mexico and companies actively exploring it. The play itself, although in its very early stages, lies within a mature basin, with a mature and developing infrastructure. Reserve potential, although not truly proven, can be thought of as significant and world class. This potential has been bolstered by the discovery of hydrocarbons trapped below tabular salt as seen in Exxon's Mississippi Canyon 211 well (1990) and more recently Phillips' Ship Shoal 349 discovery (1993) with estimated reserves of more than 100 NMBE.

Dick Standaert is the General Manager, Offshore U.S.A., for Oryx Energy. He has been in the oil industry for 20 years and with Oryx Energy for 13 years. He has a degree in geology from State University of New York.

SUBSALT IMAGING OVER THE MAHOGANY SALT SILL

Mr. Davis W. Ratcliff
Mr. David J. Weber
Diamond Geophysical Corporation

SUMMARY

Exploring for hydrocarbon below salt has been, and will continue to be, a high-risk/high-potential business endeavor. Recent subsalt discoveries have generated a tremendous interesting subsalt exploration, both in the Gulf of Mexico as well as in other basins around the world. The geophysical technology which has played the most significant role in the success of subsalt explorations is, by far, Depth Imaging. Depth imaging technology (poststack and prestack) has allowed explorationists to identify and map structural and stratigraphic features below salt that trap significant hydrocarbon accumulations.

In this paper, we discuss subsalt imaging strategies and technology applications (3-D Time and Depth Migration) that can assist the subsalt explorationist in prospect evaluation, risk assessment, well placement and field development, using the Mahogany Salt Sill Area as a calibration point. In addition to utilizing a specific "subsalt" acquisition geometry, the collective processing strategy will incorporate 2-D time imaging, 2-D poststack depth migration, 2-D prestack depth migration, side-line profiling, 3-D time imaging, 3-D poststack depth migration and "target oriented" 3-D prestack depth migration.

DISCUSSION

The Mahogany Salt Sill is an extensive salt mass that covers several offshore blocks in the Ship Shoal Area of the Gulf of Mexico. Figure 5C.1 shows a depth-migrated seismic section over the now-famous Mahogany Discovery. Notice the salt shape as well as the subsalt reflectivity and subsalt faulting. The salt body has been remobilized and has both salt sill and salt dome components, with thickness variations ranging from a few hundred feet to over 8,000 feet thick. This variation in salt shape and thickness creates difficult imaging problems below salt. An integrated time and depth migration strategy can be used to obtain high quality subsurface imaging around and beneath the salt structure.

Figure 5C.2 shows another example of a seismic line over the salt sill. It has been processed using conventional techniques. Figure 5C.3 shows the same seismic line processed using prestack depth migration technology. Notice the excellent image of the bottom of salt on the depth migrated data versus the poor base of salt on the conventional time image. Also notice the improved subsalt imaging on the depth-migrated section versus the highly distorted and chaotic image below salt on the conventional migration. The Conventional time imaging technology can be used to correctly image sediments and faulting above salt as well as the top of salt. The time imaging also provides velocity information above salt and is considered an initial building block for subsequent prestack depth migration work and velocity model building. The prestack depth migration is used to improve the base of salt and subsalt imaging once an accurate velocity model is generated.

The velocity model building procedure is the most time-consuming, interpretive and critical part of subsalt imaging. One essential tool that can be used to quality control the velocity model is a plot of the prestack depth migrated CDP gathers. Figure 5C.4 shows the depth-migrated gathers after several velocity iterations. Notice how the sediments above salt, top of salt and base of salt are nearly flat, indicating that an accurate velocity field was used. Also notice how the base of salt is present on all offsets ranging from 300 meters out to 6,000 meters. Acquisition of 3-D seismic data using long offsets (6,000m) have provided several geophysical benefits to the Mahogany Salt Sill area. The benefits include improved based of salt and subsalt imaging, improved prestack velocity analysis and better AVO analysis outboard of salt.

CONCLUSIONS

Exploration beneath the Mahogany Salt Sill has been, and will continue to be, a significant exploration

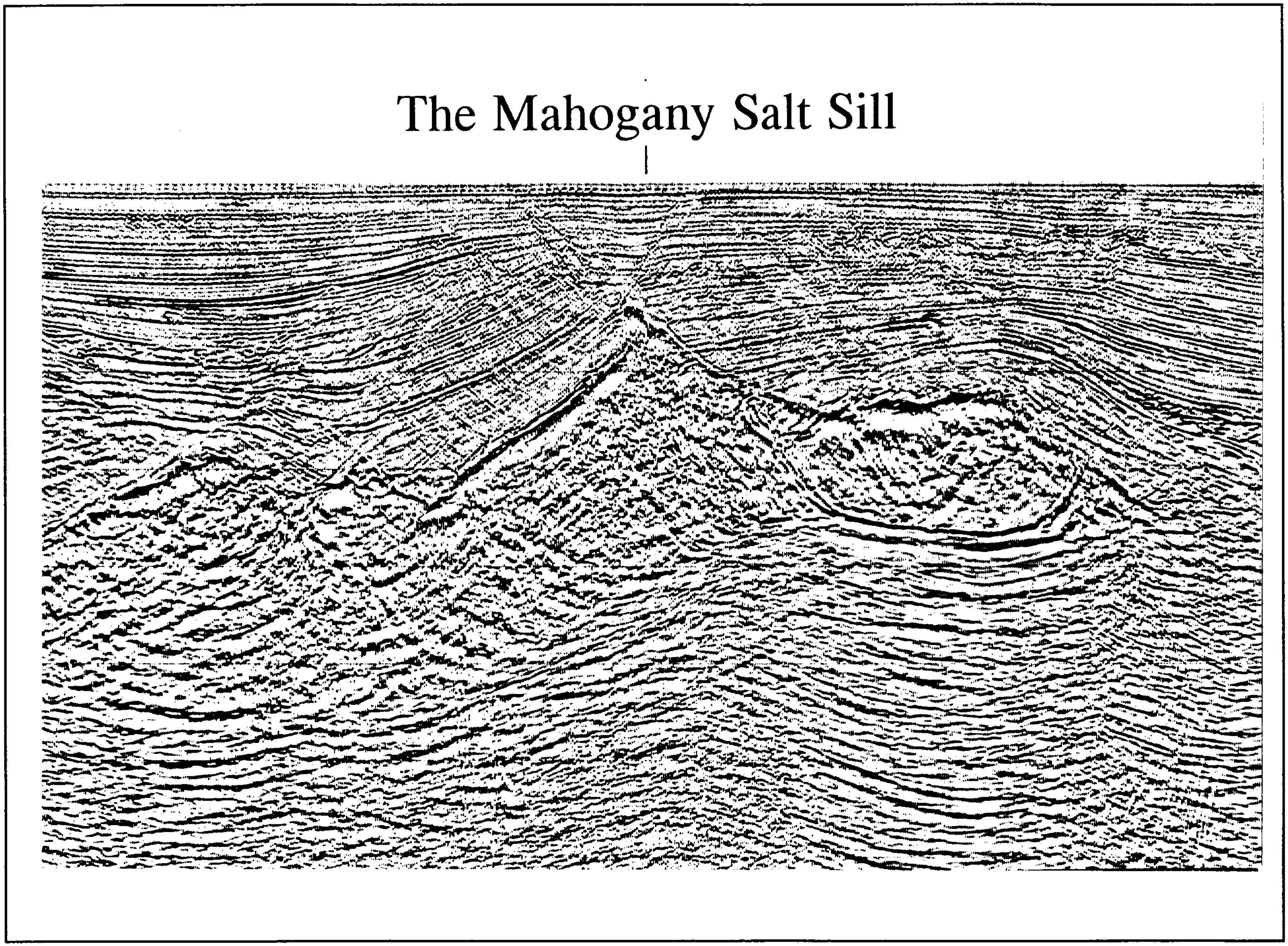

Figure 5C.1. Depth migrated data.

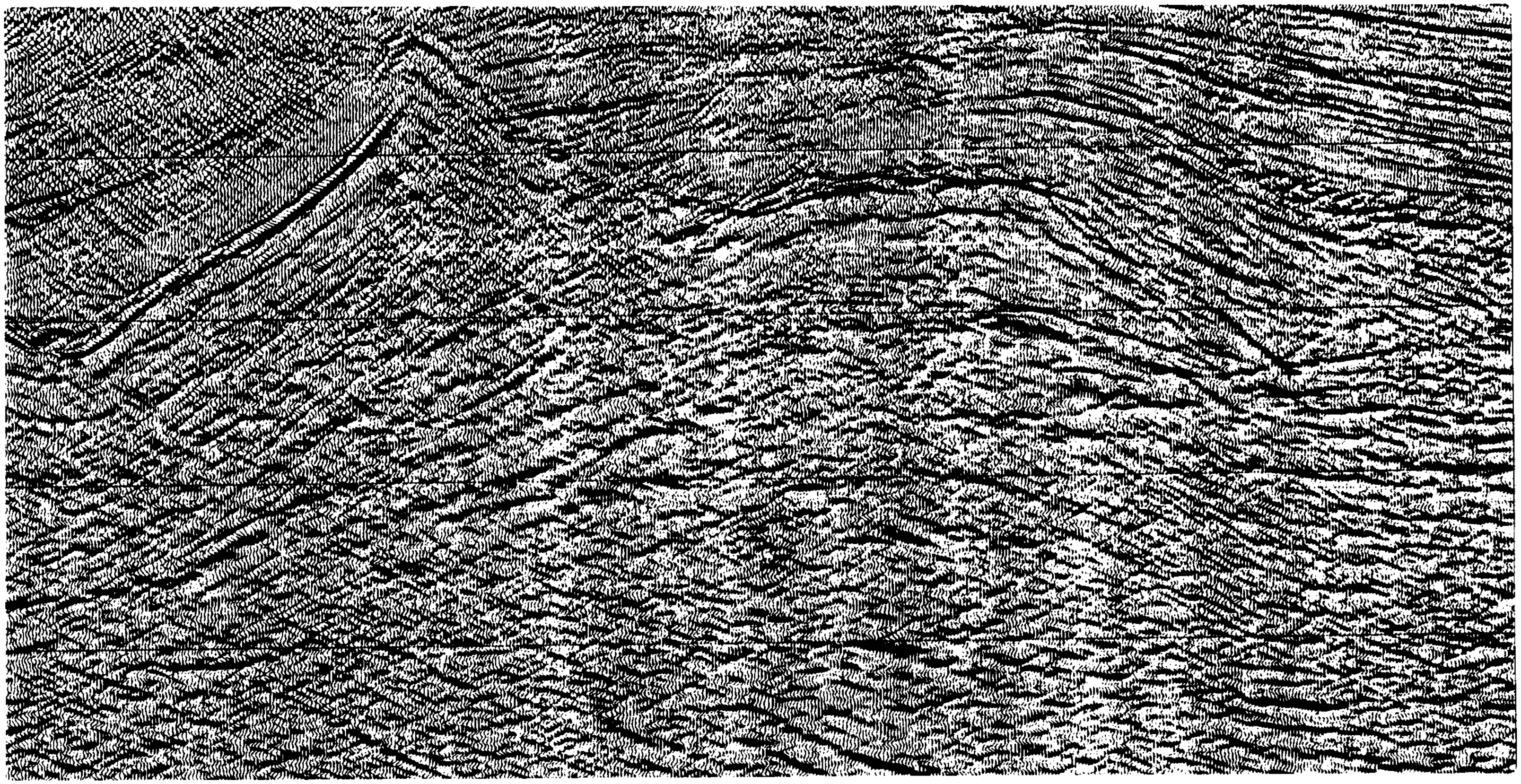

Figure 5C.2. Conventional migration.

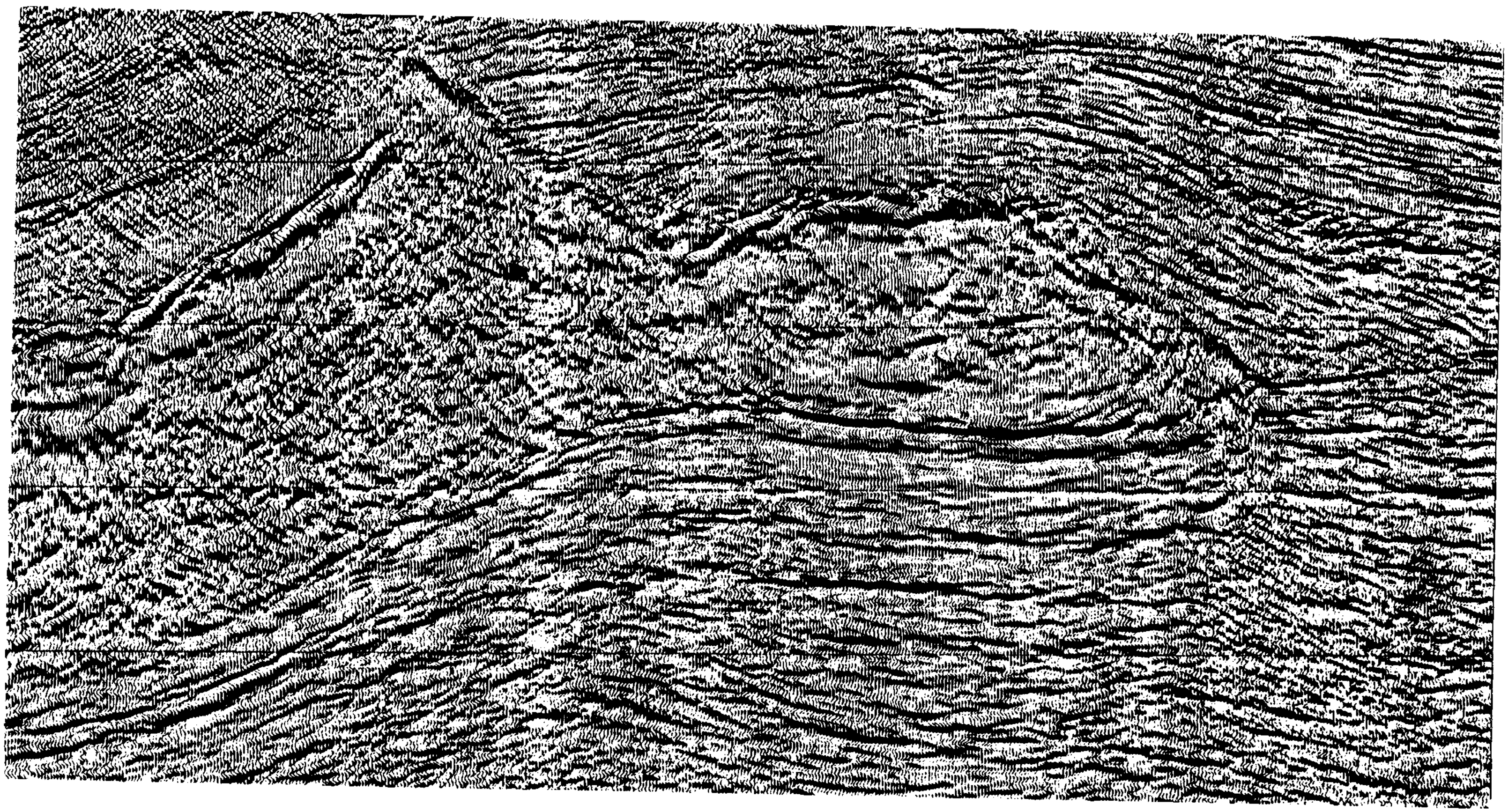

Figure 5C.3. Prestack depth migration.

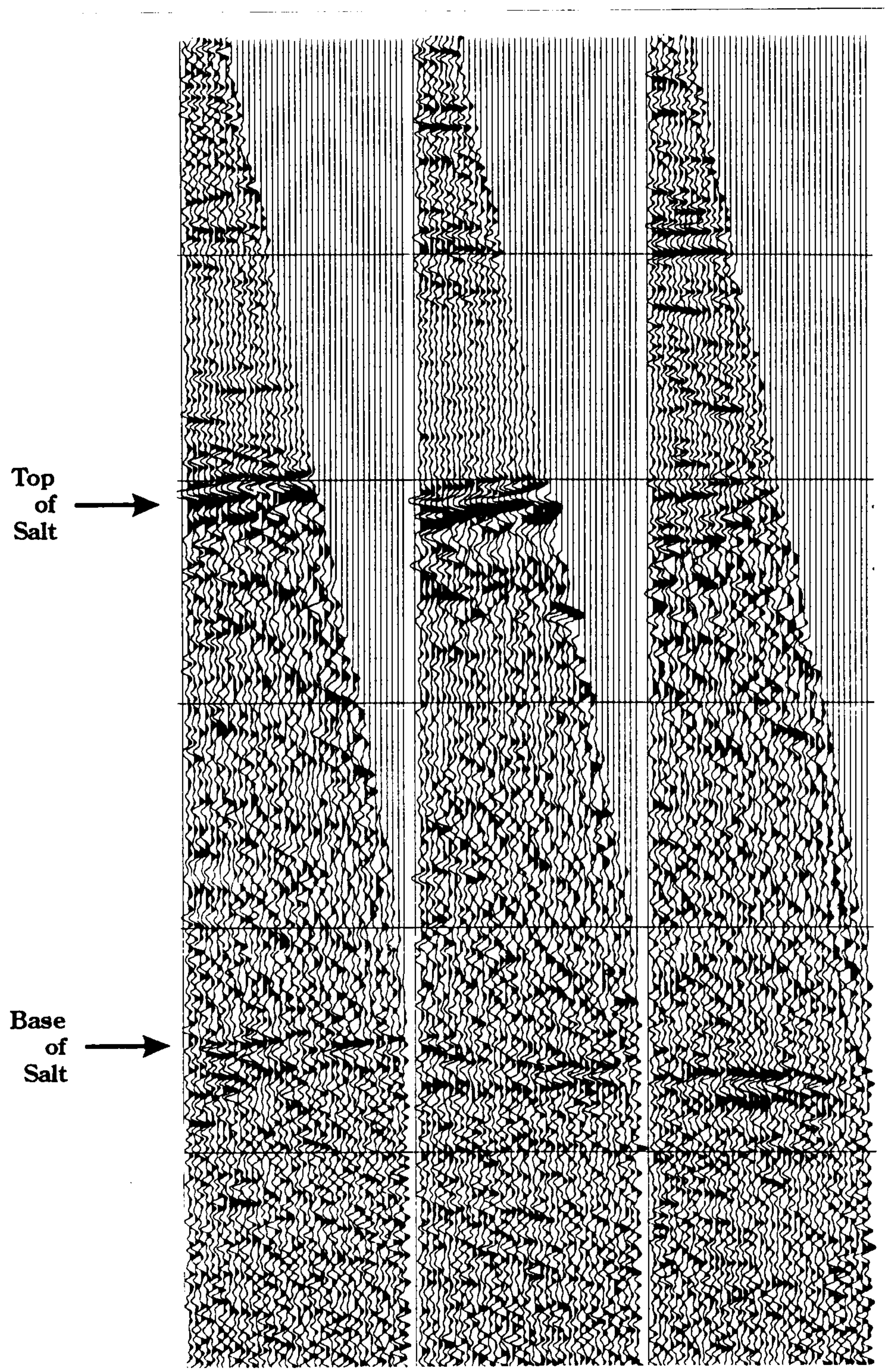

Figure 5C.4. Prestack depth migrated CDP gathers (offset range 300m - 6,000m).

strategy. The Mahogany Discovery has breathed new life into the Gulf of Mexico, with its resource estimates of 100-300 million barrels of oil. Depth migration technology has made a major impact in the subsalt exploration play. A well-planned imaging strategy, which includes 3-D prestack depth migration, can provide excellent structural and stratigraphic images below salt. The geophysical imaging techniques that were developed by research scientists years ago have given the industry the ability to once again increase profitability and reduce exploration risks in an area that was thought to be a "Dead Sea."

ACKNOWLEDGMENTS

The authors would like to thank PGS Tensor for their excellent 3-D time and 3-D depth imaging technology applications. Specifically, we thank Karen Chevis, Kurt Sellers, John Anderson and Kenny Lambert of PGS Tensor. Also, we would like to acknowledge PGS Exploration for their highly effective 3-D subsalt acquisition techniques which were used over the Mahogany Salt Sill 3-D Project.

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Mr. Davis W. Ratcliff is vice-president of Diamond Geophysical Service Corporation and president of the recently formed Diamond Geoscience Research Corporation. For the past 10 years Mr. Ratcliff has been involved in the geophysical imaging of complex salt structures. Before joining Diamond, he was the supervisor of geophysical technology for Amoco Production Company's U.S. and European exploration business unit. More recently, he has been named the 1994 recipient of the Society of Exploration Geophysicists' (SEG) distinguished Virgil Kauffman Gold Medal award for his contributions in 3-D structural imaging. He holds a B.S. in mathematics from the University of New Orleans.

MAHOGANY SUBSALT PROSPECT

Mr. Tim A. Wallace
Phillips Petroleum

The Gulf of Mexico is a world-class producing region. The offshore exploration industry was pioneered here starting as early as the late 1930s. In the past 50 years, the industry has successfully produced billions of barrels of oil and trillions of cubic feet of gas for the consumers of America. As the basin has matured as a petroleum province, the expectation of remaining reserves has declined. Many in the petroleum industry were ready to abandon the Gulf by 1990. Revenues generated from area wide leasing had been in decline. The deep water Gulf showed continued promise, but only for those who could manage the large expense and long lead time before production. For a number of companies, the exploration focus shifted to a new play called the subsalt play. The subsalt play had been theorized for several years; however, few were willing to take the risk of testing this theory at a cost of $12 million to $15 million per well. In 1993, a prospect dubbed Mahogany was drilled as a discovery below a salt layer of greater than 3,000 feet in thickness. The discovery, which is still in the appraisal stage, created a boom in activity. Geophysical contractors developed services targeted at subsalt exploration. OCS leasing expenditures more than tripled from the previous year. Two additional operators moved in rigs to drill below the Mahogany salt sheet on acreage adjacent to the discovery well. The possibility exists of a new play with large scale reserves in the middle of the most mature offshore basin in the world.

In the mid 1980s, seismic data quality had improved to the point that it was apparent not all salt was deeply rooted. There is a large area on the southern part of the Louisiana shelf, in fact, that is dominated by salt sheets that flowed down slope from salt dome feeder stocks. The industry began evaluating the possibility the sedimentary section below this salt could contain the necessary elements for commercial accumulations of hydrocarbons. Several geologic questions had to be addressed before the exploration play could move forward. What kind of reservoir conditions could be expected? What kind of drilling conditions could we expect in and below salt? How could we improve the quality of seismic data to reliably map the location of structures below the salt?

In the federal OCS Sale in the Central Gulf of Mexico in 1990, Phillips Petroleum Company leased Ship Shoal blocks 349 and 359 based on evidence that a relatively shallow base of salt was present. Mapping of the base of salt indicated a structure may be present on the lease, however data quality was still too poor to actually map the sedimentary section below salt. After acquisition of the lease, a recent technology development called post stack 3–D seismic depth migration was applied to a 3–D seismic data set acquired over the prospect which revealed mappable data below salt. Interpretation of the dataset showed a large structure, which if full of hydrocarbons would contain a very large field. The prospect was named Mahogany.

The discovery well drilled in 1993 by Phillips Petroleum Company, Anadarko Petroleum Corporation and Amoco drilled into salt at about 7,300 feet beneath the sea floor and exited salt over 3,000 feet deeper. The well, drilled to a total depth of 16,500 feet, tested at a rate of 7,256 barrels of oil per day and 7.3 million cubic feet of gas per day from a subsalt reservoir. The high flow rates on the well suggest a significant accumulation of hydrocarbons could be present. With information from the well, the seismic data was processed with the emerging technology 3–D Pre–Stack Depth Migration (PSDM). This processing revealed a clarity far beyond that of the data on which the prospect was originally leased, however, still inferior to the suprasalt data. The application of PSDM technology has become a critical step in the appraisal process to reduce drilling risk.

Early 1994, the Mahogany #2 appraisal well was spud and drilled as a deviated hole from the location of the discovery well. That well tested at a rate of 4,366 barrels of oil per day and 5.3 million cubic feet of gas per day from a separate zone than was tested by the original well. The appraisal well confirmed a continuity of sands and favorable reservoir conditions to allow for high production rates.

The Mahogany discovery proved that conditions can be present below the salt present in much of the Gulf of Mexico to maintain exploitable quantities of hydrocarbons. The find revealed a new play, with potential reserves of hundreds of millions of barrels of oil, in the middle of a mature basin that many were ready to abandon. The response of the industry has been to increase quickly monetary and human resources to the Gulf of Mexico subsalt exploration effort. At least 10 companies have participated in subsalt exploration wells since the Mahogany discovery. Five geophysical contractors are targeting their services towards subsalt exploration. At least two drilling contractors have advertised moving rigs into the Gulf in the hopes of securing long–term subsalt drilling contracts. The Mahogany discovery has had as great a short–term impact on the Gulf of Mexico exploration industry as any well in the history of Gulf of Mexico exploration. Only time will tell if that impact is warranted.

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PRESENT AND FUTURE SUBSALT EXPLORATION

Mr. Kenneth Nadolny
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Recent discoveries in the subsalt play have touched off a wave of excitement that has not been seen in recent years in the Gulf of Mexico. Oil and gas exploration in the Gulf of Mexico has always been influenced by salt and the structures formed by or hidden by salt. The original significant oil and gas discovery in the Gulf of Mexico basin (Spindletop) is related to a salt-formed structure. Over the years, both onshore and offshore oil and gas has been found around and under salt structures, primarily salt domes. Some of the oil and gas deposits were found by drilling beneath salt wings that protruded from the flanks of the salt dome, and some might say these were the first subsalt discoveries.

Salt acting as a fluid can be easily deformed into a wide variety of shapes. The shallow and deepwater areas of the Gulf of Mexico have examples that illustrate the types of structural styles that a salt mass can be deformed into. Salt movement can be characterized as having primarily vertical movement and primarily horizontal movement. The salt that is characterized by vertical movement results in the typical salt diapir. These domes are located primarily in the shallow water areas of Louisiana.

The deepwater areas of the Gulf of Mexico illustrate horizontal movement of the salt. The Sigsbee ridge in the deepwater Gulf of Mexico defines the southern limit of a major horizontal salt sill. As sediment is deposited over the salt sheet, small mini basins can be formed which will deform the underlying salt. As more sediment is deposited the salt becomes even more deformed.

Looking at a bathymetric map of the Sigsbee ridge we can see the edge of the ridge and the small mini basins that are being formed in the salt layer. Down dip from the edge of the ridge we see that we can see basin floor fans that are being deposited at the edge of the ridge.There have been 18 significant subsalt wells drilled in the Gulf of Mexico (Table 5C.1). Five wells have encountered significant amounts of hydrocarbons.

The subsalt play beneath allochthonous or horizontal salt sheets was apparently first developed by Gulf Oil in the early 1980s with two wells drilled in a subsalt section. The West Cameron 505 was the first well, as we know, to purposely drill a subsalt prospect beneath an allochthonous salt sheet. The Eugene Island 324, although not drilled through salt, tested a section analogous to a subsalt section.

One of the more significant wells was drilled in 1986 by Diamond Shamrock in South Marsh Island 200. This well penetrated a 1,000' salt interval, and then found a near 1,000' thick, high quality and good porosity sand.

The Mississippi Canyon 211 drilled by Exxon in 1990 encountered oil and gas bearing sands beneath a salt sheet in deep water. The first significant shallow water well was the Ship Shoal 349 #1 Mahogany discovery drilled by Phillips in 1993. This well was followed by the Teak discovery in 1994 and a second, confirmation well in Mahogany.

The latest subsalt discovery was recently announced by Shell and Amerada Hess in Garden Banks 128. This well reportedly did not actually drill through salt, but rather drilled under the edge of a sill. This would be the fourth oil and gas discovery on a subsalt prospect in the Gulf of Mexico. Fifteen wells have been drilled for subsalt prospects since 1987 with four discoveries and one prospect still drilling. The recent relatively high success rate exhibited by recent wells is not uncommon in the initial phases of exploration in a new trend or play.

The identification of subsalt prospects has been made easier with the advent of regional 3-D surveys over the Gulf of Mexico. Most of the shelf and immediate deepwater areas are covered by regional 3-D surveys. In addition to a large quantity of data, the quality of data has been steadily improving especially with the advent of high performance computers and 3-D depth migrations. As contractors and oil companies become more adept at performing depth migrations, the quality of subsalt data should continue to improve. The integration of well control and better quality data will extend the subsalt play under more complex salt features and in deeper water.

The next several years should continue to sustain a high level of subsalt drilling as the recently identified subsalt prospects on the shelf and near shelf are drilled. Most of the southern additions of Louisiana and High Island have subsalt potential. The depth to the top of salt can vary from several hundred to 20,000'. As industry becomes more adept at drilling below salt, deeper salt sills will become more prospective. The future of the subsalt trend will rely on continued improvement in subsalt depth imaging and the extension of the subsalt play to the ultra deepwaters of the Gulf of Mexico.

REFERENCE

Ewing, T.E. 1991. Structural Framework, in Salvador, A., (ed.) The Gulf of Mexico Basin: Boulder, Colorado, Geological Society of America, The Geology of North America, Vol. J, pp. 31-52.

Table 5C.1. Significant Subsalt Wells - Federal Offshore Gulf of Mexico (major sill well penetrations).

WELL NAME	DATE DRLD(TD)	RESULTS	TOP OF SALT	TVD THICKNESS OF SALT	WELL(TD)	DRLD TVD SEDIMENT THICKNESS BELOW SALT
GARDEN BANKS 171 #1 MARATHON*	05/84	DRY	-8400	1110	10597	997
WEST CAMERON 505 #2 GULF	09/84	DRY	-13900	1690	18500	2820
S. MARSH ISLAND 200 #1 DIAMOND SHAMROCK*	02/86	DRY	-8730	990	13500	3700
VERMILLION 356 #1 AMOCO	12/87	DRY	-8400	2100	17000	6360
LAKE WASHINGTON # 1 AMOCO (ONSHORE)	04/90	DRY	-9350	4075	21241	7781
MISS. CANYON 211 #1 EXXON	06/90	OIL & GAS	-5750	3030	14670	5820
BAY MARCHAND #1 AMOCO	05/91	DRY	-9820	4340	18277	4260
GARDEN BANKS 165 #1 CHEVRON	04/92	DRY	-5765	6950	18000	5200
SOUTH MARCH IS. 169 #1 AMOCO	12/93	P&A'D	N/A	N/A	18020	N/A
SHIP SHOAL 349 # 1 PHILLIPS	10/93	OIL & GAS	TITE	TITE	16500	TITE
SOUTH TIMBALIER 260 #1 PHILLIPS	05/94	OIL & GAS	TITE	TITE	16610	TITE
SHIP SHOAL 349 #2 PHILLIPS	08/94	OIL & GAS	TITE	TITE	18603	TITE
VERMILLION 349 #1 PHILLIPS	05/94	DRY	TITE	TITE	16146	TITE
SHIP SHOAL 360 #2 UNOCAL	08/94	P&A'D	N/A	N/A	19000	N/A
SHIP SHOAL 250 JAPEX	09/94	P&A'D	N/A	N/A	17772	N/A
SHIP SHOAL 368 #1 AMERADA HESS	SPUD 06/94	DRLG	N/A	N/A	PTD 17500	N/A
SOUTH TIMBALIER 289 #1 CNG	SPUD 10/94	P&A'D	N/A	N/A	18034	N/A
GARDEN BANKS 128 #1 SHELL	07/94	OIL & GAS	N/A	N/A	17477	N/A

* Unintentional subsalt well

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Dwight "Clint" Moore is presently Project Geologist for Anadarko Petroleum on their Offshore Gulf of Mexico Exploration Team. Nearly all of his 15-year career has focused on exploration and development in the Offshore Gulf of Mexico. He worked 10 years with Diamond Shamrock (Maxus) prior to joining Anadarko in 1987. Clint earned degrees in geology and finance from Southern Methodist University in 1978.

Stefan (Steve) Rutkowski is Geological Advisor, Offshore/Alaska Exploration for Anadarko. He received his geological degree in 1968 at the University of La Plata in Argentina. Prior to joining Anadarko in 1980, he worked as a geologist for various oil companies in several overseas locations. From 1980 to 1991, Steve was Anadarko's International Exploration Manager. At the end of 1991, he transferred to Anadarko's offshore group to work on the subsalt geology of the Gulf of Mexico, where he continues to date.

SESSION 5D

DISTRIBUTION AND ABUNDANCE OF CETACEANS, PART II

Session: 5D - DISTRIBUTION AND ABUNDANCE OF CETACEANS, PART II

Co-Chairs: Dr. Robert Avent and Dr. Randall Davis

Date: November 17, 1994

Presentation	Author/Affiliation
Major Oceanographic Features of the Northwestern and Central Gulf of Mexico	Dr. Giulietta S. Fargion Texas A&M University
Remote Sensing and Geographic Information System Support for the GulfCet Project	Mr. L. Nelson May, Jr. Mr. Thomas D. Leming Mr. Mark F. Baumgartner National Marine Fisheries Service Southeast Fisheries Science Center
Cetacean Habitats: A Preliminary Analysis	Dr. Randall Davis Texas A&M University at Galveston
Marine Birds of the Northern Central and Western Gulf of Mexico	Dr. Dwight E. Peake The University of Texas Medical Branch at Galveston Dr. Giulietta Fargion Texas A&M University at Galveston Dr. Robert Benson Texas A&M University
Acoustic Tracking of Sperm Whales - Preliminary Results	Dr. William E. Evans Mr. Mike Duncan Mr. Troy Sparks Texas A&M University

MAJOR OCEANOGRAPHIC FEATURES OF THE NORTHWESTERN AND CENTRAL GULF OF MEXICO

Dr. Giulietta S. Fargion
Texas A&M University at Galveston

SUMMARY

Five recent studies have investigated the hydrographic features of the northwestern-central Gulf of Mexico. Together they provide a nearly comprehensive hydrographic data set for the period 1992-1993. The time evolution of Loop Current anticyclonic eddies Unchained ("U"), Vazquez ("V"), Whopper ("W") and Extra ("X") are described by dynamic height and remote sensing data. The effects of these features on primary production and marine mammal location are also discussed.

INTRODUCTION

The primary physical oceanographic components of the Gulf of Mexico (GOM) are the Loop Current, eddies derived from this feature, and the Mississippi River plume. Eddies are important physically and biologically because they function as pumping mechanisms, mixing water masses and their constituent organic and inorganic compounds. Biggs and Muller-Karger (1994) suggest that the co-occurrence of cyclonic circulation cells in association with anticyclonic eddies may enhance primary productivity by increasing nutrient resources in surface waters. Cyclonic eddies lead to higher primary production because of the increased upward nutrient flux at their periphery. This cyclonic eddy-anticyclonic eddy pairing transports high-chlorophyll shelf water seaward, by at least 100-200 km. Upwelling and mesoscale features are manifest in the patterns of chlorophyll concentrations and are therefore revealed in satellite imagery (Smith *et al.* 1986, Waring *et al.* 1993).

Correlation of GOM marine mammal sighting data with mesoscale features suggests that cetaceans, due to their trophic interactions, are more abundant in these regions of high primary productivity. A rational explanation for this observation is that cetaceans tend to habitate those areas where food is plentiful. This phenomenon has been observed in the Gulf Stream as well, where sightings of large whales were associated with shelf-edge areas where warm core rings were located and particularly at the edges of those rings (Waring *et al.* 1993).

Over the period 1992-1993, ship surveys, aerial surveys, and satellite coverage allowed continuous monitoring of the Loop Current, eddy shedding, and eddy propagation at unprecedented spatial and temporal resolution. These MMS sponsored studies include the GulfCet Program and the three program units of the Louisiana-Texas Shelf Physical Oceanography Program (LATEX): Latex-A studied the shelf circulation, Latex-B the Mississippi River plume, and Latex-C the eddy system. The Ship of Opportunity Program (SOOP) also examined the eddy system over the continental slope of the northwestern (NW) GOM. The integration of *in situ* and remotely sensed hydrographic data demonstrated that the GOM is a complex region where cyclonic-anticyclonic pairs and cyclonic-anticyclonic-cyclonic triad systems interact, merge, and separate several times before disintegrating, or "spinning down" (Jockens *et al.* 1994).

EDDY TIME CHRONOLOGY

At least three anticyclonic eddies "U," "W," and "X," each with a diameter of at least 300 km, were shed from the Loop Current during the 1992-93 period and moved with their associated cyclonic eddies into the western Gulf. Eddy Unchained ("U") was shed in midsummer 1992. This eddy was detected by satellite altimeter data as an anticyclonic geopotential anomaly of +50 dyn cm (Hamilton *et al.* in press, Biggs *et al.* 1994), and in August 1992 the eddy captured an Argos drifter from the Louisiana shelf. During GulfCet Texas Institute of Oceanography (TIO) Cruise 2 (August 1992), the new Eddy "U," as well as older Eddy Triton, were present in the central and NW corner of the Gulf, respectively (Figure 5D.1). Eddy Triton was spinning down in the NW corner with a dynamic height of 125 dyn cm, while Eddy "U" had a dynamic height greater than 140 dyn cm. During this cruise 1,146 km of survey effort were conducted in continental slope waters. A group size of nine sperm whales (*Physeter macrocephalus*) were seen at the edge of Eddy "U." A group of 120 pantropical spotted dolphins (*Stenella attenuata*) were sighted at the edge of Eddy Triton.

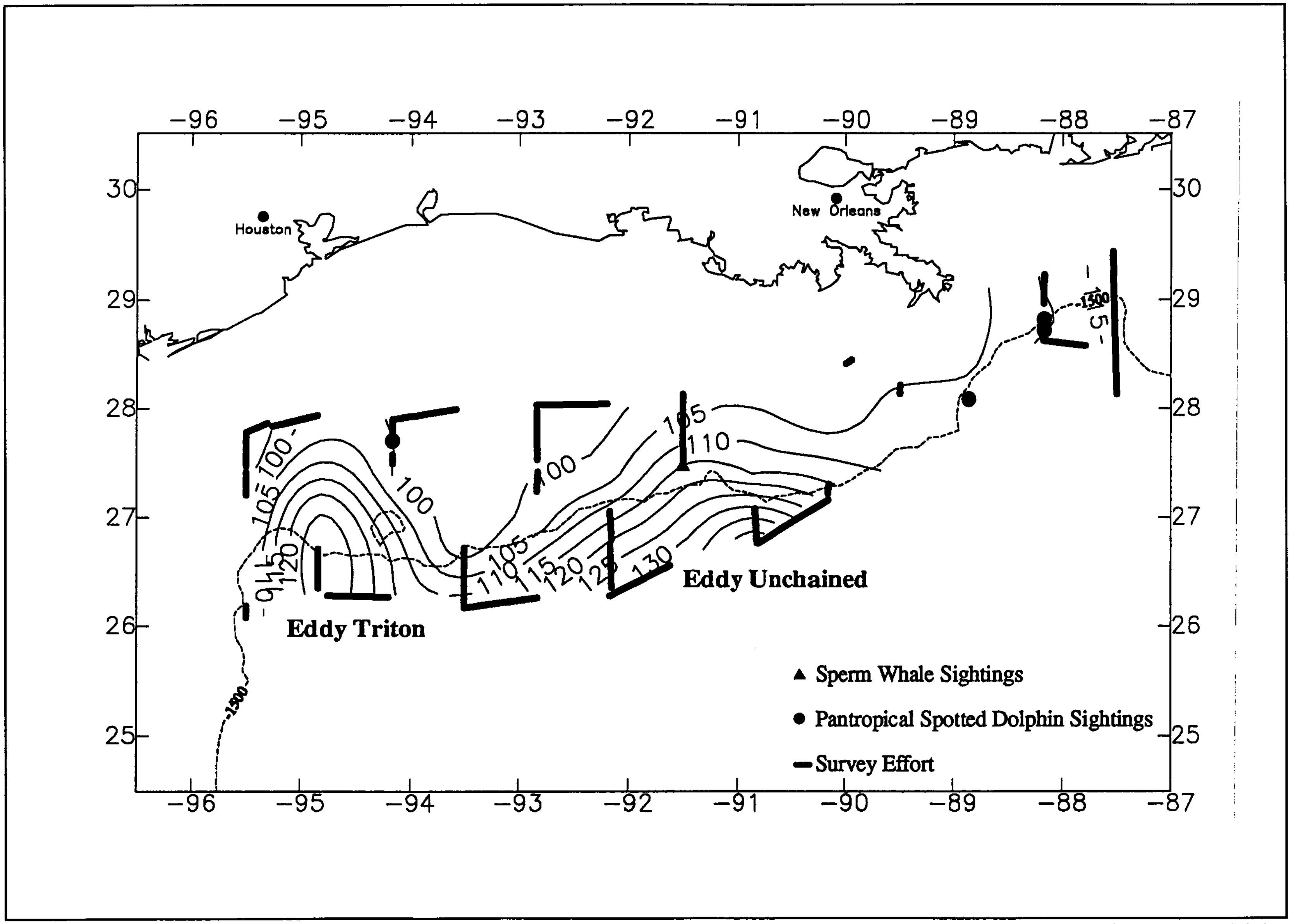

Figure 5D.1. TIO Cruise 2 surface dynamic topography (cm) with respect to 800 m, sperm whale and pantropical spotted dolphin sightings, sighting effort, and prominent eddies shown.

Eddy "U" was vigorous and large, about 300 km in diameter, and centered at 25° N and 90° W in September 1992 (Hamilton *et al.* in press). In early fall 1992, drifter trajectory and satellite altimeter data showed that this vigorous eddy ("U") soon cleaved into two eddies: a minor eddy, Vasquez ("V"), with a dynamic anomaly of +27 dyn cm, and a major eddy, still referred to as Eddy "U," with a dynamic anomaly of +40 dyn cm (Biggs *et al.* 1994). A NOAA-AVHRR image from 12 October 1992 captured these two eddies after the split (Figure 5D.2). Two hydrographic surveys by SOOP and Latex-C in late October confirmed the separation of "V" from "U" (Table 5D.1). Dynamic heights at this time were 142 dyn cm and 157 dyn cm for Eddies "V" and "U," respectively (Hamilton *et al.* in press, Biggs *et al.* 1994).

During this period, the smaller Eddy "V" was centered at the base of the northwestern continental slope, northwest of Eddy "U." Between September and December 1992 Eddy "V" moved westward along the 2,000 m isobath. The remainder of Eddy "U" advected west by southwest (WSW) until it eventually collided with the continental margin of the western Gulf in spring 1993. GulfCet TIO Cruise 3 entirely surveyed Eddy "V" at its position at the base of the NW corner of the Gulf in late November 1992. The dynamic height of Eddy "V" was greater than 140 dyn cm. Two groups with a total of two sperm whales were seen at the periphery of Eddy "V," and a total of 515 km of sighting effort were completed (Figure 5D.3).

In the later half of December 1992, Eddy "V" abruptly moved northward onto the continental slope in the northwestern corner of the Gulf. It remained at about the same size (approximately 100 km diameter) and in approximately the same position through May 1993 (Fargion *et al.* 1994a). In January 1993, a Latex-C survey showed Eddy "V" to have a dynamic height greater than 135 dyn cm (Fargion *et al.* 1994a). In the ensuing months, Eddy "V" continued to spin down while remaining in the same region. In late February 1993, GulfCet TIO Cruise 4 found that Eddy "V" continued to spin down to a dynamic height of about 125 dyn cm (Figure 5D.4). Two groups of 24 sperm whales and two groups of 40 pantropical spotted dolphins were seen at the edge of Eddy "V." A total of 203 pantropical spotted dolphins (10 groups) were scattered at the edge of cyclonic eddies. The total sighting effort for this winter cruise was 584 km.

A NOAA-AVHRR image in mid-February confirmed the location of both Eddies "U" and "V" in the GOM, with Eddy "U" in the southwest and Eddy "V" spinning down in the northwest. This image also indicated that an interaction between the two eddies had occurred with a subsequent water exchange. Analysis of altimetry data suggested that Eddies "U" and "V" began to coalesce by mid-to late-March 1993 (Jockens *et al.* 1994). In early April, a Latex-C drifter, which had been circulating in Eddy "U," shot north-northeast into the region occupied by Eddy "V." Throughout the remainder of April, the joined eddies were centered about 24.5° N and 96° W with an arm of Eddy "U" extending to the northeast into the region formerly occupied by Eddy "V." Thereafter, Eddy "V" existed primarily as an "arm" extension of Eddy "U." Satellite altimetry data showed the presence of cyclonic rings on the northwest and southeast flanks of Eddy "V" (Jockens *et al.* 1994). As April progressed, the arm strengthened and extended further North. A NOAA-AVHRR image, in mid April, confirmed the altimeter data.

In late April to early May 1993, Eddy "V" was beginning to pinch off of Eddy "U" again, and had its center located at about 27° N and 94.5° W. A Latex-A hydrographic cruise confirmed the presence of the anticyclonic Eddy "V" on the shelf with an associated cyclonic eddy to its' northwest (Jockens *et al.* 1994). Altimetry and NOAA-AVHRR data confirm that Eddy "U" and Eddy "V" separated again by the second week of May (Jockens *et al.* 1994). The thermal structure obtained from a Latex-C aerial survey in mid-May also showed a full separation of Eddy "V" from Eddy "U" as well as a weakening of Eddy "V." A Latex-A drifter, deployed in early-May, circulated in Eddy "V" throughout May. Satellite altimeter data also indicated a cyclonic eddy to the South of Eddy "V" (Jockens *et al.* 1994). All that remained of Eddy "V" by the end of May to the beginning of June was a small region adjacent to the shelf with weak, generally anticyclonic circulation, and a broad region of cyclonic circulation to the southeast. The data taken on GulfCet TIO Cruise 5 in early June suggested that a very weak anticyclonic cell remained. It was equally possible that the anticyclonic circulation was absent from the region

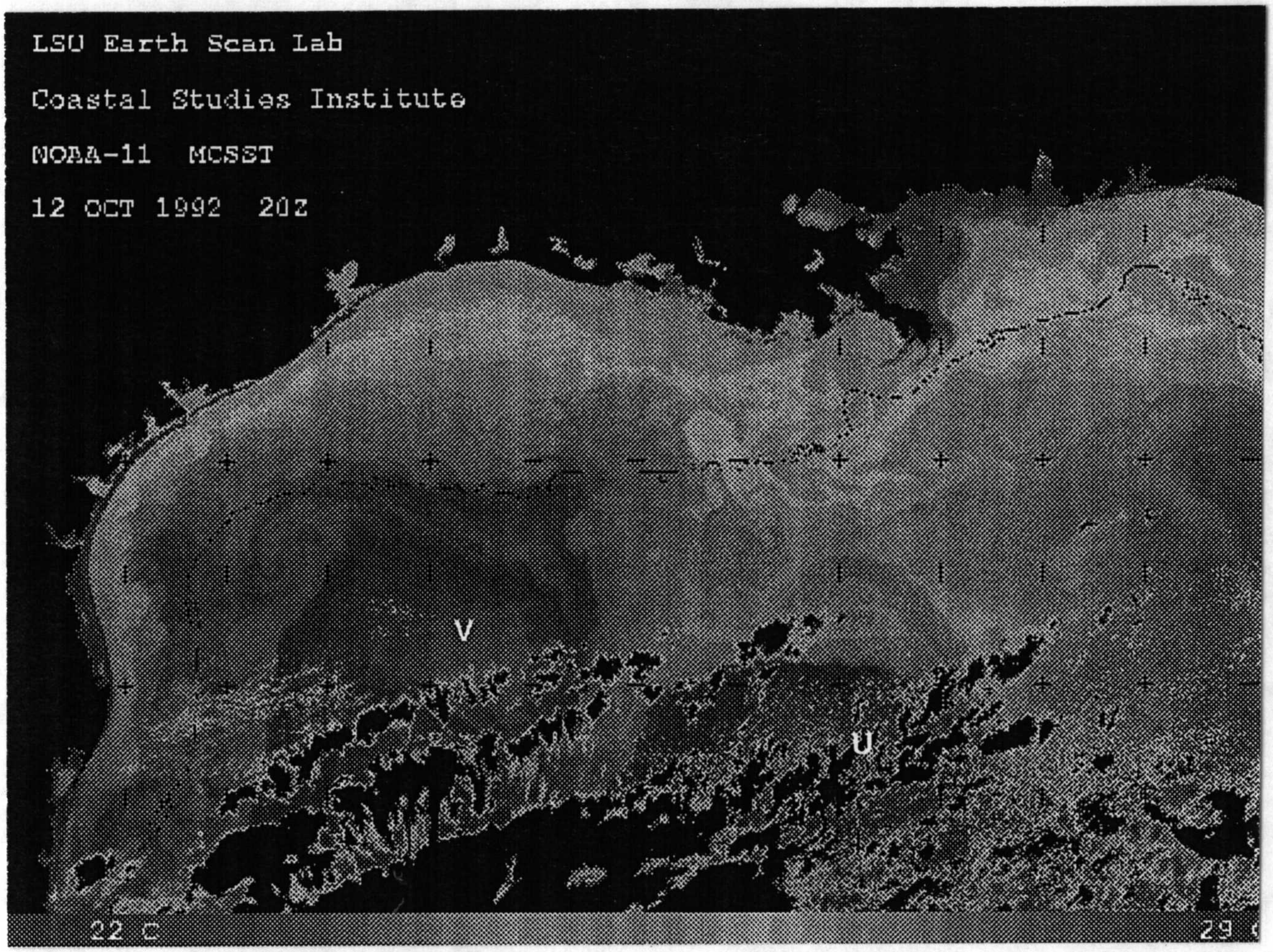

Figure 5D.2. NOAA-AVHHR SST (○C) analysis of the western Gulf of Mexico for 12 October 1992, showing Eddy "V" (northwest) and eddy "U" (southeast) (Image courtesy of Coastal Studies Institute, LSU).

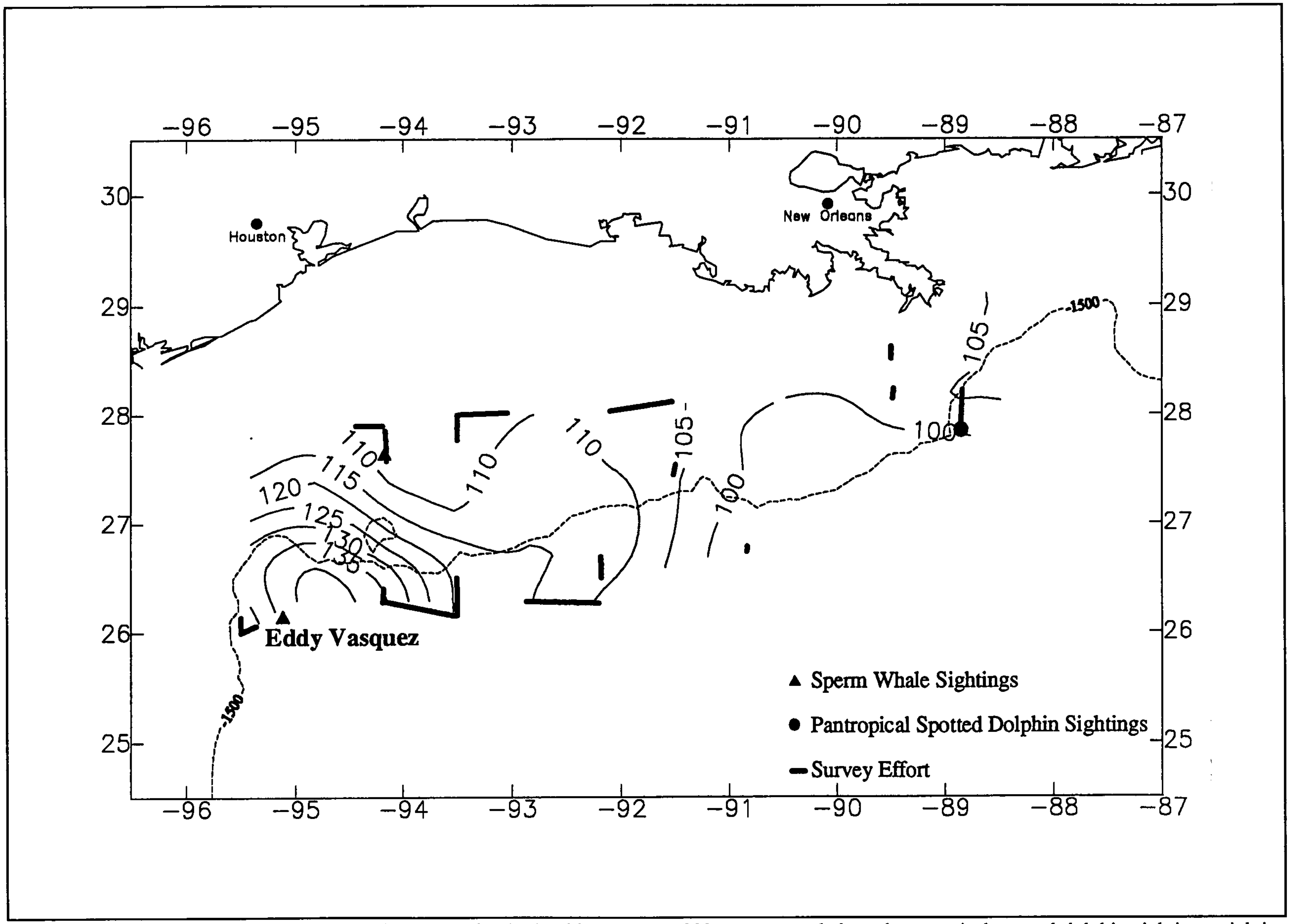

Figure 5D.3. TIO Cruise 3 surface dynamic topography (cm) with respect to 800 m, sperm whale and pantropical spotted dolphin sightings, sighting effort, and prominent eddies shown.

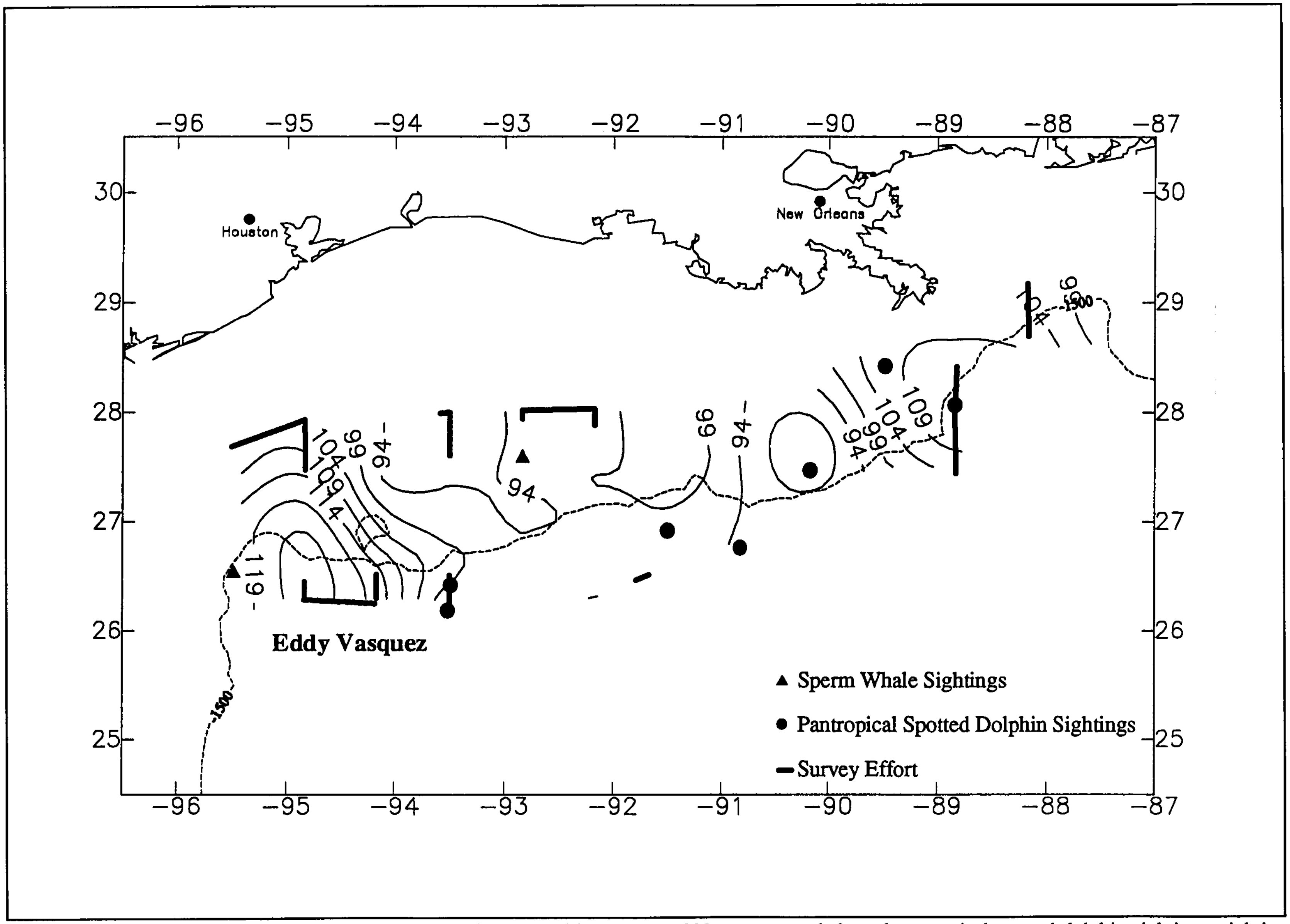

Figure 5D.4. TIO Cruise 4 surface dynamic topography (cm) with respect to 800 m, sperm whale and pantropical spotted dolphin sightings, sighting effort, and prominent eddies shown.

Table 5D.1. Oceanographic features located during GulfCet, LATEX, and SOOP programs during 1992-1993, and their properties.

Survey	Date	Oceanographic Feature	8°C Isotherm Depth (m)	Dyn. Height (800 dbar)
Latex-C Surveys F02 & F03	7 Aug 1992 9 Aug 1992	Eddy "U"	550 m	115 cm
GulfCet TIO Cruise 2	10 Aug 24 1992- 24 Aug 1992	NW corner of Eddy "U," Eddy "T"	 > 600 m 625 m	 > 135 cm > 125 cm
Latex-C Survey F04	11 Oct 1992	Eddy "U" & Eddy "V"	both > 675 m	
SOOP Cruise 92G-13	28 Oct 1992- 31 Oct 1992	Eddy "U" & Eddy "V"	718 m 656 m	157 cm 142 cm
GulfCet TIO Cruise 3	8 Nov 1992- 22 Nov 1992	Eddy "V"	650 m	140 cm
Latex-C Survey F05	19 Dec 1992	Eddy "V"	650 m	
Latex-C Surveys F06 & F07	4 Jan 1993 6 Jan 1993	Eddy "V"	> 650 m	135 cm
SOOP Cruise 93G-01	9 Jan 1993- 12 Jan 1993	Eddy "V"	678 m	133 cm
GulfCet NMFS Cruise 203	4 Jan 1993- 14 Feb 1993	Eddy "V"	>650 m	
GulfCet TIO Cruise 4	12 Feb 1993- 27 Feb 1993	Eddy "V" & "no name" Eddy	625 m 600 m	125 cm 110 cm
Latex-C Surveys F08 & F09	12 May 1993 16 May 1993	Eddy "V" (moving inshore)	600 m	
GulfCet NMFS Cruise 204	6 May 1993- 13 June 1993	Loop Current & ps. Eddy "V"	> 750 m	
GulfCet Cruise TIO 5	23 May 1993- 5 June 1993	Eddy "V" not present		
SOOP Cruise 93G-07	1 June 1993- 4 June 1993	Eddy "W"	788 m	170 cm
Latex-C Surveys F010 & F011	28 Aug 1993- 5 Sept 1993	North side Eddy "W" & Eddy "X"	575 m > 675 m	125 cm > 145 cm
GulfCet TIO Cruise 6	28 Aug 1993- 5 Sept 1993	North side Eddy "W" & Eddy "X"	575 m > 675 m	125 cm > 145 cm
Latex-C Survey F012	28 Oct 1993 31 Oct 1993 1 Nov 1993	Eddy "W"	650 m	
GulfCet TIO Cruise 7	3 Dec 1993- 14 Dec 1993	North side Eddy "X"	> 625 m	>125 cm
Latex-C Surveys F013 & F014	16-18 Dec 1993 23 Dec 1993	Eddy "X"	> 625 m	130 cm

formerly occupied by Eddy "V." Figure 5D.5 shows the sperm whale and pantropical spotted dolphin distributions were scattered throughout the study area, and 992 km of survey effort were completed. At the same time, the LATEX-A drifter buoy changed course to move in a cyclonic loop to the southeast of Eddy "V" (Jockens *et al.* 1994). Eddy "V" appears to have dissipated completely in the summer of 1993. There is evidence from June and July drifter tracks that a cyclonic eddy may have formed in that region.

Eddy Whopper ("W") was formed in June 1993. It was a large eddy that also formed a subsidiary warm anticyclonic eddy, similar in size to Eddy "V," at the base of the continental slope at about 93° W. Unlike Eddy "V," however, this northern portion of Eddy "W" apparently interacted with a cyclonic eddy on the lower slope and moved rapidly south by southeast, away from the slope in August 1993 (Hamilton *et al.* in press, Biggs *et al.* 1994). Eddy "W" had an anticyclonic geopotential anomaly of +55 dyn cm. Similar to Eddy "U," Eddy "W" also split into two portions shortly after its formation: a combination of drifter, altimeter, and SST data shows that the northern (minor) portion collided with the continental margin of the NW Gulf in summer 1993, while the southern (major) portion advected WSW and collided with the western margin of the GOM in December 1993 (Fargion *et al.* in press, Biggs *et al.* 1994). Eddy "W" was surveyed in August of 1993 by GulfCet TIO Cruise 6 while the eddy moved about the NW corner of the GOM (Figure 5D.6). At that time, the eddy had a "bone" shape with a dynamic height of 120 dyn cm. Eighty five sperm whales and 16 pantropical spotted dolphins were seen at the edges of eddies "W" and "X." The total sighting effort for this summer cruise was about 1104 km.

By late August 1993, another eddy, Eddy Extra ("X"), a large vigorous Loop Current eddy, was located by ship (GulfCet TIO Cruise 6) on the continental slope at 89.5° W. It was shown to have a dynamic height of 145 dyn cm (Figure 5D.6). Eddy "X" interacted with an isolated cyclonic eddy on the lower slope between 93° and 92° W, causing the cyclonic eddy to move eastward towards the Loop Current (Hamilton *et al.* 1994). Eddy "X" subsequently moved westward along the base of the slope as tracked by AVHRR satellites in late November. In the satellite images from that time, Eddy "W" appears to be in the NW corner with the cyclonic eddy on the eastern side. In early December 1993, Eddy "X" was surveyed by ship (GulfCet TIO Cruise 7) and had a dynamic height greater than 125 dyn cm. Figure 5D.7 shows the three groups with 16 sperm whales and five groups of 108 pantropical spotted dolphins that were seen at the edges of Eddy "X" and its associated cyclonic eddies. The total sighting effort for this last TIO cruise was about 730 km. Analysis of NOAA-AVHRR satellite data suggested that Eddies "W" and "X" began to coalesce by mid-to-late December, and by early January 1994 they appear to have formed one large eddy with elongated arms. Unfortunately, altimeter data was not available for this period. Intense cloud cover over the Gulf resulted in poor NOAA-AVHRR satellite coverage for the first quarter of 1994. The first cloud-free NOAA-AVHRR image was in early May 1994, and no evidence of eddy "W" or "X" was found in the NW corner of the Gulf. Clarification of the fate of these eddies will probably be resolved by the Latex-C and SOOP programs, as these programs are to be carried out through 1994-1995.

FRESHWATER INFLUX

Two major events related to the Mississippi River occurred during the study period 1992-1993. The first occurred in the fall of 1992 when Mississippi River fresh water extended outward into the Gulf to the 2,000 m isobath; the second event was the "great" flood of 1993, occurring during the summer. Walker and Rouse (1993) reported an unusual Mississippi River plume feature which occurred in October 1992. Under maximum discharge and under strong northeasterly winds, shelf water was rapidly forced away from the Mississippi River delta and over the continental slope, extending from 88° 20' W to 90° 50' W and offshore farther than the 1,000 m isobath. This information was confirmed the following month by TIO Cruise 3, but by that time the fresh water intrusion into the Gulf had extended to the 2,000 m isobath. This nutrient laden fresh water resulted in higher values of chlorophyll at those stations touched by the plume.

A combination of natural variability and global-scale circulation anomalies during the 1992-1993 period resulted in severe and persistent precipitation over the central United States, and brought the total flow of the Mississippi River to new records. Monthly mean Mississippi River discharges during April and May were 50% higher than the long-term mean

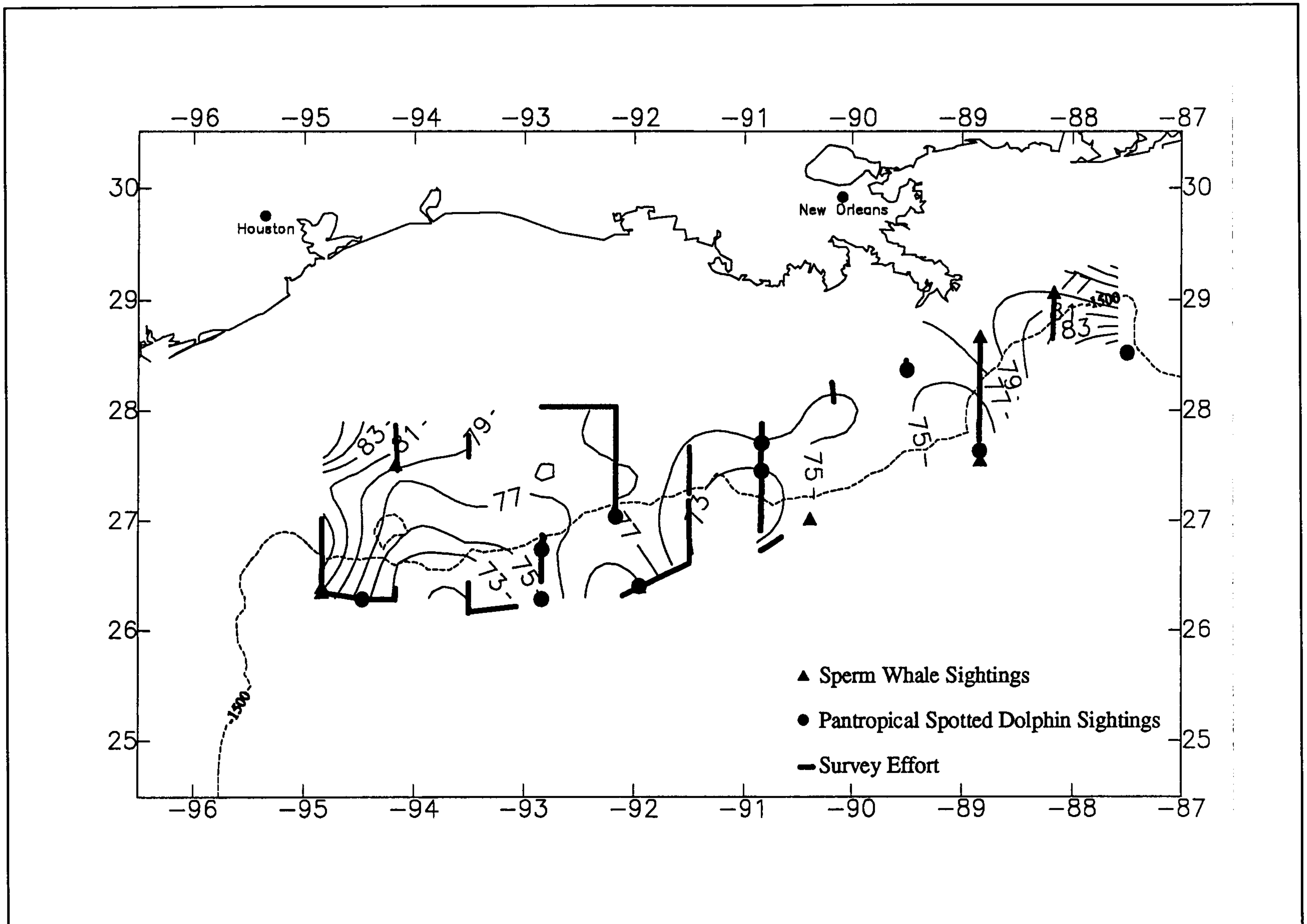

Figure 5D.5. TIO Cruise 5 surface dynamic topography (cm) with respect to 500 m, sperm whale and pantropical spotted dolphin sightings, and sighting effort.

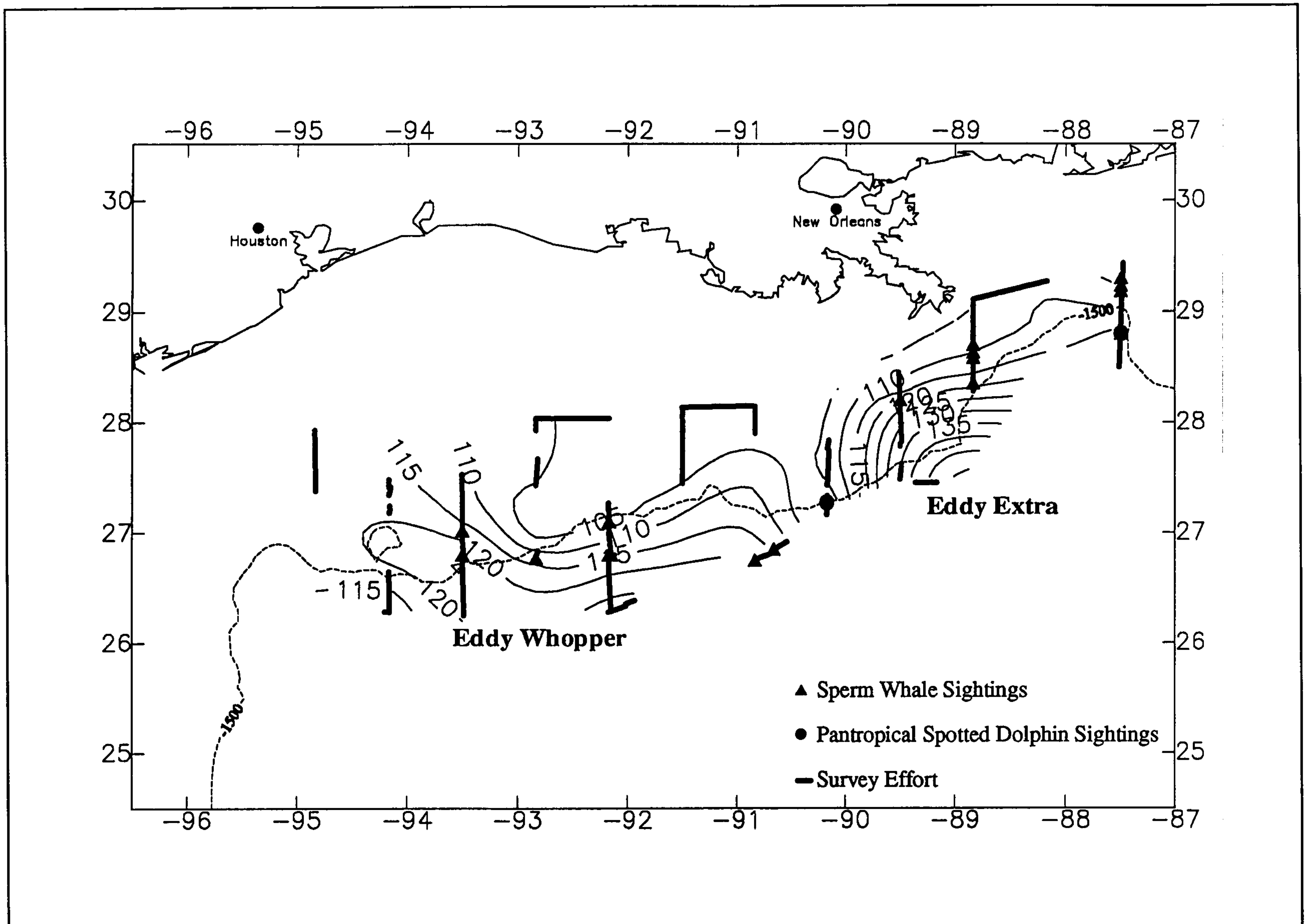

Figure 5D.6. TIO Cruise 6 surface dynamic topography (cm) with respect to 800 m, sperm whale and pantropical spotted dolphin sightings, sighting effort, and prominent eddies shown.

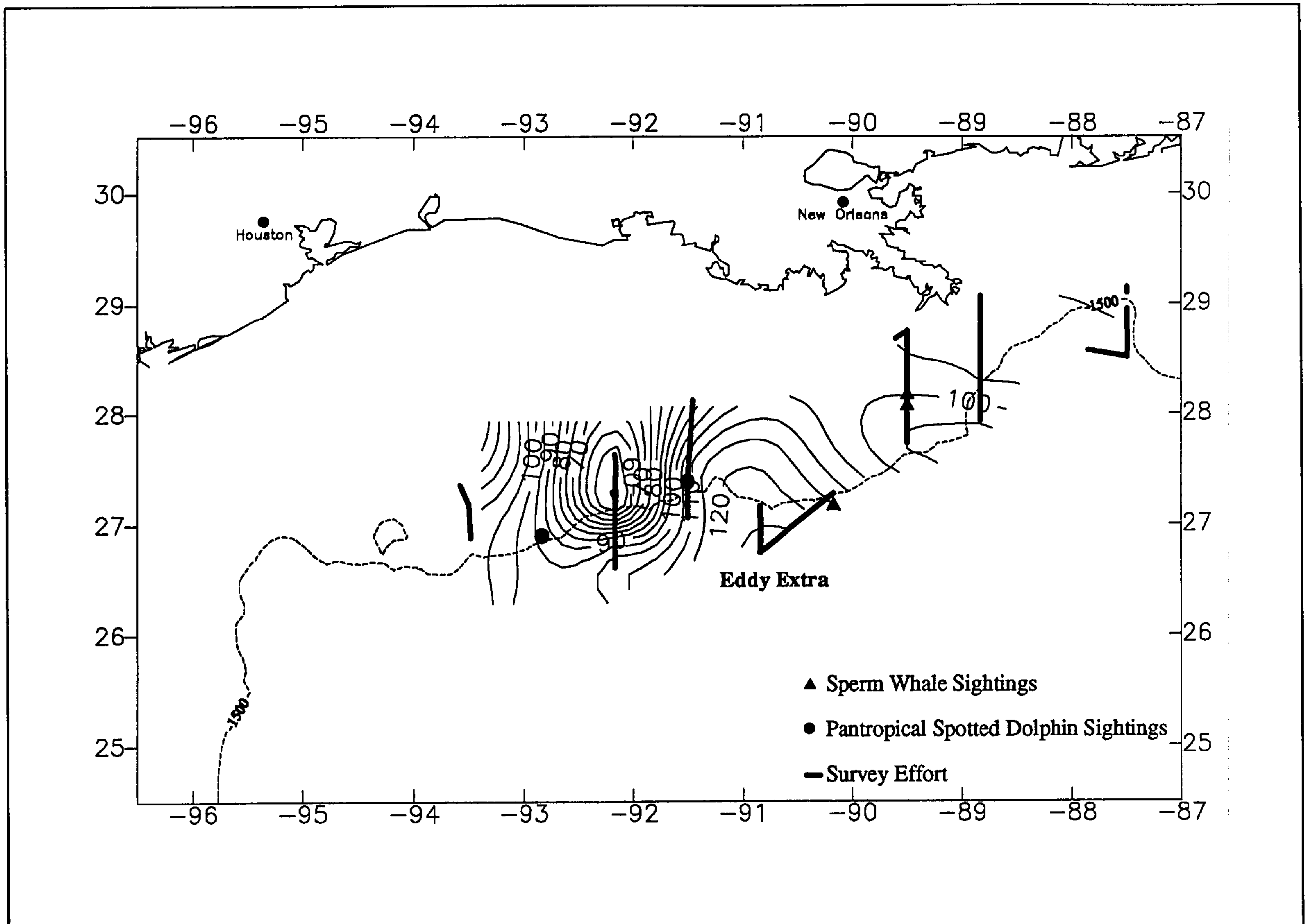

Figure 5D.7. TIO Cruise 7 surface dynamic topography (cm) with respect to 800 m, sperm whale and pantropical spotted dolphin sightings, sighting effort, and prominent eddies shown.

(1930-1992), and August discharge rates were higher than the long-term peak monthly mean discharge which usually occurs in April. Undoubtedly, the 1993 El Niño/Southern Oscillation (ENSO) event contributed to the flooding of the Mississippi and Missouri River valleys. The "great flood" of the Mississippi River caused significant changes to the landscape and ultimately, to the coastal ocean. This flooding event was exceptional for the season (summer), duration (weeks to months) and magnitude, all of which created unusual hydrographic features in the Gulf of Mexico. The effects of fresh water were detected not only in the northern Gulf, but also in the Florida Keys, and along the U.S. east coast (Walker *et al.* 1994). The most obvious effect of the increased Mississippi River flow was increased nutrient influx with correspondingly increased phytoplankton concentrations. Dortch (1994) reported that total phytoplankton concentration during the period of flooding was more than an order of magnitude greater than normal. High concentrations of phytoplankton result in an increased carbon flux to the bottom, either as a result of dead plankton sinking or as zooplankton fecal pellets. This higher flux may consequently create large areas of hypoxia.

Wind measurements from Louisiana coastal stations and continental shelf buoys suggest that the eastward flow of the Mississippi plume in the summer 1993 was at least partially wind-driven (Walker *et al.* 1994). From mid-July through August, surface winds along the Louisiana coast were predominantly westerly and southwesterly. Another concurrent factor was the presence of Eddy "X" at the delta of Mississippi. Eddy "X" could have enhanced the eastward direction of the plume of fresh water. Previous studies have shown a positive correlation between the Mississippi River flow and the interannual variations in chlorophyll concentration, which in turn influences the development of primary productivity in the Gulf. Higher chlorophyll values have been found in association with the fresh water influx from the Mississippi river and cold cyclonic eddies (Fargion *et al.* 1994b).

CONCLUSION

The study area in 1992-1993 presented a complex hydrographic scenario. The following features were seen: a) new warm anticyclonic eddies with associated cyclonic eddies moved in and out of the northern GOM; b) recently formed warm anticyclonic eddies interacted with older eddies in the northwestern corner of GOM; and c) unusual freshwater outflow extended offshore as far as the 2,000 m isobath in fall of 1992 and in the summer of 1993 fresh water discharge streamed to the east of the Mississippi delta. As a result of eddy movement, each of the GulfCet surveys had a unique opportunity to view meso- to large-scale hydrographic features. No generalizations can be made regarding eddy path, residence time, or frequency of occurrence in the study area. Generally, however, after separation from the Loop Current, anticyclonic eddies drift westward until their progress is halted by the northwestern continental slope, in the "eddy graveyard." In the central-northwestern GOM anticyclonic warm eddies with their affiliated cold cyclonic eddies, in addition to the fresh water influx from the Mississippi River, are the primary circulation features which can enhance primary productivity and subsequently increase production at higher trophic levels. Biggs and Muller-Karger (1994) reported in a Texas Sea Grant Program communication that the continental slope of the NW Gulf is a region where pelagic predators are abundant. Since these predators (such as skipjack, blackfin tuna, blue marlin, swordfish, and shark) require consistent food sources, they are not likely to be sustained by low primary productivity or infrequent episodes of enhanced primary productivity. Primary productivity, therefore, must be maintained relatively consistently. Particular areas where this level of production are most likely to remain relatively consistent are, the Mississippi River plume vicinity and the area just peripheral to the eddy pathway from the Loop Current. It is suspected that cetacean food sources, as well, would most likely be concentrated in these areas of consistently higher primary productivity. Cetacean foraging efficiency would be maximized when feeding effort was concentrated in these areas. It is in association with these areas that GulfCet sightings have often been reported. Data from the period 1992-93 suggest that Loop Current features (i.e., warm eddies and associated cold eddies) are a frequently used habitat for sperm whale and pantropical spotted dolphins.

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REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM SUPPORT FOR THE GULFCET PROJECT

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Southeast Fisheries Science Center

INTRODUCTION

The National Marine Fisheries Service -Southeast Fisheries Science Center (NMFS-SSC) is providing remote sensing and geographic information system (GIS) support for the project. The GIS will be used to integrate and analyze the various data types to explore possible relationships between the distribution and abundance of marine mammals and satellite and shipboard measurements of environmental variables in the Gulf of Mexico.

GIS HARDWARE AND SOFTWARE

The GIS hardware consisted of a Silicon Graphics UNIX workstation with 80 megabytes of random access memory, online access to 12 gigabytes of hard disk and optical storage media, and other peripherals. The software was the Advanced Geographic Information System software, AGIS. (AGIS is a proprietary GIS software package developed and marketed by Delta Data Systems, Inc. 131 Third Street, Picayune, MS 39466.) AGIS is capable of storing and analyzing raster and vector data (Aronoff 1989) simultaneously.

BASE MAP COORDINATE SYSTEM

All of the digital map layers used in the GIS data base were registered to a Gulf of Mexico master image (GMMI) that includes the GulfCet study area and encompasses the area from 18° to 31° North Latitude and 80° to 98° West Longitude. The GMMI is a raster image consisting of three land cover classes: land, water, and land pixels adjacent to water (coastline). The file was generated from vector coastline data reformatted from the Digital Chart of the World data base (U.S. Defense Mapping Agency 1992). Data were earth located within the GMMI with longitude/latitude coordinates using a simple cylindrical projection (linear longitude/latitude) system (Snyder 1987). The dimensions of each pixel in the GMMI were 0.01° longitude by 0.01° latitude.

DATA ACQUISITION AND PROCESSING

The locations of cetaceans observed from aircraft and vessels were recorded with global positioning system receivers and later converted to vector maps organized by survey platform, cruise leg, cruise number, and season as appropriate. Other attribute information recorded for each sighting included the date, time of day, species, herd size, and a flag variable to indicate whether the sighting was on effort or off effort. Survey tracklines were also stored as vector maps with attribute information to enable retrieval and display for specific dates, survey number, and survey platform.

Sea surface temperature (SST) and surface salinity measurements acquired by thermosalinigraphs aboard the vessels were converted to line vector maps corresponding to survey tracklines. SST gradients were also derived from the thermosalinigraph measurements and stored as line vectors. Water temperature data from CTD and XBT measurements were converted to raster and vector maps by depth class using standard depths defined by the National Oceanographic Data Center.

Of the 344 satellite images that were acquired to support the ship and aircraft surveys during the two year field effort, a total of 118 were selected based on the distribution of cloud cover and the availability of survey data within ±24 hr of the overflight. The images were collected by the Advanced Very High Resolution Radiometer (AVHRR) carried aboard the NOAA-11 and NOAA-12 polar orbiting satellites. Each satellite provided partial or full coverage of the study area twice per day (one daytime and one nighttime overflight) depending on the orbital path and cloud coverage. The data were obtained on computer compatible tapes from the level 1b archives

(Kidwell 1985) maintained at the National Satellite, Data, and Information Service and the satellite receiving station operated by NMFS at Stennis Space Center. The satellite images were processed into SST images using the multichannel SST algorithms described by McClain *et al.* (1985). The images were rectified to fit the GMMI using the earth location data included with each raw image file and the nearest neighbor resampling technique (Schowengerdt 1983). SST gradient maps were derived from the satellite images and stored in the data base.

In addition to the survey, environmental, and satellite data collected for the project, other public domain GIS data sets were obtained from the U.S. Geological Survey and Minerals Management Service. These included coastlines, boundary of the U.S. Exclusive Economic Zone, state and international boundaries, and bottom depth maps (Herring 1993).

PROCESSING PROTOCOL

A total of seven environmental variables are currently being analyzed relative to cetacean sightings: SST, SST gradient, surface salinity, depth of the 15°C isotherm, temperature at 100 m, bottom depth, and bottom depth gradient. The cetacean sightings and environmental data acquired along each survey trackline have been extracted and are currently being analyzed using plots and tabular listings. Environmental profiles for each species are also being developed using tabular summaries and plots. Kolmogorov-Smirnov (K-S) two sample tests (Conover 1980) are being used to compare the distributions of aircraft and ship survey effort for uniformity across the observed ranges of each environmental variable. K-S tests are also being used for similar comparisons of cetacean sightings with survey effort.

An analysis of the distribution of cetaceans and environmental variables relative to documented oceanographic features is currently in progress.

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CETACEAN HABITATS: A PRELIMINARY ANALYSIS

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One of the objectives of the GulfCet Program was to gain a better understanding of the oceanographic habitat of cetaceans. To accomplish this, we have began an analysis of the hydrographic data in relation to the distribution of different cetacean species. This analysis is only in the initial phases, so the results must be considered preliminary. The average hydrographic conditions for cetaceans sighted in the study area are shown in Table 5D.2. The average hydrographic values are shown in Table 5D.3 for four commonly observed species during GulfCet cruises, pantropical spotted dolphins, sperm whales, Atlantic spotted dolphins, and bottlenose dolphins. There was no significant difference between the average hydrographic conditions and those observed for the pantropical spotted dolphin and sperm whale sightings for the six selected hydrographic variables. On average, these two species were found in areas of very deep water, between 1,105-1,242 meters. They were also found in an area of relatively steep bottom gradient, 19-24 meters per 1.1 kilometers. Average sea surface temperature was about 19-20° C and surface salinity was normal for offshore areas for the Gulf of Mexico. The Atlantic spotted dolphin and bottlenose dolphin appeared to be located closer to the edge of the continental shelf in water that was typically 197-294 meters deep. None of the other hydrographic variables were significantly different, except the bottom depth gradient, which was slightly less than for pantropical spotted dolphins and sperm whales. This indicates that Atlantic spotted dolphins and bottlenose dolphins were probably found over the continental shelf, as opposed to steeper regions of the continental slope. Further in-depth analyses, using the GIS and canonical correspondence analysis, will be necessary to determine the relationship between cetacean sightings and hydrographic variables. This analysis will be complete in early 1995.

Table 5D.2 Mean hydrographic values for cetaceans sighted in the GulfCet study area.

Depth of the 15° Isotherm (m)	Water Temperature at 100 m (C°)	Bottom Depth (m)	Bottom Depth Gradient (m/1.1 km)*	SST (°C)	SST Gradient °C/1.1 km	Surface Salinity (PSU)
194	19.5	1,009	19	24.7	0.07	35.6
(141-294)	(17-26)	(100-2000)	(0-120)	(14-31)	(0.07)	(16-37)

* 1.1 km is the size of a remote sensing pixel.

Table 5D.3. Mean hydrographic values for four commonly observed species in the GulfCet study area.

Species	Depth of the 15° Isotherm (m)	Water Temperature at 100 m (C°)	Bottom Depth (m)	Bottom Depth Gradient (m/1.1 km)*	SST (°C)	SST Gradient °C/1.1 km	Surface Salinity (PSU)
Pantropical Spotted Dolphin	198	19.2	1,242	19	25.3	0.07	35.6
Sperm Whale	195	19.9	1,105	24	23.7	0.08	35.8
Atlantic Spotted Dolphin	184	19.3	197	11	22.7	0.09	34.9
Bottlenose Dolphin	189	19.1	294	16	24.2	0.08	33.6

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MARINE BIRDS OF THE NORTHERN CENTRAL AND WESTERN GULF OF MEXICO

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The GulfCet Texas Institute of Oceanography (TIO) cruises presented a unique opportunity to expand the knowledge of the pelagic avifauna of the northern-central and western Gulf of Mexico by a systematic bird survey of areas previously never or only minimally investigated in an organized fashion. Clapp *et al.* (1982, 1983) summarized all available records of seabirds from the northern Gulf of Mexico; a majority of these records for pelagic species have been obtained onshore, usually after storms. Duncan and Harvard (1980) did limited ship-based surveys in waters offshore Alabama. Although spotting small dark birds from a moving aircraft is difficult, Fritts and Reynolds (1981) and Fritts *et al.* (1983) conducted aerial surveys of birds in the Gulf of Mexico which included offshore areas of Louisiana and Texas and provided much useful information regarding pelagic seabirds in the Gulf. Bird observations were made on TIO Cruises 3-7 and the data provides information on the species, distribution, and relative abundance of birds in the GulfCet study area.

Forty-three species of birds were seen during these cruises. Twenty-two of these species are non-seabirds and include ducks, herons, and passerine species. These observations provide examples of the Trans-Gulf pathway for migrating landbirds. Twenty-one species of seabirds, defined as coastal, offshore, or pelagic species of birds which have their usual habitats and food sources in the sea or oceans were observed (Harrison 1983). Table 5D.4 summarizes the seabird species, number of sightings, and water depth where sightings occurred as well as the mean group sizes. Although no new seabird species for the Gulf of Mexico area were seen, two species, Cory's Shearwater and Band-rumped Storm-Petrel, will be added to the official Louisiana bird list pending acceptance of the records by the Louisiana Rare Birds Committee.

The predominant species noted on each TIO cruise was different. Figures 5D.8 - 5D.11 present the relative abundance of species on Cruises 3, 4, 5, and 6 (sighting rates are defined as the total number of individuals seen on each cruise while observing on-effort divided by the number of hours spent on-effort for each cruise). The most common species for TIO Cruise 3 are total jaegers (Pomarine Jaeger and unidentified jaeger) and *Puffinus* shearwaters (unidentified small *Puffinus sp.* and Audubon's Shearwaters). For Cruise 4, Laughing Gull, Herring Gull, total jaegers, and Northern Gannet are the predominant species. On TIO Cruise 5, Band-rumped Storm-Petrels, total jaegers, and Bridled Tern were the major species seen. Black Tern, *Puffinus* shearwaters, and Bridled and Sooty Terns predominated on Cruise 6. Seventy percent of the bird sightings and individuals on Cruise 7 were Pomarine Jaegers. Jaegers, small *Puffinus* shearwaters, and Band-rumped Storm-Petrels, interestingly, were not considered to be significant components of the Gulf of Mexico avifauna by Fritts *et al.* (1983).

Although the Wilson's Storm-Petrel has previously been considered the most abundant Storm-Petrel in the Gulf of Mexico, all but one of the Storm-Petrels identified to species on Cruises 3-7 were Band-rumped Storm-Petrels. These sightings of Band-rumped Storm-Petrels occurred throughout the GulfCet study area. The world population of Band-rumped Storm-Petrel is approximately 50,000-100,000 birds and the entire Atlantic Ocean population may number less than 15,000 birds (Croxall *et al.* 1984). Although Clapp *et al.* (1982) listed only five records for this area, the Gulf of Mexico may represent an important and previously unrecognized nonbreeding habitat for this uncommon species. In light of this, the possible exposure of these birds to oiling from a spill becomes particularly significant.

Audubon's Shearwater is another species with a limited Atlantic Ocean population, numbering less than 5,000 pairs (van Halewyn *et al.* 1984). Clapp *et al.* (1982) and Fritts *et al.* (1983) noted only 26 records of this species in the northern Gulf of Mexico. The TIO cruise data suggests, however, that it is much more common in the study area than previous information would indicate. Because this species rests on the water and dives for food items, it is at high risk for oiling (Fritts *et al.* 1983).

Despite the prior belief that Pomarine Jaeger is uncommon in the northern Gulf of Mexico (Duncan and Harvard 1980), this species was common on the November through May cruises. Sightings occurred throughout the study area; on the February cruise, most sightings occurred in the areas with the greatest water depths. The primary foraging behavior for jaegers during much of the winter in this area seems unlikely to be kleptoparasitistic in view of the large numbers of jaegers relative to other species; a flock of at least 100 jaegers seen feeding over a group of sperm whales suggests scavenging may be an important jaeger feeding method this time of year.

While the Black Tern is not strictly a pelagic species, a large offshore concentration of Black Terns was noted on Cruise 6 (August 1993) in the area of the Mississippi River plume where fresh water streamed eastward. Although large flocks were observed feeding over fish schools, more notable were the numbers of Black Terns resting on flotsam. These observations suggest that despite the conclusions of Clapp *et al.* (1983) and Fritts *et al.* (1983) that the Black Tern is not very susceptible to oiling, this species may be at high risk of oiling during migration.

Other notable bird sightings made on the TIO cruises include two records of the White-tailed Tropicbird and two records for the Brown Noddy Tern. Less than approximately 15-20 previous records exist for either species from the northern-central and western Gulf of Mexico, and the GulfCet records represent some of the few offshore records in this area.

The GulfCet TIO bird observations, therefore, add significantly to the knowledge of the avifauna of the Gulf of Mexico through the first intensive ship-based offshore bird survey for the northern-central and western Gulf. Forty-three total species of birds and 21 species of seabirds were observed, including two probable additions to the list of Louisiana bird species. Several species which were not previously well known in the Gulf of Mexico, including Band-rumped Storm-Petrel, Audubon's Shearwater,

Table 5D.4. Seabird Sighting Results for TIO Cruises 3-7.

Species	Total Number Sightings	Water Depth Range (m)	Mean Water Depth (m)	Mean Group Size
Cory's Shearwater (*Calonectris diomedea*)	5	89-1809	1004	1.4
Audubon's Shearwater (*Puffinus lherminieri*)	44	107-2184	1563	2.52
Pterodroma sp.	1	1314	1314	1
Wilson's Storm-Petrel (*Oceanites oceanicus*)	1	144	144	1
Band rumped Storm-Petrel (*Oceanodroma castro*)	14	216-2714	1640	1.42
Unidentified Storm-Petrels (*Hydrobatidae*)	16	196-1979	1094	1.68
White-tailed Tropicbird (*Phaethon lepturus*)	2	1758-1982	1870	1.5
Northern Gannet (*Sula bassanus*)	20	103-2341	450	2.85
Masked Booby (*Sula dactylatra*)	16	569-2306	1343	1.18
Magnificent Frigatebird (*Fregata magnificens*)	15	75-1772	755	1.46
Pomarine Jaeger (*Stercorarius pomarinus*)	102	136-2587	1633	1.72
Unidentified Jaeger (*Sternocarius* sp.)	50	109-2380	1477	3.66
Laughing Gull (*Larus atricilla*)	76	100-2313	898	1.74
Bonaparte Gull (*Larus philadelphia*)	1	219	219	1
Herring Gull (*Larus argentatus*)	52	9-2584	703	2.22
Royal Tern (*Sterna maxima*)	6	9-2584	731	1.33
Sandwich Tern (*Sterna sandvicensis*)	6	102-1611	598	2.2
Common Tern (*Sterna hirundo*)	5	176-1410	613	1
Least Tern (*Sterna antillarum*)	2	106-1603	854	2
Unidentified white-back *Sterna sp.*	7	136-1667	917	1.57
Bridled Tern (*Sterna anaethetus*)	35	105-2176	944	1.48
Sooty Tern (*Sterna fuscata*)	11	125-1993	1448	7.54
Unidentified dark-back *Sterna sp.*	11	186-2006	1192	1.33
Black Tern (*Chlidonias niger*)	59	75-2104	411	26.6
Brown Noddy (*Anous stolidus*)	2	1396-1591	1494	1

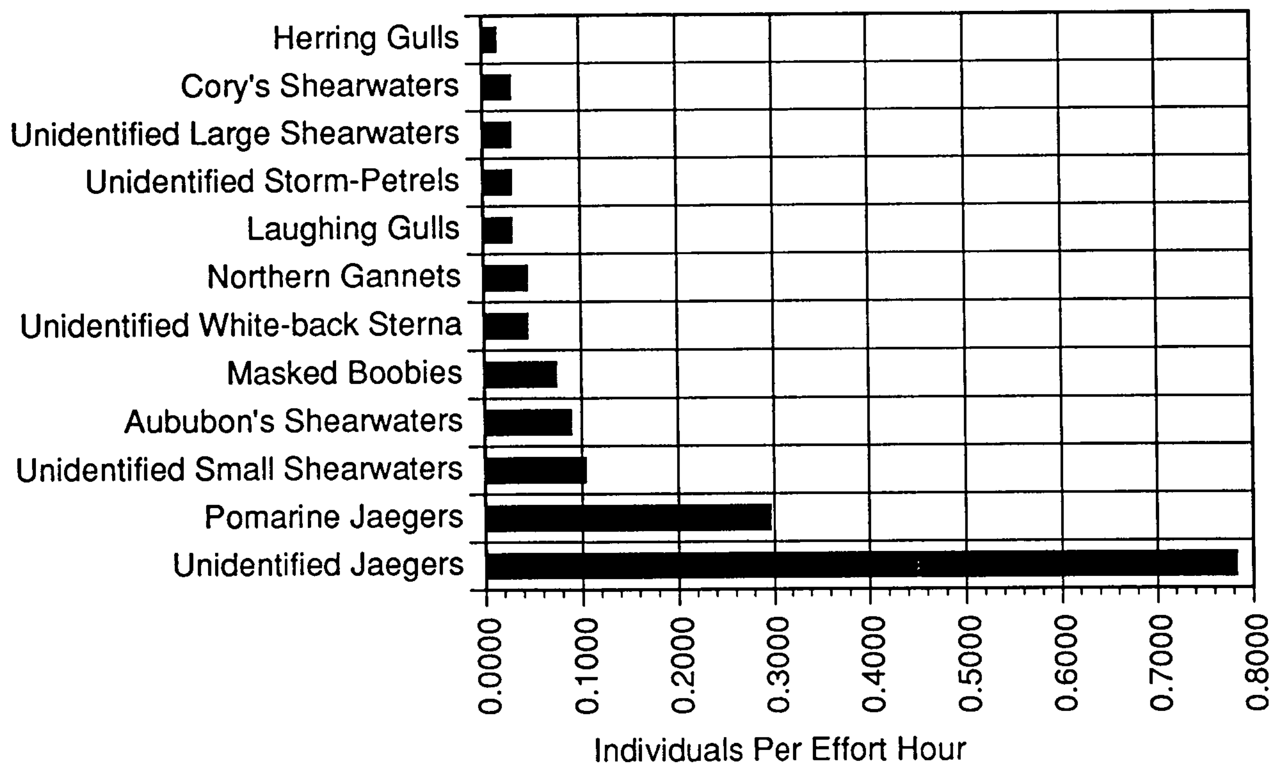

Figure 5D.8. Cruise 3 overall relative bird abundance.

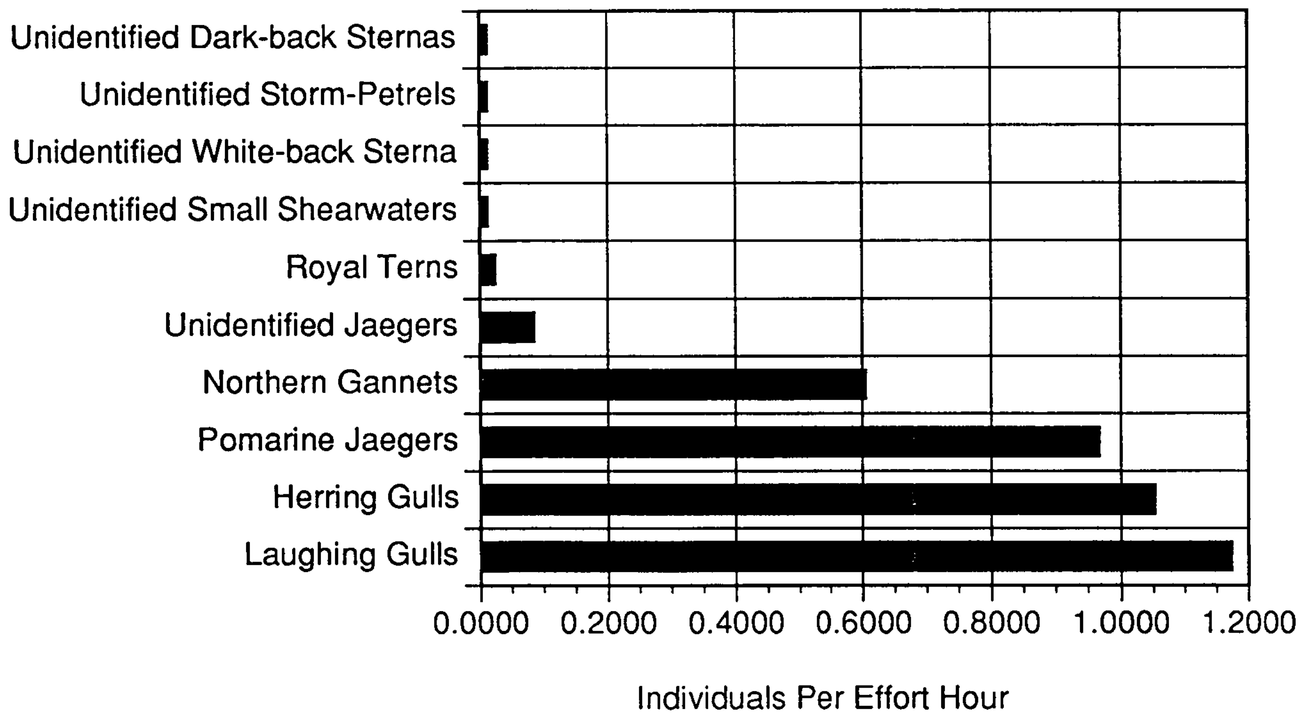

Figure 5D.9. Cruise 4 overall relative bird abundance.

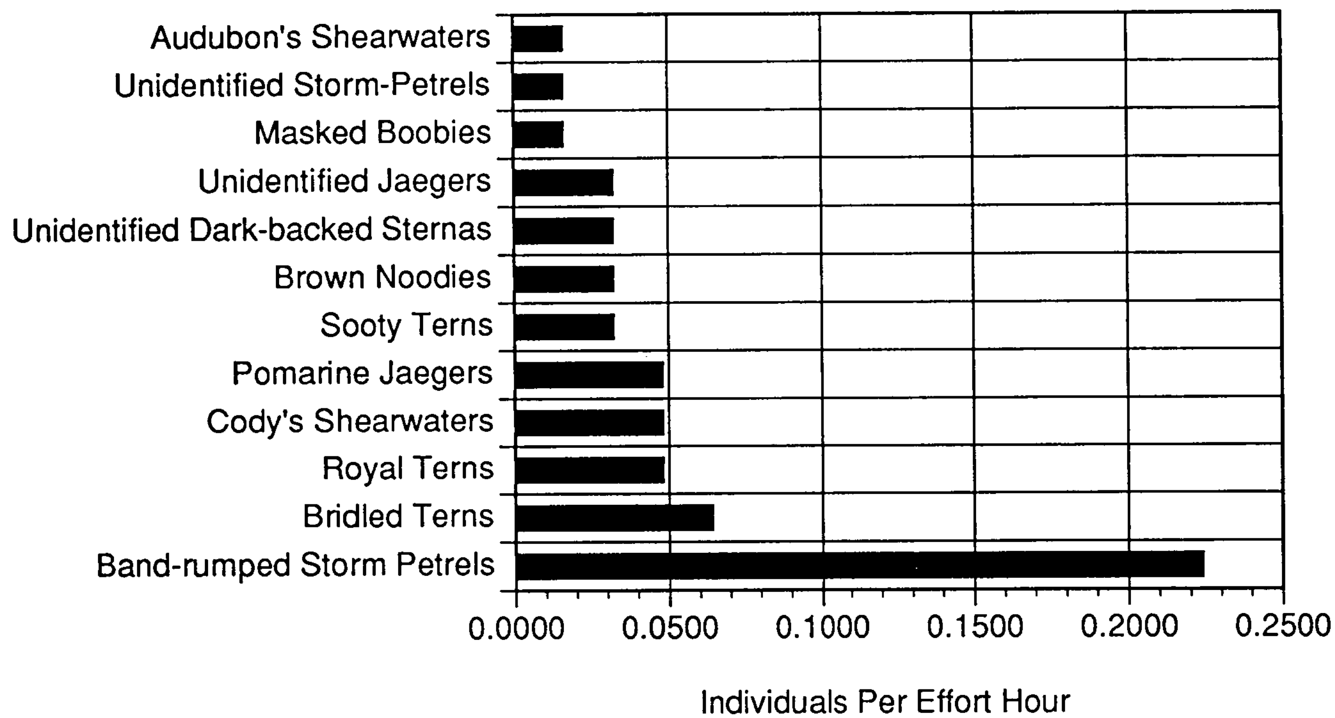

Figure 5D.10. Cruise 5 overall relative bird abundance.

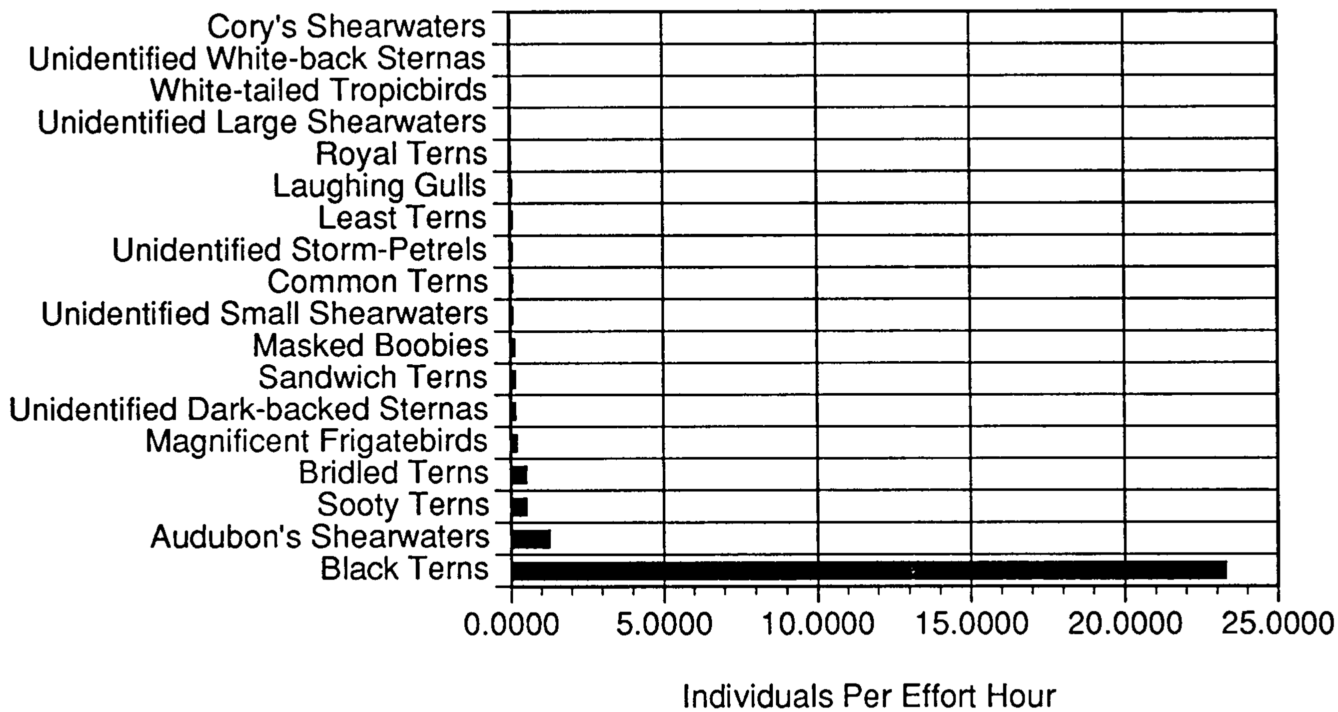

Figure 5D.11. Cruise 6 overall relative bird abundance.

and Pomarine Jaeger, apparently are important constituents of the avifauna of the northern Gulf. The GulfCet data, furthermore, demonstrate that the Gulf of Mexico is an important seabird habitat.

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ACOUSTIC TRACKING OF SPERM WHALES - PRELIMINARY RESULTS

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Mr. Mike Duncan
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ACOUSTIC LOCALIZATION AND TRACKING EFFORTS ON GULFCET CRUISE 8

GulfCet Cruise 8 was designed to test the feasibility of tracking sperm whales acoustically using the horizontal towed array and vertical arrays of sonobuoys. During the cruise (20-28 August 1994), 49 sonobuoys were deployed, 33 of which were used in three-buoy vertical arrays. Plots of the location of the ship and presence of whales were noted every 10 seconds. The cruise track is a good description of the distribution of sperm whales in the study area during the 8 days of the cruise. Sperm whales were encountered throughout the eight-day period in the small area off the mouth of the Mississippi River (see Figure 5D.12). We maintained contact with sperm whales 68% of the time ranging from 80-89% from 21-22 August, then reducing 59, 21, 51% for the final three days. While in the main study area we maintained nearly constant contact. During the three final days we moved to the east, southwest and south to determine the extent of the distribution of the groups being tracked. All whales encountered were within the study area in Figure 5D.13. We photographed a total of 244 sperm whale encounters, though that number will likely include a number repeat contacts.

Both sonobuoys and a towed linear array were used in an attempt to localize sperm whales at depth as well as track them. By using multiple receivers at known locations in a known acoustic environment, enough travel time information could be collected to estimate the location of the acoustic source. The linear array was towed near the surface while the sonobuoys were deployed in close proximity to each other in order to approximate a vertical array. Figure 5D.13 illustrates the combined use of the towed array and the sonobuoys.

The localization and tracking efforts on GulfCet Cruise 8 centered around a matched field type of approach. Given an estimate of the acoustic environment, known receiver positions, and assuming linear ray paths, the most probable location of the source was determined by finding the best match between observed arrival time differences and differences between several hundred pre-defined locations in the acoustic field. We usually selected about 1,024 points in 3-D space over some volume of ocean. Travel time differences for these points were computed taking the temperature effect on the vertical sound speed profile into account. Thirty XBTs were deployed and provided accurate real-time temperature versus depth data. Data on salinity were not collected; therefore 35 psu was assumed. The location associated with the set of travel time differences most closely matching the set produced by the source was presumed to be an approximate location. Figure 5D.14 is an example of the matched field model output. It was found during the cruise that the accuracy of the model could be improved upon by including higher order terms in the time delay calculations. For example, three hydrophones produce three time delay variables; dt_{12}, dt_{13}, dt_{23}. The accuracy is improved on by artificially increasing the dimensionality of the problem with the second order terms; $dt_{12}dt_{13}$, $dt_{12}dt_{23}$, $dt_{13}dt_{23}$.

This technique was used with varying degrees of success. The primary difficulty encountered was that of signal identification. It was sometimes quite hard to identify signals on each of the receivers that were the result of a single source click. Oceanic multipaths and multiple sources made this even more difficult. Also the lack of salinity data was a likely source of error. A more suitable model would include acoustic wave refraction. This would allow us to glean location information from the arrival times of acoustic multipaths and thus turn them into an asset rather than a hindrance. The model also proved to be rather unwieldy for real and near-real time use. This was mostly due to the data acquisition method. The same computer was used for acquisition and processing which slowed the overall process down considerably. Also, times of signal arrival were estimated from the digital record by hand (i.e., picked out one by one on the computer display by the user). Ideally this process could somehow be automated. The amount of qualitative judgment that went into arrival time estimation, especially for multiple targets, would tend to make this kind of automation a less than trivial task.

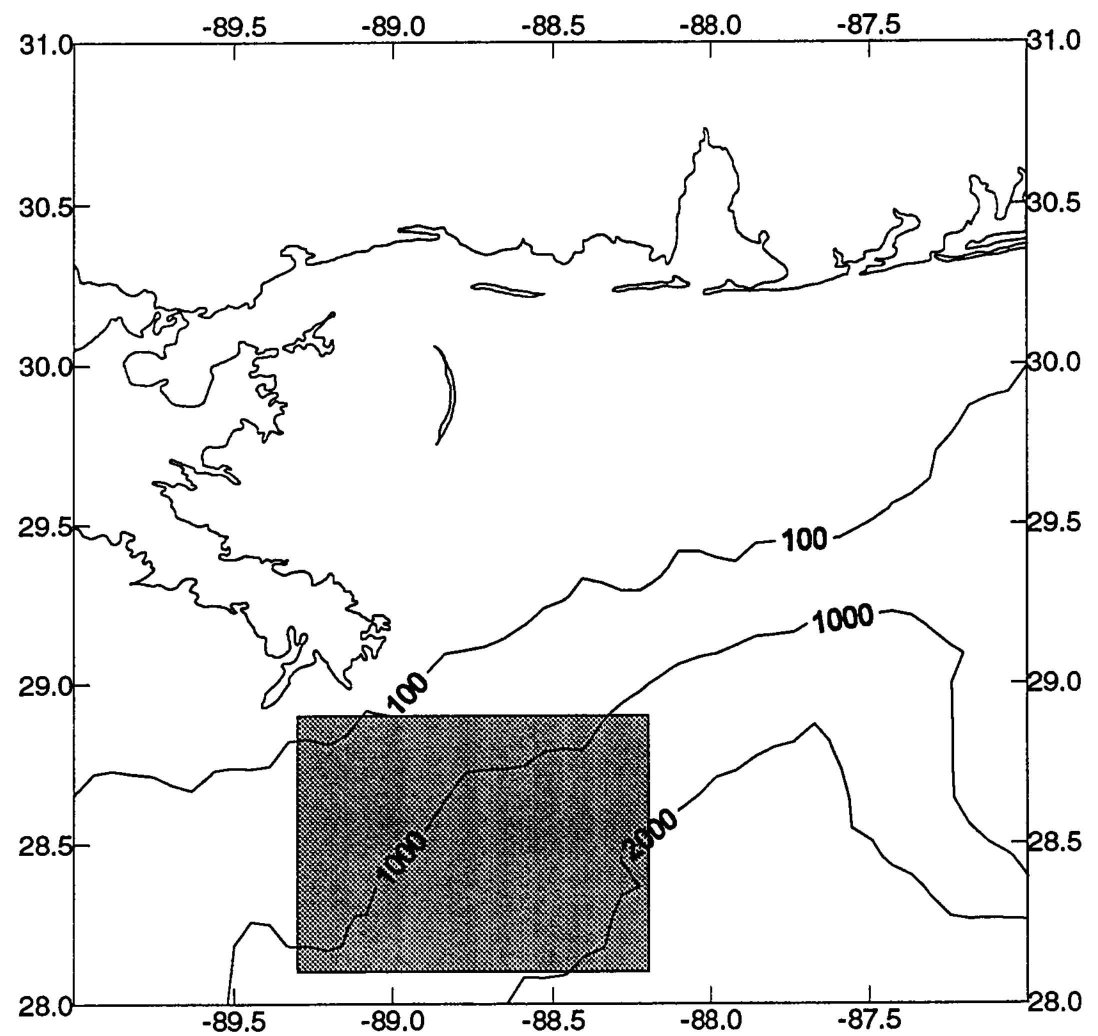

Figure 5D.12. TIO acoustic localization and tracking cruise study area.

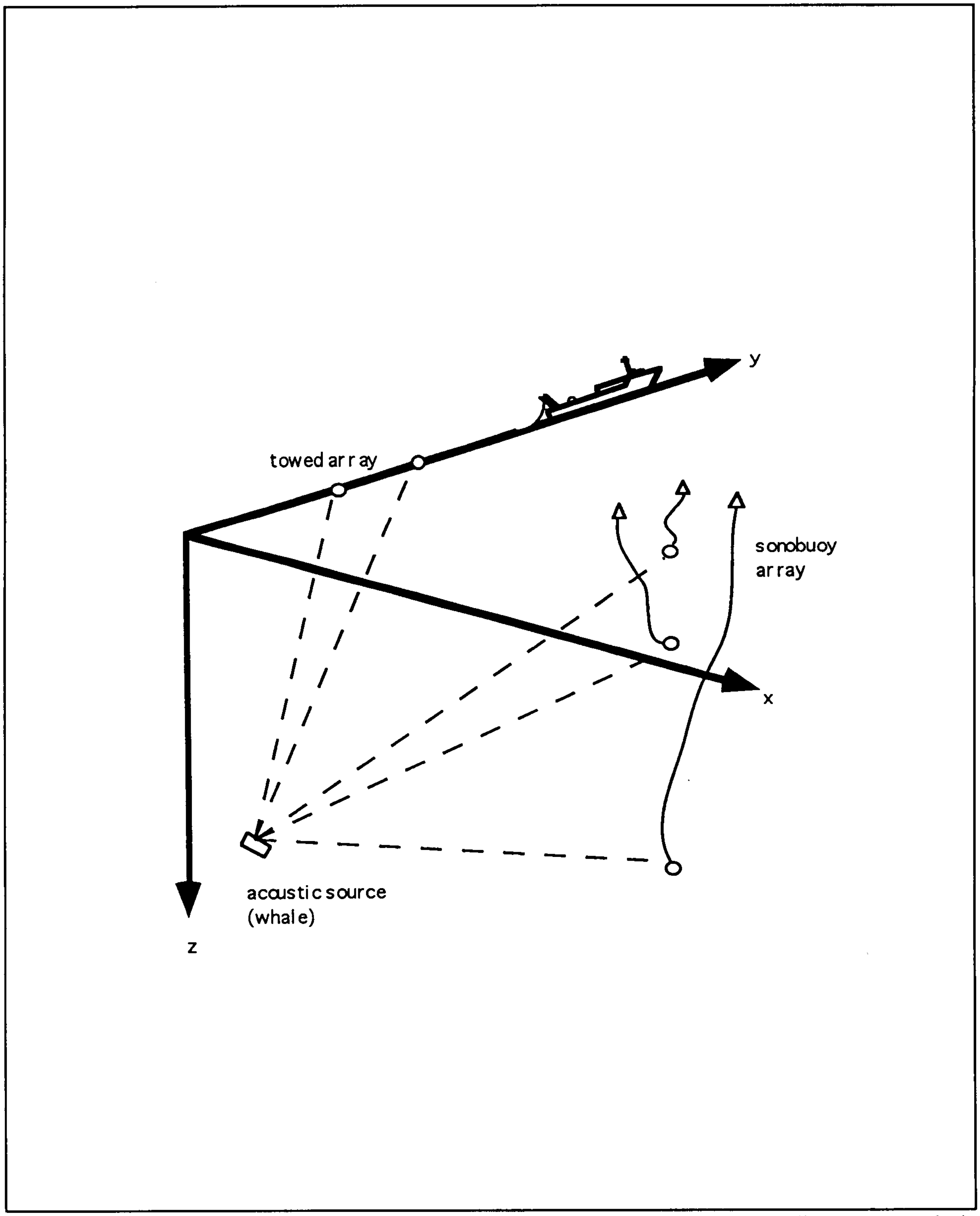

Figure 5D.13 Array configuration. Three sonobuoys are used in conjunction with the towed linear array to obtain ten travel time difference estimates. The origin of the coordinate system used was the location of the aftmost trace in the towed array. The orientation of the axes was the same as shown.

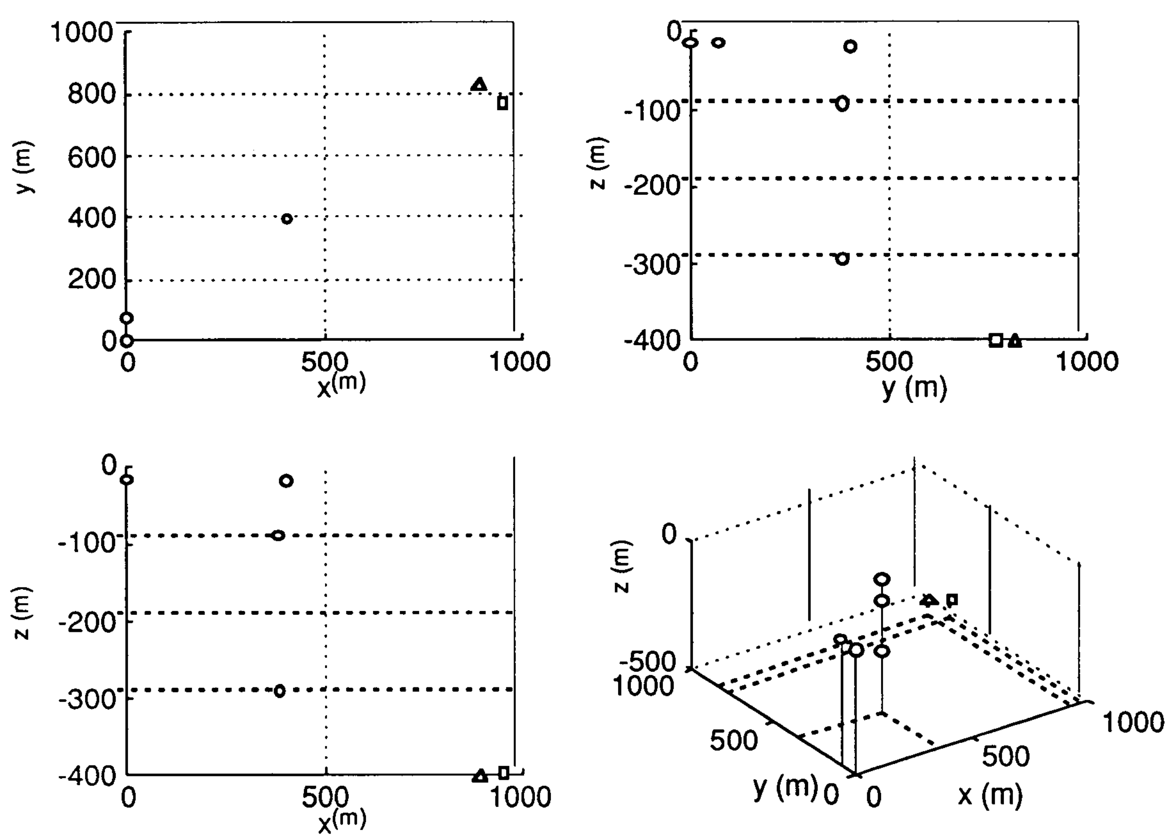

Figure 5D.14. Matched field model output. Given a hydrophone array similar to the one shown in Figure 5D.12, the matched field model estimates the location of a test acoustic source. Views along each of the coordinate axes are shown (see Figure 5D.12), as well as a three dimensional perspective. Circles represent the hydrophone locations. The location of the test source is indicated by a square, and the triangle represents the estimated location.

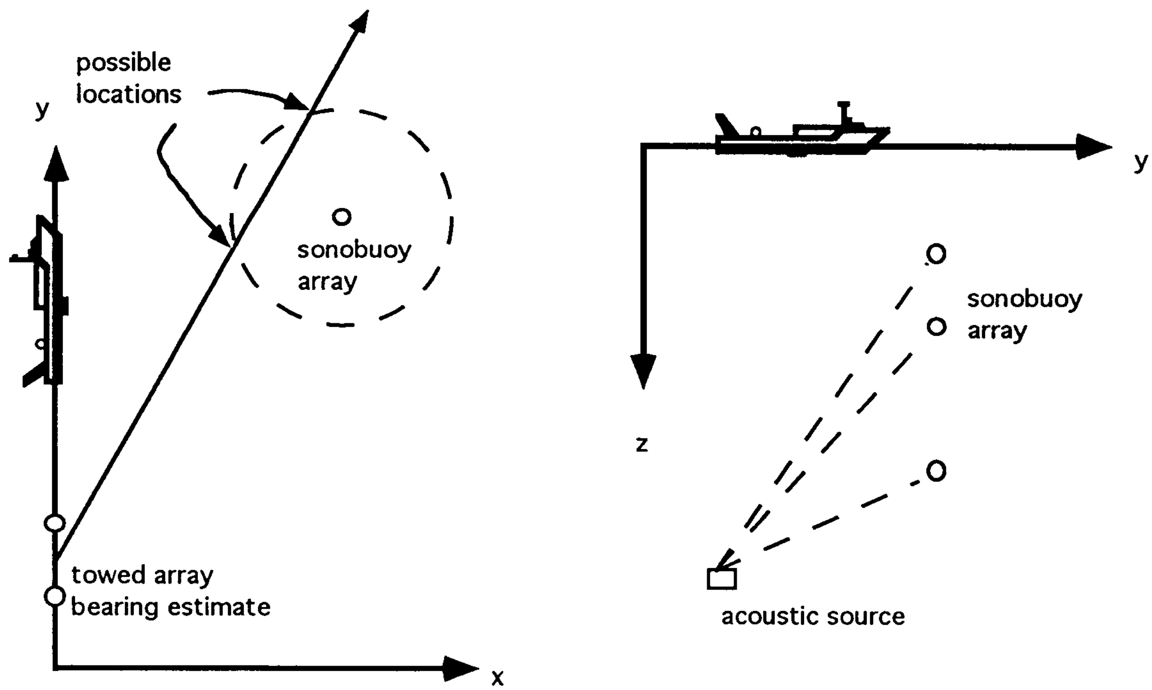

Figure 5D.15. A "de-coupled" version of the array configuration. Range and depth of the source are estimated first using the vertically aligned sonobuoys. Azimuth may then be determined from arrival time estimatesat the towed array. Because the acoustic field no longer needs to be continually re-calculated due to changing relative receiver positions, computation time is minimized.

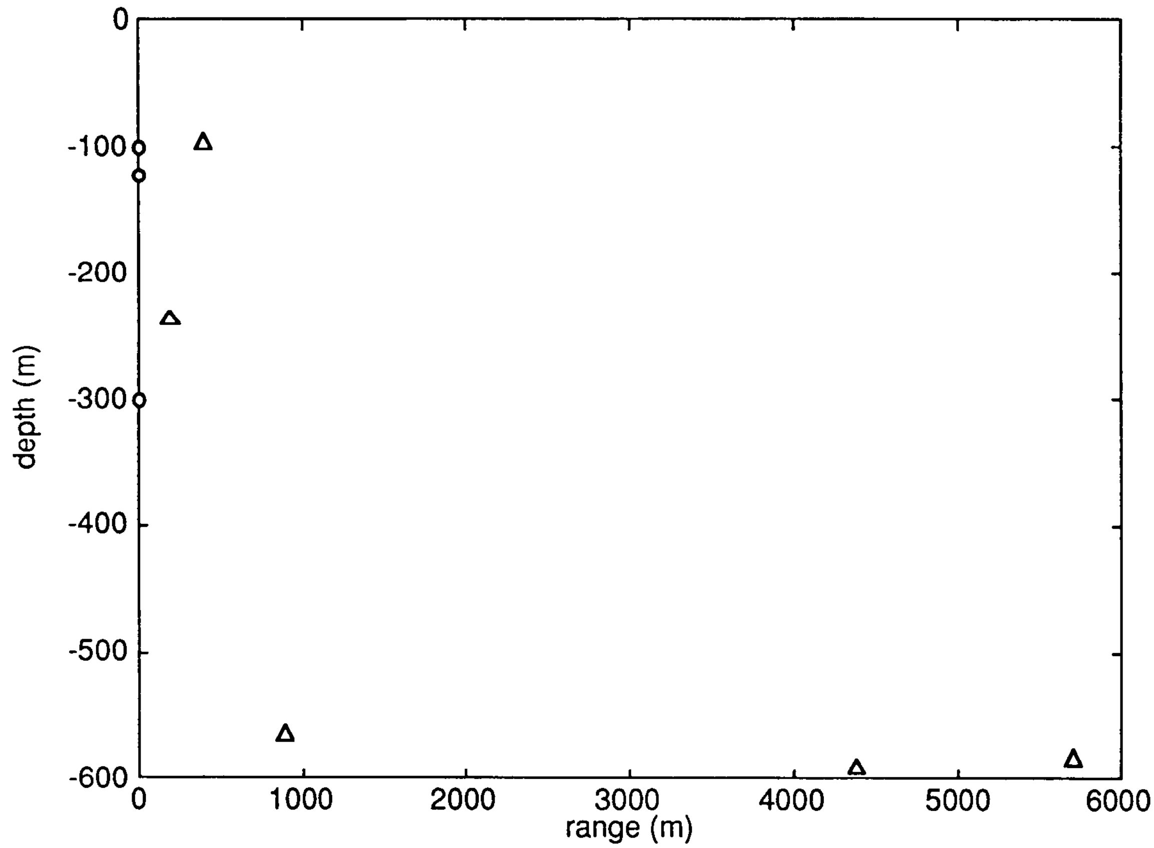

Figure 5D.16. Example of the model output for a single vertical array of sonobuoys. Range and depth are estimated for five whales encountered during GulfCet Cruise 8. Estimates lying near the model bounds are suspect.

During the cruise it was also found that the signals recorded from the towed array near the surface were very unlike those recorded by the sonabuoy hydrophones. This was not altogether mystifying ,as surface scattering may drastically change the shape of a reflected wave form. This increased the difficulty of obtaining distinct arrival time differences between signals received by the array and those received by the sonobuoys. For this reason it was decided that the towed linear array was best processed independently of the sonobuoy array. The sonobuoy array of three hydrophones was used to obtain depth and range estimates in relation to the vertical array axis. This information could then be coupled with corresponding towed array information on source bearing to produce two possible source locations. This also speeds up the required computation time as we now are looking at a 2-D instead of 3-D acoustic field which does not have to be constantly re-evaluated due to the movement of the towed array receivers. The range and depth from the vertical array may also stand alone as valuable information, as depth, at least, is uniquely defined. Figure 5D.15 illustrates the independent use of the towed and sonobuoy arrays. Figure 5D.16 is an example of range and depth estimates from the vertical array output from the model. The model found the closet match in the pre-computed field, so those points lying near the boundaries of the field should be views with some suspicion.

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The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Royalty Management Program** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.