OCEANS '88

"A PARTNERSHIP OF MARINE INTERESTS"

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PROCEEDINGS

VOL 1

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BALTIMORE CONVENTION CENTER, BALTIMORE, MARYLAND OCTOBER 31—NOVEMBER 2, 1988
DONALD SCHAEFER, GOVERNOR OF MARYLAND, HONORARY CHAIRMAN
ADMIRAL PAUL A. YOST, COMMANDANT UNITED STATES COAST GUARD, GENERAL CHAIRMAN

OCEANS '88

A Partnership of Marine Interests

PROCEEDINGS

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OCEANS '88

Proceedings

Volume One

A Message from the Chairman

It is with great pleasure that I extend to you a cordial welcome to the OCEANS '88 Conference and Exhibition. This year's theme, "A Partnership of Marine Interests," is designed to recognize the broad range of interests and institutions which now address marine technological issues, as well as the myriad national and global needs which are supported by marine technology and ocean engineering.

During the remainder of this millennium, the United States, as well as other seafaring nations, will advance their focus on the coastal regions and oceans in order to satisfy emerging economic and recreational needs, meet national defense requirements and, concurrently, plan for the significant socio-environmental concerns associated with accelerated ocean resource and ocean space development.

Given the complexity of the managerial challenges ahead—and the reality that budgetary resources must be utilized prudently—our perspective is that a new "Partnership of Marine Interests," acknowledging the diverse Federal interagency participants, the state governments, the range of comprehensive intergovernmental groups and the relevant international interests, should be pursued. Cooperation and coordination provide the cornerstones for resolving the conflict-use which may emanate from the competing claimants for oceanic resources, as well as constitute the threshold for effective public policy formulation and implementation.

OCEANS '88 provides a timely forum for open discussion of the domestic and global issues related to the role of marine technology in satisfying the specific energy, transportation, fisheries, seabed resource development, law enforcement, safety, environmental, national security and other ocean policy needs and issues. It is an opportunity to discuss how marine technology can be more effectively applied and advanced toward the attainment of both national and international objectives.

This year's conference features an extensive exhibit area to review the latest state of the art in marine technology products, services, systems and publications. Also the conference serves as an arena where industrial representatives, national, state and local governmental officials, academic representatives, public and special interest groups with marine interests, and members of the international community can meet and exchange views in both formal and informal settings.

A number of special events have been planned, including a "Vessel Visit and Orientation" in Baltimore's Inner Harbor, and several specialized topical workshops. In order to provide a closer commonality between the program of more than 400 policy and technical papers presented and the marketing needs of the exhibitors, a "Marine Commercial Development" workshop highlights opportunities for coastal and oceanic oriented businesses in both domestic commerce and international trade.

I thank you all for your participation and support of OCEANS '88.

Paul A. Yost
Admiral, U.S. Coast Guard
Commandant
General Chairman, OCEANS '88

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Welcome to Baltimore and the OCEANS '88 Conference and Exposition

Baltimore Convention Center
October 31–November 2, 1988

On behalf of the sponsors of OCEANS '88, the Marine Technology Society (MTS) and the Oceanic Engineering Society (OES), our General Chairman, Admiral Paul A. Yost, Commandant, U.S. Coast Guard, and our federal interagency and intergovernmental advisory board and conference staff, we extend a cordial welcome to you to the inaugural of the Oceans conference in the port of Baltimore.

OCEANS '88 is now an international as well as national symposium, co-sponsored by the MTS and OES in cooperation with a number of other marine oriented organizations. This year's three-day event involves more than 2,000 conferees presenting more than 400 technical and policy papers, and a display of 175 exhibits featuring the latest development in marine technology and products, services and information systems. Thus, OCEANS '88 is of professional interest to:

- Marine industrial officials
- Oceaniclaw of the sea and marine-oriented academic faculty
- Independent researchers and professional associations
- Federal, marine agency, policy and program officials
- State and territorial marine agency personnel
- Coastal, oceanic and marine agency personnel
- Marine trade media
- International ocean community representatives

In addition to the formal program and exhibits, OCEANS '88 will feature:

- A Chesapeake Crabcake Reception to welcome all conferees.
- A Plenary Session, introduced by Honorary Chairman Governor William Donald Schaefer of Maryland, and featuring several nationally-known federal and intergovernmental officials commenting on the "Partnership of Marine Interests" theme.
- A two-day Ocean Enterprise Workshop designed to examine commercial opportunities for marine-oriented firms and complement both the technical program and the exhibitors' comprehensive range of products and services.
- A Vessel Orientation in Baltimore's inner harbor to provide conference registrants with visits to a U.S. Coast Guard multi-mission, medium endurance cutter; a hydrographic vessel from the National Oceanic and Atmospheric Administration; the HMCS Cormorant, a Canadian research ship; a remotely operated vehicle (ROV); Maryland's historic replica, the Dove; and other vessels with interesting state-of-the-art, naval and engineering designs and systems.
- Emory Kristof, from the National Geographic Society, offering a hands-on tutorial workshop in the use and application of underwater stereographic video. Applicants will be accepted on a first come, first served basis to this workshop.
- A special workshop organized by the Environmental Protection Agency on the timely subject of "Medical Waste: Protecting Our Shores."
- An Ocean Policy Forum, organized by the Center for Ocean Management Studies of the University of Rhode Island on "A Deepest Ocean Presence: The Economic, Political, Scientific and Technical Considerations in the National Interest."
- An Ocean Policy Roundtable on "U.S. Ocean Policy: Agenda for the 1990s," organized by Dr. Bilianca Cicin-Sain and Mr. Robert Knecht of the Ocean and Coastal Policy Center of the University of California at Santa Barbara.
- A workshop on the Future of Passenger Vessels, a small but emerging growth industry within the larger maritime commercial complex.
- An "Oceans Evening" reception at the National Aquarium to commemorate the Silver Anniversary of the Marine Technology Society and honor its past presidents.
- An Oceans '88 Film Festival, introduced by Mr. Charles Sachs, nationally known passenger vessel historian, and Mr. Ralph White, renowned marine photographer.

The entire proceedings of OCEANS '88 have been recognized by the U.S. Senate and House of Representatives in Joint Resolutions designating the period of October 30 to November 5 as National Marine Technology Week. This initiative is the result of the efforts of Senators Lowell Weicker, Ted Stevens, Ernest Hollings, Daniel Inouye, John Kerry, Frank Lautenberg, Claybourne Pell, and Representative Walter Jones and other members of Congress.

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Authors List

MARINE DEBRIS AND THE SOLID WASTE DISPOSAL CRISIS

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ABSTRACT

Persistent wastes from ocean and land sources damage wildlife, impede maritime commerce and foul our beaches. Solutions to the marine debris problem include eliminating both land and sea sources. The MARPOL model is widely supported and may well control ship-source persistent debris. Land source marine debris control, however, will necessitate innovative solutions to the much broader solid waste disposal crisis in the U.S. In order to motivate, support, and lead this effort, the "ocean ethos" in the U.S. society must be invoked. The marine debris issue may have the broad appeal necessary to bring public sentiment to bear directly on the solid waste disposal problem. The early development of a national solid waste agenda and the identification of a single responsible Federal entity will be key early milestones in the ultimate solution of the marine debris problem.

1. INTRODUCTION

Population growth, burgeoning technology and unbridled consumption in the developed world have combined to create an immense solid waste problem. The United States, with the highest, per capita solid waste generation rate in the world, is just beginning to develop a realistic appreciation of the urgency of this problem. That its proportions are reaching critical levels is evidenced in the recent reports of the impacts of inert, persistent wastes on ocean resources. These wastes are now so prevalent in the environment that ocean and coastal accumulations from land-based sources and from ships are killing marine life, interfering with maritime commerce and detracting from enjoyment of our natural heritage (1, 2, 3, & 4).

A significant factor in the marine debris problem is the persistence of modern synthetic materials. They are generally not destroyed or significantly degraded by natural forces in time scales relevant to their transport to, residence time in, and impacts upon aquatic environments (5). By virtue of this persistence, materials discarded or otherwise released into the environment on land have some probability of being transported by natural forces to debris "sinks" such as the sea or freshwater lakes. Upon reaching the aquatic environment either indirectly from the land or directly through ocean discharge, the floating materials are transported in the two dimensional surface environment by winds and currents. These forces serve to concentrate floating debris in convergence zones, along drift lines, and on the ocean margins. Persistent materials that are non-buoyant reach the sea floor in the vicinity of their discharge, accumulating in patterns mirroring the activities which generated them. Further, persistence guarantees that these accumulations become larger and larger. Currently, this is a one-way system which can only result in ever-more serious impacts.

At issue here is the need to control, reduce and/or eliminate the flow of persistent wastes into the aquatic environment. To actually solve the marine debris problem, all input must be eliminated and the current (for all practical purposes, permanent) standing stock of debris must be cleaned up and destroyed or re-utilized. We know that at current levels, debris in the marine environment causes problems. This debris will not go away through elimination of further supply, so it also must be removed. Similarly, even small amounts of continued input will increase the levels of impacts now recognized. For these reasons, elimination of this problem must encompass both the ocean sources and the land-based sources. While these goals are similar, their accomplishment will surely be vastly different.

2. THE OCEAN SOURCE SOLUTION

Ship-source ocean pollution has been recognized as an international problem since offshore oil platforms and supertankers began leaking, blowing-out and going aground (Torrey Canyon, Amoco Cadiz, Santa Barbara, etc.). To establish international standards and mechanisms for controlling discharges of oil and other polluting cargos into the oceans, the International Convention for the Prevention of Pollution from Ships was formed in 1973 (6) under the International Maritime Consultative Organization (now the International Maritime Organization, IMO). The Convention was modified in 1978 to create five optional annexes, each addressing a separate type of ship source pollutant. This step was necessary to permit nations to ratify the Convention and the oil discharge provisions (Annex I) without being bound by the terms of Annexes II through V which address noxious liquid substances carried in bulk, harmful substances in packaged forms, sewage, and garbage, respectively. The Convention is referred to as "MARPOL (73/78)".

For centuries customary international law has permitted ships operating outside the territorial seas of any nation to discharge their garbage overboard. This will be changed on December 31, 1988 when Annex V, the "Regulations for the Prevention of Pollution by Garbage from Ships," enters into force for the thirty one ratifying nations representing over 50 percent of the world's shipping tonnage. The Annex specifically applies to all manner of ships, including fishing and recreational vessels, cargo ships, fixed or floating platforms and submersible craft. Annex V and the IMO "Draft Guidelines for the Implementation of MARPOL Annex V, Regulations for the Prevention of Pollution by Garbage from Ships" provide the authority and model by which nations may eliminate the ocean sources of persistent marine debris.

The United States has ratified Annex V and is tailoring implementing regulations for U.S. citizens, ships, and ports based on the Guidelines. In drafting the U.S. implementing legislation, entitled the "Marine Plastic Pollution Research and Control Act of 1987" (MPPRCA), Congress recognized that full realization of the intent of Annex V requires a fundamental change in maritime attitudes and behavior towards garbage (7). In response to this, the MPPRCA mandates the establishment of education and public awareness programs. It also sets up penalty schedules that will prevent discharge violations from becoming part of the cost of doing business. A "snitch clause" is included which allows up to one-half of any fines levied against violators to be paid to persons providing information leading to successful prosecution. The current approach to regulations under the MPPRCA will preserve ship operators' options for provisioning and shipboard waste handling while educating them on the reasons for, and methods to comply.

If one takes the long term approach to this problem (as one should in instituting changes in longstanding individual and industrial behavior) there is reason for optimism that ocean-source persistent debris will be virtually eliminated. The problem has received institutional attention and the preliminary solution strategies are in place (3).

The degree to which these strategies succeed will depend on the leadership, vigor, and balance Federal and State agencies bring to the education, enforcement and research programs. In order to gauge progress in solving the ocean-source persistent marine debris problem, a general set of milestones should be established, including:

1. Cooperative enforcement agreements in place between State and Federal Agencies and foreign governments by December 31, 1989;

2. Systematic marine debris monitoring systems covering each region of the U.S. by January, 1989;

3. Guidelines to States for establishing marine debris task forces through which State agencies may rationalize their actions to address marine debris sources of particular interest to their citizens by October 1, 1988;

4. Issuance of certificates of adequacy for garbage reception facilities in all major ports in the U.S. by January, 1990;

5. The production and broadcasting of national public service television announcements on the marine debris issue by June 1989;

6. The establishment and advertising of marine debris information and education materials outlets for broad public use by January, 1989;

7. Official recognition of the IMO guidelines for the implementation of Annex V, concurrent with IMO official adoption (September, 1988), including a continuing commitment to improve them;

8. U.S. commitment to the development of Annex VI to MARPOL (73/78) to specifically address the control of discharges of solid cargos transported in bulk;

9. Diplomatic initiatives to promote ratification and implementation of Annex V by all maritime nations as standing Department of State policy, by December 31, 1988, and

10. Research and monitoring programs to assess the effects of persistent marine debris on depleted, threatened, and endangered species, continuous (8).

That is the easy part. The other component of this problem, its land-based sources, will not be so easily solved.

4. THE LAND-BASED SOURCE SOLUTION

We do not know how much solid waste is illegally dumped or accidently lost each year in the U.S.. There are statistics on what is collected and disposed of legally. Municipal wastes generated in the U.S. amounted to 158 million tons in 1986 according to EPA testimony before Congress July 26, 1988 (9). Ten million tons of that was plastic, six million tons of which was plastic packaging materials. By the year 2000, EPA expects a 60% increase in plastic waste by weight. The total municipal wastes generated in 2000 is expected to reach 193 million tons, increasing in volume by 22 percent. The U.S. plastics industry produced over 53 billion pounds of new plastics in 1987 (10), about one quarter of the world production. About 25 percent of the U.S. production each year goes to plastic packaging.

EPA further testified that in the U.S., 80% of municipal waste is landfilled and that one-third of the nations landfills will reach capacity by 1992. It is certain that disposal costs will soar in the near future. These increases will motivate industries and the public in two distinct directions.

First, rising disposal costs will cause individuals and industries to seriously explore means to reduce the amounts of wastes they generate. Re-utilization, recycling, packaging alternatives, composting, home incineration, etc. are all action areas likely to be explored. Second, they will be much more likely to take advantage of low risk opportunities to illegally dump their garbage, exacerbating the litter problem. The balance of public choice in this dilemma will seriously impact the flow of persistent debris into aquatic environs. To achieve the long-term solution of the marine debris problem, the public must face the municipal solid waste crisis armed with accurate information about the consequences of their choices. As the designated steward of natural resources in the public trust, particularly for the long-term, it is essential that the Federal Government provide direction in this issue. That direction and leadership is overdue.

When considering the range of actions the government may take in addresssing the solid waste problem, the first step should be to review existing models of public process that may be applicable. For example, there are regulatory mechanisms in place to control land-source persistent debris but, they have not prevented littering and other careless acts that release trash into the environment. A drive in the country or a visit to your favorite fishing hole provides ample evidence that present anti-litter laws simply have not worked. There is little reason to suspect that they will become more effective if pressures for illegal dumping increase.

More stringent regulatory systems may be worthy of consideration for eliminating land-source debris. For example, throughout the 70's and 80's, significant public attention and government regulation have been focused on toxic pollutants. These types of pollutants are generally similar to persistent debris in that many are stable (persistent), they originate on land, they are transported by water, they accumulate, they are difficult to remove from the environment, and they can only be effectively controlled at their sources.

It is tempting to model measures for controlling land-source debris after the methods in use to control toxic pollutants. Such methods include prohibitions on manufacture, cradle-to-grave record keeping, elaborate waste handling and destruction systems and permitting systems with varying justification and liability requirements. Such measures could certainly work, however, there are three fundamental differences between toxic pollutants and inert debris that lead one away from these types of stringent regulatory methods:

1. Virtually everyone is a potential contributor to the persistent debris problem;

2. The weight and volume of inert, persistent wastes exceeds toxic pollutants by many orders of magnitude, and

3. Land-source persistent wastes pose little direct human health hazard and few known population-level threats for wildlife.

In view of number three, it is unlikely that the populace will accept being burdened with onerous handling and record keeping requirements for the persistent components of their trash.

If stringent regulation is not justified, and current anti-litter and waste management statutes are inadequate, what is to be done? Clearly, the long-term health of the coastal oceans is in some mounting jeopardy due to accumulating persistent wastes, just as it is from accumulating toxic pollutants, bio-pollutants, and habitat loss. Just as clearly, protection of ocean life and productivity, is going to necessitate a fundamental revision of waste management and disposal policies, politics and behavior; right down to the individual citizens.

The gravity of this situation is not in the marine debris problem; it is in the solution to the broader, incredibly more urgent solid waste management problem. While the solution to the solid waste disposal problem in the developed world will largely solve the marine debris problem, the reverse is certainly not true. A paradox of sorts arises here in that society (and for the most part government), in the United States appears to be highly concerned with the marine debris problem and much less motivated by the national solid waste crisis. The foundation of this incongruity lies in the emergence of a national, deep-seated "ocean ethos" through the 1960's and 1970's (11). Blatant evidence of this preoccupation with ocean issues can be seen in the labyrinth of federal agencies, commissions, committees and institutions with authorities or jurisdictions over marine affairs. A recent compilation counted 54 marine oriented federal agencies and entities, 86 federal statutes addressing marine affairs, and 51 congressional subcommittees (32 House, 19 Senate) with ocean jurisdiction of some sort (12).

While it is exceedingly difficult to see how this massive ocean bureaucracy could provide the leadership needed to address the solid waste crisis, public concern and support suggests that an effective start could be made here. Is it appropriate to use the marine debris problem's current appeal to the public and to government entities to lead them into facing the national solid waste disposal problem? Nothing else seems to have generated as much concern to date or have as much potential to motivate the legal, technological and behavioral evolution required to solve the solid waste, hence, the marine debris problem.

In recognizing the linkages between solid waste management on land and the pollution of the oceans, the ocean bureaucracy must organize itself to develop, or initiate and support the development of, a national solid waste management agenda. Some signposts of progress in this endeavor would include:

1. Preparation and publication of a national policy and goals statement regarding solid waste disposal issues;

2. Designation of a single agency or other Federal entity to carry out these policies and be responsible for meeting the goals set out in the national agenda;

3. Identification of recycling, especially plastics, as a primary national goal, consolidating all related Federal authorities that promote recycling under a single act and agency;

4. Establishment of required solid waste education curricula for elementary and secondary schools nationwide;

5. Establishment of a long-term national public awareness campaign focusing on national needs for solid waste disposal efficiency;

6. Review and revision of any statutes providing incentives to create solid waste or disincentives to recycling, re-utilization or other efficient waste management processes as may be developed;

7. Review and revision of existing solid waste disposal enforcement policies and resources to insure maximum effectiveness of existing authorities;

8. Developing of methods and a program to monitor the flow of land-source persistent wastes into the aquatic environment;

9. Initiation of a thorough technical and economic evaluation of incineration and heat recovery incineration options for destruction of solid wastes, both land-based and offshore;

10. Evaluation of the options for ocean disposal of certain categories of inert solid wastes, and

11. Evaluation of the uses for intermediate products or by-products of waste destruction such as ashes and slag, mixed plastic blocks, chemicals and heat, etc.

5. CONCLUSIONS

In order to facilitate the solution to the marine debris problem, these actions should be undertaken immediately. The ocean community must recognize their critical role in initiating and maintaining the drive toward effective solutions for the national solid waste management crisis.

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FEDERAL PROGRAMS AND PLASTICS IN THE OCEANS

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ABSTRACT

In response to increasing concern over plastic pollution in the oceans, the Administration formed the Interagency Task Force on Persistent Marine Debris. Eleven Federal agencies participated on the Task Force, which the National Oceanic and Atmospheric Adminstration (NOAA) led. The Task Force assessed existing information and programs, and recommended additional activities to reduce problems caused by marine debris.

Marine debris causes three types of problems: 1) it affects fish and wildlife by entangling them and they ingest it; 2) it litters beaches, and can create human health problems if it has stored toxic or infectious substances; and 3) it clogs vessel intake ports and propellors.

The Task Force recommended that Federal agencies expand public awareness campaigns, continue research on effects plastic debris causes, and support local activities to remove debris. In December 1987, the President signed a law which will prohibit disposal of plastic materials in oceans prior to January 1, 1989.

1. INTRODUCTION

During 1987, the White House Domestic Policy Council (DPC) formed the Interagency Task Force on Persistent Marine Debris, which the National Oceanic and Atmospheric Administration (NOAA), chaired, to:

> "assess the problem and the need for research, identify potential reduction measures, and consider alternative actions to address the problem of plastic marine pollution."

Representatives of seven Departments, four independent agencies and the White House participated on the Task Force:

- Department of Agriculture, Animal and Plant Health Inspection Service
- Department of Commerce, National Oceanic and Atmospheric Administration
- Department of Defense, U.S. Navy
- Department of Health and Human Service, Food and Drug Administration
- Department of the Interior
- Department of State
- Department of Transportation, U.S. Coast Guard
- Council on Environmental Quality
- Environmental Protection Agency
- Marine Mammal Commission
- Office of Management and Budget
- White House Office of Policy Development

The Task Force reviewed available data on sources and effects of persistent marine debris and developed a series of recommendations to reduce the problems.

One of the major foci of the report was to determine the extent of ongoing programs in the Federal, state, and local governments, and the private sector. Were these efforts coordinated or complimentary? Were Federal agencies pursuing similar goals through research, education, and/or mitigation activites? What were the appropriate roles for various levels of government, interaction with the environmental community, and private sector?

In this paper, I summarize two parts of The Report of the Domestic Policy Council Interagency Task Force on Persistent Marine Debris (hereafter cited as ITFPMD, 1988)—the recommendations and who is doing what to alleviate problems caused by marine debris. For comprehensive discussions of the problems, sources of debris, and legal issues, I suggest readers go to the Report (1), several excellent references cited therein, including Center for Environmental Education (2), Heneman (3), Laist (4), and Fowler (5 and 6), other papers presented during this panel, and others at this conference.

2. RECOMMENDATIONS

The DPC endorsed all of the general and specific recommendations that the Task Force made—five general recommendations and 23 more specific recommendations.

These recommendations are aimed at reorienting the priorities of the Federal government to address appropriately the problems of persistent marine debris (pmd). These recommendations direct agencies to increase effort and provide technical as well as educational materials to state and local governments, private citizens, and industry.

Recommendation 1: Federal Leadership:

Federal agencies should provide leadership and continue formal and informal coordination activities related to marine debris with international organizations, state and local governments, private industry and environmental groups. Federal agencies acknowledge that an effective program is only possible with strong state and local involvement.

Recommendation 1A: Federal agencies should cease disposal of plastic materials into the ocean from all Federal vessels as soon as possible.

Recommendation 1B: Federal agencies should review their procurement and concession policies in coastal facilities to reduce the amount of plastic packaging, containers, and other products that are improperly disposed of and become persistent marine debris.

Recommendation 1C: Federal agencies should continue to participate actively in international forums to reduce persistent marine debris.

Recommendation 1D: Federal agencies should encourage plastic waste recycling by: 1) providing separate receptacles for different types of trash at coastal facilities; 2) purchasing and using recyclable products and materials whenever possible; and 3) providing technical support to state and local agencies and industry on recycling.

Recommendation 1E: NOAA should coordinate and disseminate information related to persistent marine debris. NOAA should call at least two meetings of appropriate Federal agencies each year to discuss each agency's education, regulatory, and research programs, as well as to ensure that a contined coordinated effort is made to maximize the effect of existing Federal programs.

Recommendation 1F: NOAA should continue to sponsor the informal Marine Debris Roundtable.

Recommendation 1G: The Administration should support the NOAA/Marine Entanglement Research Program by including it in the Administration's FY 1990 budget and for at least five years thereafter.

Recommendation 1H: Persistent marine debris should be included as an element in the 5-Year Federal Plan for Ocean Pollution Research, Development, and Monitoring.

Recommendation 2: Public Awareness/Education Program:

Concerned Federal agencies should work with each other, state and local governments, private industry, and environmental groups to develop comprehensive educational materials on problems caused by marine debris and ways to solve them.

Recommendation 2A: Federal agencies should cooperatively support a major public awareness campaign by providing seed money and encouraging funding by the private sector.

Recommendation 2B: The U.S. Coast Guard, U.S. Navy, and other Federal agencies should include materials relative to persistent marine debris problems in all educational materials for employees and candidates for licenses.

Recommendation 2C: Federal agencies should use all appropriate media to explain both problems marine debris causes and proper disposal methods. Federal agencies should support formation of an interagency information exchange for available educational materials.

Recommendation 2D: The U.S. Coast Guard should begin a public education campaign on the requirements of the Marine Plastic Pollution Research and Control Act as soon as possible to assure that owners and operators of all vessels, ports, and the boating public are aware of requirements prior to their entering into force.

Recommendation 3: Vigorously Implement All Laws Related to Marine Debris:

The Department of Transportation, EPA, NOAA, and Navy should vigorously implement the Marine Plastic Pollution Research and Control Act and other laws to reduce plastic pollution in the marine environment.

Recommendation 3A: Each agency should make compliance with requirements of the Marine Plastic Pollution Research and Control Act a high priority.

Recommendation 3B: The Coast Guard and other Federal enforcement agencies should make enforcement of regulatory requirements of the Marine Plastic Pollution Research and Control Act a high priority.

Recommendation 3C: NOAA should encourage regional fishery management councils to include requirements that fish and shellfish traps and pots have degradable panels or latches.

Recommendation 4: Research and Monitoring:

Federal agencies should carry out research to:

a) identify and quantify deleterious effects that marine debris causes for fish and wildlife, coastal communities, and vessels;

b) determine land-based sources of marine debris; and

c) assess potential uses for, by-products of, and effects of by-products of degradable plastic products.

Recommendation 4A: NOAA, the Fish and Wildlife Service, the Marine Mammal Commission and other agencies should expand research and monitoring activities to determine more precisely impacts of persistent marine debris on fish and wildlife populations, particularly endangered, threatened, and depleted species.

Recommendation 4B: Federal agencies should work with state and local governments, universities, merchant vessel owners and operators, commercial and recreational fishermen, and local communities to quantify economic impacts caused by persistent marine debris.

Recommendation 4C: EPA, NOAA, Coast Guard, and other agencies should carry out research to determine contributions of land-based and vessel sources of plastic refuse to the overall problems, as well as ways to reduce plastic debris from all sources.

Recommendation 4D: NOAA should work with fishermen and equipment manufacturers to develop pragmatic ways to:

1) reduce loss of fishing equipment, particularly traps, trawl nets, and gill nets;
2) improve ways to recover lost fishing traps and nets; and
3) recycle used fishing nets and net fragments.

Recommendation 4E: The National Bureau of Standards should work with the ASTM (formerly known as American Society for Testing Materials) and other industry associations to develop standards and criteria for what constitutes "bio-degradable" and "photo-degradable".

Recommendation 4F: EPA, FDA and NOAA should work with plastic manufacturers to examine how degradable plastics react in the environment, including potential environmental effects as the plastic degrades.

Recommendation 5: Beach Clean-up and Monitoring:

Federal agencies should work cooperatively among themselves, as well as with state agencies, private industry, and environmental groups to remove marine debris from beaches and other parts of the marine environment. Federal agencies should encourage coordination with state and local authorities to conduct systematic monitoring of marine debris accumulation and impacts to assess compliance with regulations prohibiting disposal of plastics and controlling other solid waste discharges into U.S. waters.

Recommendation 5A: Federal agencies which manage coastal properties should step up actions to remove persistent marine debris.

Recommendation 5B: Federal agencies should support local volunteer beach clean-up efforts as well as the collection and interpretation of data on what the volunteers remove. Federal managers should encourage employees to participate in volunteer clean-ups.

3. FEDERAL PROGRAMS

Of the eleven Federal agencies participating on the Interagency Task Force, eight are directly involved: NOAA, EPA, the Navy, the Coast Guard, the Department of State, the Fish and Wildlife Service, Minerals Management Service, and Natioanl Park Service within the Department of the Interior, the Animal and Plant Health Inspection Service, and the Marine Mammal Commission. Each has a different role and accordingly, diverse programs to address the breadth of the problem. Table 1 briefly summarizes roles and ongoing programs of Federal agencies.

Almost none of the work conducted on persistent marine debris is identified as such in official government budgets or program documentation. For instance, debris removal from national wildlife refuges and seashores comes under the official heading of "Operations and Maintenance" and video tapes produced by Sea Grant universities are funded through the communications department at schools. Therefore, determining precisely how much government agencies are spending on various aspects of marine debris is difficult. Table 2 shows approximate Federal agency expenditures (FY 1987 dollars) on persistent marine debris.

Department of Commerce, NOAA. The only Federal program on marine debris directly budgeted is the NOAA/National Marine Fisheries Service Marine Entanglement Research Program (MERP). Congress has funded MERP at approximately $750,000 since FY 1985. MERP supports a variety of research by Federal and university scientists (mostly biologically oriented), educational programs for fishermen and the general public, and mitigation. MERP established the Marine Debris Roundtable as a way for Federal agencies to coordinate their activities with environmental groups, state agencies, and private industry groups.

Department of the Interior

Minerals Management Service (MMS). The MMS in the Gulf of Mexico region has taken an active role in local efforts to increase awareness of persistent marine debris within the oil and gas industry and citizens there. MMS organized the Take Pride in the Gulf Task Force to bring together interested parties.

MMS regulates activities on oil and gas platforms in Federal waters. MMS regulations prohibit disposal of solid wastes, including plastics, from offshore platforms and supply vessels.

National Park Service (NPS). The NPS manages national parks, national seashores, and waterways throughout the country. As part of its educational programs for visitors, NPS includes information on beach debris and litter control. The NPS maintains the property it manages, including removal of refuse. Officials at Gateway National Seashore in New York Harbor estimate that they spend approximately $1.7 million per year removing debris from beaches. In a survey of costs associated with cleaning beaches managed by the NPS, officials estimate that they spent approximately $950,000 from operational budgets to clean beaches, in addition to over 50,000 man-hours of volunteer labor which picked up and removed debris from beaches.

The Take Pride in America campaign focuses on care and stewardship of public lands. Local parks and groups use the Take Pride banner to organize beach clean ups and gain media access.

Fish and Wildlife Service (FWS). The FWS manages coastal wildlife refuges, from which it removes debris, and monitors debris affecting wildlife, particularly sea birds.

Department of Defense, U.S. Navy. The Navy is developing shipboard compactors, pulpers, and thermal processors for plastics. As new equipment becomes available, the Navy will test it aboard ship. The Navy is altering its procurement practices to reduce plastic packaging brought aboard ship.

Department of Transportation, U.S. Coast Guard. The Coast Guard is currently preparing regulations to implement Public Law 100-220, effectively Annex V of MARPOL, which will take effect on December 31, 1988. The regulations will prohibit discharge of plastic materials from U.S. ships worldwide and from all ships within the U.S. Exclusive Economic Zone. The Coast Guard leads the U.S. delegation at the International Maritime Organization, where the U.S. has raised a number of marine pollution issues including Annex V.

Department of Agriculture
Animal and Plant Health Inspection Service (APHIS)

APHIS regulates garbage on ships which arrive in U.S. ports and have previously visited ports other than continental U.S. and Canadian ports. Garbage regulated by APHIS includes food and any wrapping or preparation equipment which has contacted food. APHIS requires all food-associated garbage from those vessels to be incinerated or cooked prior to disposal in landfills.

Environmental Protection Agency (EPA). Through regulations implementing the Clean Water Act and Ocean Dumping Act, EPA prohibits discharges of solid wastes, including plastics, from waste water treatment plants and point sources on land. EPA conducts research to determine types and sources of plastic material which becomes marine debris. EPA funded the Center for Environmental Education to produce Oceans of Plastic: More Than a Litter Problem (CEE, 1987).

Marine Mammal Commissison (MMC). The MMC supports research to determine extent of problems caused by persistent marine debris, particularly ghost fishing nets. MMC jointly sponsored, with NOAA, the First International Workshop on Fate and Impact of Marine Debris, in 1984, and has actively supported research and educational programs on the effect of debris on marine mammals and other wildlife.

4. CONCLUSION

The medical wastes which washed ashore along the New York and New Jersey coasts during the summers of 1987 and 1988 probably did more to get the Nation's attention than all the previous events or scientific papers combined. The media, national and state legislatures, and local administrators now realize how damaging marine pollution, and the plastic component of that overall problem, affects lives of all citizens of the Nation. Citizens are beginning to demand action to improve the situation. The Report of the ITFPMD lays out a logical strategy for addressing the problem. We do not need a plethora of new laws and regulations. We need to:

- implement the MARPOL Annex V regulations quickly;
- find effective ways of enforcing existing pollution and litter laws;
- begin a major public education campaign to gain cooperation of all U.S. citizens and others who use our coastal ocean;
- continue research and monitoring activities to understand sources of marine debris, fate of plastics in the ocean and impacts on living marine resources.

Gathering the background information for the ITFPMD Report demonstrated, once again, the difficulties one encounteres due to the multiple overlapping Federal interests in marine issues. To be sure, the research, education, regulatory activities to address persistent marine debris could be expanded with additional monies and people. However, most agencies are addressing ways to resolve the problems within their areas of responsibility.

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Table 1 FEDERAL PROGRAMS TO ADDRESS PLASTIC MARINE POLLUTION Source: ITFPMD, 1988

	EDUCATION	RESEARCH	MITIGATION
Department of Commerce NOAA	o Develops educational materials for fishermen, plastics industry boaters o Funded Newport, OR, port project o Supports nationwide beach cleanups	o Conducts research on impacts of pmd on fish, marine mammals, sea turtles	o Supports photodegradable plastic research o Requires fishing pots and traps to have degradable parts o Requires NOAA vessels to bring all plastics ashore
Department of the Interior MMS	o Developed, with operators, video and print material for platform and supply vessel workers	o Supports research in Gulf of Mexico to determine sources and quantities of beach debris	o Prohibits disposal of solid materials from oil and gas platforms
NPS	o Volunteer beach clean ups at national seashores o Education campaign in conjunction with Take Pride	o Systematic debris accumulation surveys at selected sites	o Beach maintenance
FWS	o Displays at coastal refuges o Educational material on effects of pmd on wildlife	o Research on effects of pmd on wildlife, e.g., seabirds	o Beach maintenance
Department of Transportation Coast Guard	o Information dissemination through CG Auxiliary	o Assesses equipment to handle wastes aboard vessels o Evaluates waste stream from ships	o Regulates discharge from vessels
Environmental Protection Agency	o Supports nationwide beach clean up	o Supports and conducts research on alternative means of waste disposal and degradable technology	o Regulates effluent discharges from point sources on land, ocean dumping and solid waste disposal
Department of Defense Navy		o Developing compactors, grinders, and thermal devices to handle wastes aboard ship	o Reducing purchase of certain plastic products, e.g., 6-pack rings
Department of Agriculture APHIS			o Requires garbage from foreign vessels to be cooked prior to disposal
Department of State			o Leads international delegations to IMO, UNEP, etc.
Marine Mammal Commission	o Supports conferences and symposia for scientists and public	o Supports assessments of impacts of pmd on marine mammals	

Table 2. **Federal Expenditures Related to Persistent Marine Debris. Source, ITFPMD**
(FY 87, thousands of dollars)

	Education	Research	Mitigation
DOC/NOAA	302	435	140
DOI	80–150	78	950
DOT/CG			250
EPA	40		500
DOD/Navy		500	
MMC		5	

EDUCATION AND AWARENESS: KEYS TO SOLVING THE MARINE DEBRIS PROBLEM

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ABSTRACT

The Center for Environmental Education (CEE), a non-profit marine conservation organization, is conducting a national education campaign on the problems caused by plastic debris in the marine environment. Sponsored in part by the National Oceanic and Atmospheric Administration's Marine Entanglement Research Program and The Society of the Plastics Industry, the campaign includes the development and distribution of educational materials on this problem to the commercial fishing, merchant shipping, and plastics industries, as well as to recreational fishermen, pleasure boaters, and the general public. CEE has recently established a National Marine Debris Clearinghouse for dissemination of educational materials and a National Marine Debris Data Base that will provide a means to monitor the effectiveness of educational efforts and new legislation directed at solving the marine debris problem.

INTRODUCTION

Manmade debris in the marine environment, once considered to be merely an aesthetic problem, is now the focus of national attention. During 1987, a Presidential task force, a federal workshop, federal and international laws, several national and international conferences, and more than a quarter of a million citizens across the nation all focused on a relatively new marine pollution issue: plastic debris and its impacts.

A major reason for this heightened concern is that plastic debris is causing widespread mortality of marine mammals, turtles, fish and birds. Recent studies in Alaska indicate that as many as 30,000 northern fur seals become entangled in plastic debris, primarily fishing nets and strapping bands, and die each year. For other species, such as marine mammals, sea turtles, seabirds and fish, there is increasing worldwide documentation of ingestion of plastic debris.

Sources of plastic debris include both vessels that follow a centuries-old practice of dumping garbage at sea, and several land-based sources which discharge plastic materials via storm and sewer drains and other avenues. Plastic fishing gear, cargo sheeting, and galley wastes from ships are becoming increasingly prevalent in marine areas. Plastics generated from land-based sources include sewage-associated wastes such as plastic tampon applicators and disposable diapers. Other sources include the plastics manufacturing and processing plants which produce and transport plastic resin pellets.

Several important initiatives prior to 1988 documented what is presently known about the plastic debris problem. In 1984, at the request of the U.S. Marine Mammal Commission, the National Oceanic and Atmospheric Adminsitration's, National Marine Fisheries Service (NMFS) organized an international workshop to identify the scientific and technical aspects of the debris problem and its impacts on marine species. Later that year, Congress appropriated $1 million to NMFS to develop a comprehensive research and management program addressing the issue. Over the past three years, the NMFS Marine Entanglement Research Program has added increasing documentation on the extent the problem. A major component of this program has been the development and distribution of educational materials for sources of marine debris.

In 1986, the U.S. Environmental Protection Agency commissioned the Center for Environmental Education to prepare a report on the plastic debris problem in the marine and Great Lakes waters of the United States. The study helped to redirect attention from general 'marine debris' to those problems caused specifically by plastic items. The study showed that plastic debris is a nationwide problem for marine wildlife. It also identified the major ocean and land-based sources of plastic debris, but indicated that the total amount of debris generated by these sources is unknown. Finally the study noted the absence of appropriate laws to address the plastic debris problem (CEE 1987a).

Recognizing that exisiting pollution control authorities are inadequate, legislators have introduced bills at the local, state, and federal levels to address the plastic debris problem. In 1987, the U.S. ratified an international treaty, Annex V of the Convention for the Prevention of Pollution from Ships, or MARPOL Treaty, which would prohibit the disposal of garbage, and plastic items in particular, by all ships at sea effective December 31, 1988.

But what about the groups that have been identified as sources of marine debris? How will these groups respond to increasing public pressure and new laws that will make a centuries old practice of of tossing trash over the rail illegal? More importantly, it is forseeable that that a law which governs ocean-based activity in an area that covers over two-thirds of the earth's surface may have major enforcement problems. Therefore, solutions to the marine debris problem will largely rely on voluntary compliance.

In order for those engaged in ocean activities to understand the importance of complying with these new laws, they must be made aware of the extent of the marine debris problem. They must first understand that plastics are a different kind of trash causing the majority of problems in the marine environment. They must also be informed that the accumulation of plastic trash in the oceans has a negative impact on ocean user groups in terms of economics, safety due to vessel disablements caused by plastics, and reputation. Moreover, they must accept the fact that while no one group is responsible for all the plastic trash in the ocean, solutions to this problem will require cooperation among all groups that are now dumping plastics at sea. Education programs which explain these and other aspects of the marine debris problem could lead to solutions.

CEE'S MARINE DEBRIS EDUCATION PROGRAM

Recognizing the importance of education and awareness in soving the problems caused by marine debris, the Center for Environmental Education has developed an extensive education program for marine industries and other groups. In 1987 and 1988, under contract to the National Oceanic and Atmospheric Administration's (NOAA) NMFS Marine Entanglement Research Program, CEE began to develop and distribute marine debris education materials. Based on the types, quantities, and problems caused by plastic debris in U.S. coastal areas, six major groups were identified for educational efforts: the commercial fishing, merchant shipping, and plastics industries, recreational boaters and fishermen, and the general public. As part of this project, CEE also began working with The Society of the Plastics Industry (SPI) on a national campaign to promote the proper disposal of plastics. Subsequently CEE, NOAA, and SPI launched a national education campaign. Following is a description of some materials developed as part of this campaign.

Marine Industry and Recreational Groups

In 1987, CEE/NOAA/SPI completed the first phase of the educational campaign which consisted of public service adverstisements and brochures developed for each of the following groups: commercial fisheries, merchant shippers and the plastics industry (Figures 1-3). To date these ads have appeared in fifteen major trade journals, in addition to several regional and local publications. CEE has also distributed approximately 30,000 brochures developed for these three groups.

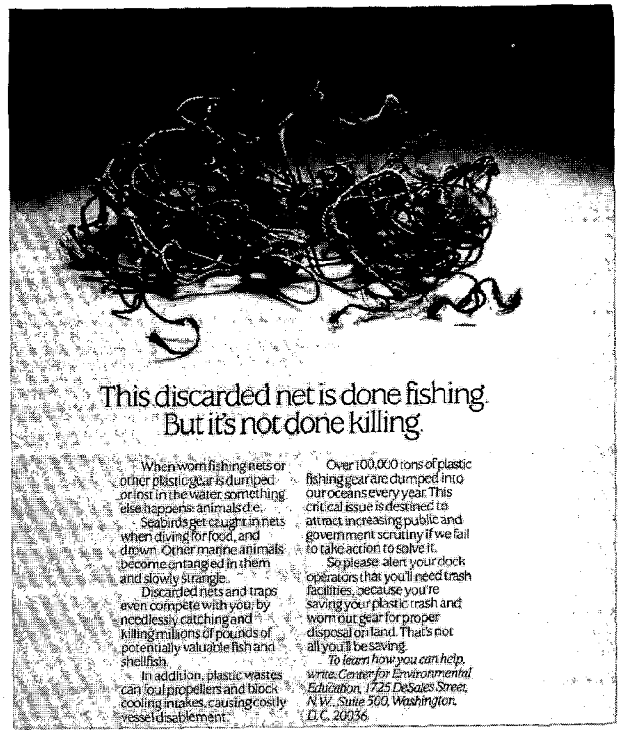

Figure 1. CEE/NOAA/SPI public service advertisement developed for the commerical fishing industry.

Figure 2. CEE/NOAA/SPI public service advertisement developed for the merchant shipping industry.

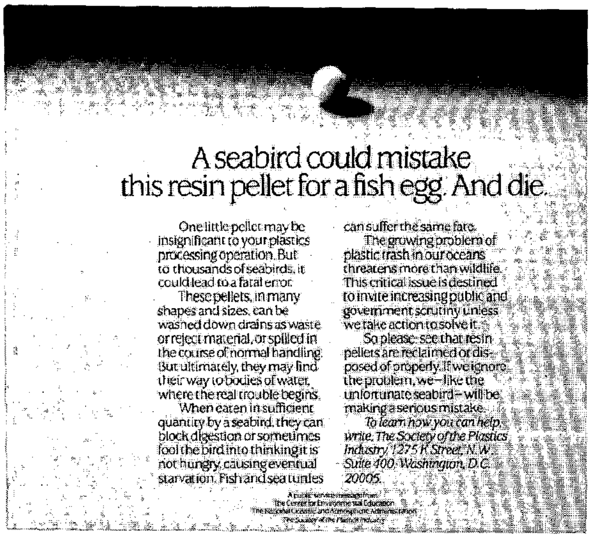

Figure 3. CEE/NOAA/SPI public service advertisement developed for the plastics industry.

In 1988, phase II of the CEE/NOAA/SPI campaign commenced with the development of public service advertisements and brochures developed for recreational fishermen (Figure 4), and for recreational boaters (Figure 5). Major journals for these groups are now being contacted to secure placement of these ads. Using these educational ads, CEE plans to develop posters for placement in marinas and bait and tackle shops.

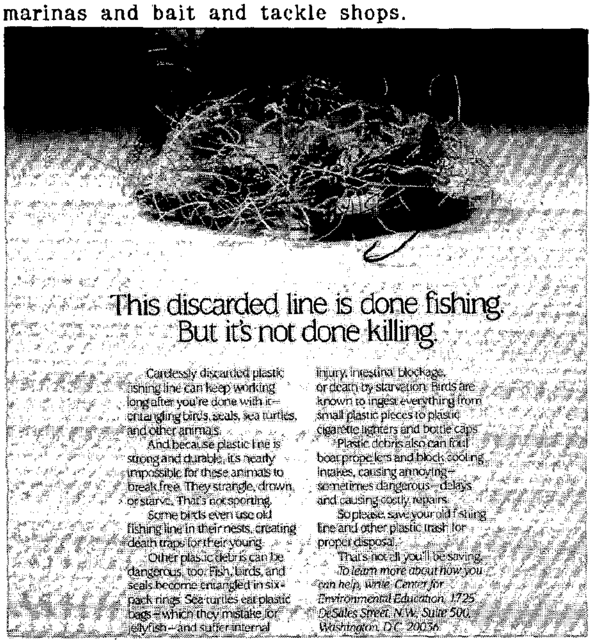

Figure 4. CEE/NOAA/SPI public service advertisement developed for recreational fishermen.

Figure 5. CEE/NOAA/SPI public service advertisement developed for recreational boaters.

General Public

Perhaps one of CEE's most successful efforts has been our citizen beach cleanups in Texas where in 1986 and 1987 CEE organized the largest beach cleanups in the history of the nation. In 1986, over 2,700 volunteers collected 125 tons of debris on 122 miles of beach. In 1987, more than 7,000 volunteers collected 309 tons of debris on 157 miles of beach. The Texas Coastal Cleanup Campaign has not only increased awareness among the general public, but helped to initiate efforts on the part of the Texas General Land Office in formulating a statewide "Adopt-A-Beach" program.

One of the most important aspects of the Texas cleanups has been the use of a system for collecting, recording, and analyzing data on the types of debris collected. From this data, CEE has been able to determine that more than 65 percent of all debris items recorded in 1986 and 1987 was comprised of plastics. In 1987, this included more than 31,000 plastic bags, 30,000 plastic bottles, and 15,000 plastic six-pack rings, in addition to numerous items indicative of ocean sources such as more than 4,900 plastic strapping bands, 7,460 plastic milk jugs, and 4,170 plastic light sticks used by fisheries (Table 1). Based on these data findings, CEE has published two reports on the debris problem in Texas which contain documentation on the sources of debris, and recommendations for federal, state and local governments, industry, and other groups to reduce the marine debris problem (CEE 1987b, CEE 1988).

Table 1. Results of data collected from the Center for Environmental Education's 1987 Texas Coastal Cleanup.

DEBRIS TYPE	NUMBER OF DEBRIS ITEMS
Plastic	
bags	31773
bottles	30295
caps, lids	28540
pieces	21619
rope	18878
6-pack holders	15631
cups, utensils	12486
milk jugs	7460
strapping bands	4933
sheeting, lrg.	4817
fishing line	4225
light sticks	4179
toys	2820
straws	2639
disposable lighters	2429
"write protection" rings	2337
vegetable sacks	2023
diapers	1914
shoes	1750
fishing net	1719
buckets	1708
tampon applicators	1040
syringes	930
hardhats	225
Total Plastic	206370
Styrofoam	
pieces	22609
cups	14998
egg cartons	3417
buoys	1048
Total Styrofoam	42072
Glass	
pieces	21214
bottles	17902
light bulbs	2327
fluorescent light tubes	1088
Total Glass	42531

DEBRIS TYPE	NUMBER OF DEBRIS ITEMS
Metal	
beverage cans	20580
pull tabs	8925
bottle caps	8273
other cans	4469
pieces	3658
wire	2807
large containers	1105
drums-rusty	268
drums-new	225
Total Metal	50310
Paper	
bags	4428
cartons	4073
cups	4511
newspaper	1415
pieces	12292
Total Paper	26719
Wood	
pieces	9306
pallets	605
crates	292
Total Wood	10203
Rubber	
gloves	4127
tires	546
Total Rubber	4673
TOTAL	382878

In 1988, CEE established a National Marine Debris Data Base for beach cleanups conducted during COASTWEEKS '88 (September 17-October 10) so that standardized information can be obtained nationwide. Sponsored by the U.S. Environmnetal Protection Agency, National Oceanic and Atmospheric Administration, and the U.S. Coast Guard, the data base will provide essential information not only for understanding specific debris problems in different parts of the country, but also for evaluating the effectiveness of Annex V and other measures implemented to reduce debris. A final national report containing information from all statewide cleanups will be produced by CEE in 1989.

In addition to the the National Marine Debris Data Base, CEE has established a National Clearinghouse on Marine Debris and Entanglement. Created in response to a growing number of requests for information on the marine debris problem, the Clearinghouse functions to disseminate CEE's educational materials and other information on marine debris to federal and state government agencies, industry groups, educators, the press and media, and the general public. This includes the distribution of 50,000 copies of CEE's **A Citizen's Guide to Plastics in the Ocean**, a guide intended to inform citizens of the growing problem of plastics in the ocean and provide suggestions on how citizens can become involved in solving this problem.

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GEOLOGICAL AND BIOLOGICAL ASPECTS OF HARDBOTTOM ENVIRONMENTS ON THE L'MAFLA SHELF, NORTHERN GULF OF MEXICO

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ABSTRACT

Side-scan sonar, underwater video, manned submersibles, and conventional surface vessel and scientific SCUBA diving operations have been combined in an interdisciplinary, multi-institutional investigation of hardbottom environments on the L'MAFLA (Louisiana-Mississippi-Alabama and Florida) shelf in the northern Gulf of Mexico. The hardbottom environments consist of: (1) moderately sloping ridges of rock rubble (e.g. nodular sideritic sandstone and mudstone) and shell hash (including bored and abraded oyster shell) to low-relief outcrops (e.g. dolomitic sandstone) on the inner-shelf (21 to 32 m); (2) mound-like features of bioclastic limestone on the mid-shelf (30 to 40 m); (3) calcareous reef-like pinnacles (largely composed of Lithothamnion) on the shelf break (72 to 100 m); and (4) quartose sandstone and pebble conglomerate at the head of the De Soto Canyon. Epifaunal communities on the inner-shelf are dominated by octocorals (Leptogorgia virgulata and Lophogorgia hebes). Deeper hardbottom environments include solitary corals and antipatharians, as well as deep water species of octocorals.

1. INTRODUCTION

Numerous hardbottom[1] areas have been observed along the south Atlantic and Gulf coasts of the United States (Buchanan 1973; Huntsman 1976; Huntsman and Manooch 1978; Shipp and Hopkins 1978; Felder and Chaney 1979; Grimes et al. 1982; Wenner et al. 1983; Chester et al. 1984; Parker and Ross 1986; Mearns 1986). Most recently, Putt et al. (1986) have reported on the presence of hardbottoms in shallow waters offshore of Louisiana (29°N; 93°W), and have described the fauna of these areas. Thick growths of bryozoans, sponges, and gorgonians cover the substrate, and snappers, groupers, amberjacks and many tropical and subtropical species were present. Most of these sites have been less well studied than the major offshore reefs in deeper water such as the Florida Middle Grounds (Smith et al. 1975; Grimm and Hopkins 1977; Hopkins et al. 1981; Clarke 1986) or the Flower Garden Banks in the northwestern Gulf of Mexico (Parker and Curray 1956; Bright and Pequegnat 1974; Bright 1983; Rezak and Bright 1983). Nevertheless, hardbottom areas in depths of 20-200 meters support extraordinary numbers of invertebrates and fishes, and serve as focal points for commercial and recreational fishing activity. For example, it has been estimated that in South Carolina waters nearly 70% of recreational bottom fishing activity was expended on hardbottoms, even though hardbottom constituted only about 8% of the total bottom area (Buchanan 1973).

[1]Hardbottom is defined as: A generic term that describes any seafloor feature or deposit with a hard or indurated surface. Therefore, there are no qualifications or restrictions placed on the origin (lithogenous, biogenous, or hydrogenous), size (shell hash and gravel to boulders to outcrops and reefs) or morphology (debris fields, platforms, ridges, banks or pinnacles) of hardbottom substrates (Schroeder et al. 1988).

Historically, offshore areas along the north-central Gulf of Mexico coast have been typified by expanses of muddy to sandy substrates (Curray 1960; Ludwick 1964) with little or no vertical relief (Parker et al. 1983). Parker et al. (1983) state that from Pensacola, Florida to Pass Cavallo, Texas, reefs of all types make up only 3.2% (2,571 acres) of the bottom between depths of 10 and 91 meters and only 50% of the 2,571 acres has relief in excess of 1 m. In the north-central Gulf of Mexico, east of the Mississippi River Delta (Figure 1), there is no published

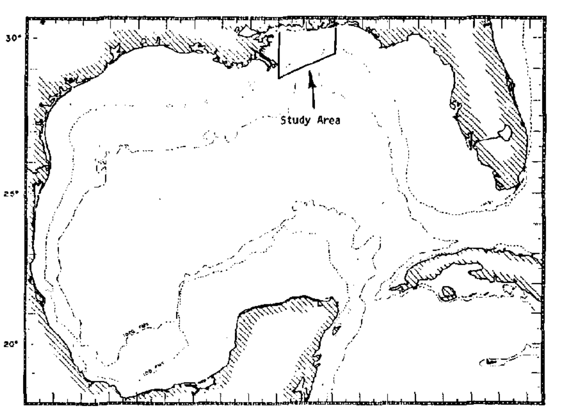

FIGURE 1. The Gulf of Mexico.

evidence that hardbottoms are a conspicuous feature of this continental shelf margin, nor were exposed hard substrates expected to occur in an area that receives such large amounts of sediment from adjacent river systems and estuaries (Shepard 1956; Ludwick 1964; Ryan 1969; Boone 1973) and that is reported to be covered by sediments with a high percentage of fine grain (silt and clay) material (Shepard 1956; Ludwick 1964; Upshaw et al. 1966; Ryan 1969; USACOE 1982). The one report of hardbottom environments on this shelf is by Ludwick and Walton (1957). They conducted a general survey of topographic high features near the shelf break, between 70-100 m, and their associated sediments and faunas. A detailed study was made of a 13 km^2 section commonly known as the Pinnacles (see Figure 2).

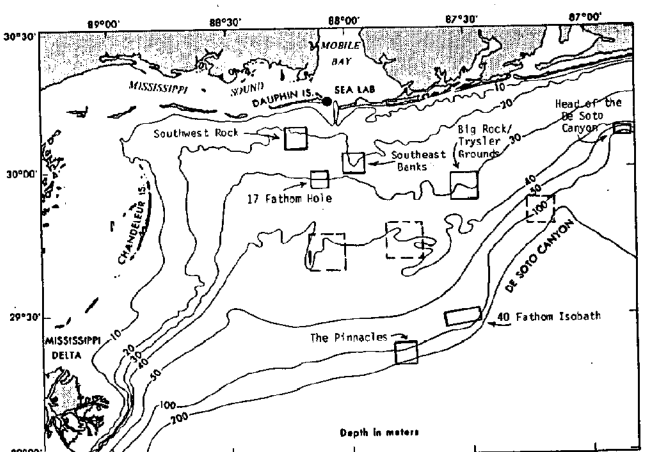

FIGURE 2. Locations of on-going and proposed study areas (solid lines) and alternative and/or future study areas (dashed lines).

Over the period April 1984 to May 1988 scientists from the Dauphin Island Sea Lab have undertaken 43 research cruises on the L'MAFLA shelf and identified hardbottoms at several locations in the depth range of 20-100 m (Figure 2). The most comprehensive data has been collected over the past two years and is currently being analyzed. In addition, Texas A&M University has just completed Year-1 of a three year research project, funded by Minerals Management Service (MMS), which includes an extensive investigation of a 1400 km^2 area on the Mississippi-Alabama outer continental shelf.

These areas support organisms including bryozoans, hard and soft corals, and sponges, as well as snappers, groupers and other fish species, and are well known to local fisherman (although not to scientists). The areal extent of these hardbottoms is unmeasured and their contribution to the recreational and commercial fishery is unknown. Based on anecdotal information from fishermen, the importance may be substantial and our preliminary data suggest that the existence of more previously uncharted and essentially unfished hardbottoms is quite likely. It is also quite possible that these hardbottom communities are staging areas for first or second year fish that could colonize newly established artificial reef habitats. Thus, siting plans for new artificial reefs should consider placing these structures adjacent to existing hardbottom communities which contain a ready source of colonists (Stone et al. 1979; Grimes et al. 1982; Stone 1986).

2. METHODOLOGY

Physiographic description and classification of hardbottom study sites are based on a combination of side-scan sonograph image maps, subbottom seismic profiles, bathymetric information from fathometer records and ground truthing (u/w TV-video, SCUBA diving, manned submersible dives and grab and dredge sampling). Side-scan sonograph images are plane-view graphic records of electronic signals that are directly proportional to acoustic energy that is backscattered from the seafloor (Fleming 1976). Backscattered energy is influenced (1) by the altitude and orientation of the seafloor surface (bathymetry) and (2) by surface reflectivity, which is a function of material density and surface roughness (sediment or bottom texture). Thus, the image represents the geological nature of the seafloor, and provides a useful map base for surficial geologic data.

Map plots of sites sampled by grab and dredge operations and observed by u/w TV video or during manned submersible dives and SCUBA dives are currently being integrated with precise bathymetric maps (constructed from digitized fathometer records) and side-scan images to compile and interpret the geology of each area. The classification of the hardbottom environments is focusing on: (1) the nature of the rock/substrate features (e.g. outcrops, clasts or slabs, mounds or ridges of loose shell or rock rubble, hard pan, pinnacles or reef-like structures); (2) areal extent; (3) vertical relief; (4) relationship to adjacent unlithified sediments; and (5) the general composition of the live cover.

Substrate samples have been collected during wet-diving operations and manned submersible dives as well as ship board grab and dredging operations. The geological description of these hardbottom substrates, based on a combination of analytical methods (thin-section petrography, X-ray diffractometry, scanning electron microsopy, stable-isotope ratios, and radiocarbon dating), will form a basis for interpretation of their origin and allow comparison with previously described materials of a similar nature elsewhere. Unlithified sediments are being analyzed by sieve and hydrometer for particle size and by acid dissolution for determination of carbonate content.

Dredging operations have verified the presence of dense octocoral populations on the inner to middle shelf hardbottoms. Because these species are sessile, their age structure integrates factors which affect recruitment and mortality rates in a particular habitat (Grigg 1975). Diving operations to date have focused on tagging and measuring soft corals to evaluate the age structure of populations at three sites; Southeast Banks, Southwest Rock and 17 Fathom Hole (Figure 2). We are in the process of sectioning corals collected from these three sites and examining growth rings to determine age structure of the population (Grigg 1974). Future efforts will attempt to estimate densities and growth rates of soft corals and evaluate productivity across the shelf.

3. GEOLOGY

Alabama-Northwest Florida Inner-shelf.
1) Southeast Banks: The Southeast Banks area is located approximately 28 km Southsoutheast of the entrance to Mobile Bay (Figure 2), in water depths of 21 to 26.5 m. Schroeder et al. (1988) have characterized two sites within this area. The first is a rock rubble field on a moderately sloping bottom of shell hash and silty sand. Rocks are irregularly shaped slabs of sandstone, up to 0.8 x 0.7 x 0.2 m, varying in color from buff to dark gray. Most of the rocks have epifaunal encrustations and many have pitted surfaces due to Lithophaga borings. The second is a relatively flat bottom of sand and rock rubble south and east of Site 1 containing similar rock substrate.

2) Southwest Rock: The Southwest Rock area lies approximately 17 km south of Dauphin Island (Figure 2), in 20 to 22 m of water. Two sites have been described by Schroeder et al. (1988). Site 1 is a rock outcrop, known as "Southwest Rock". It is 7 to 9 m across and rises 1 to 1.5 m above a relatively flat, muddy sand bottom. A second, similar feature, approximately 1.5 to 3.5 m across is located 10 m to the southwest. Scattered rock rubble is present in the vicinity. The rock material is a well-indurated, medium gray, shell-bearing sandstone with irregular holes and pits due to dissolution and boring. The outcrops are coveredwith an encrusting epifauna.

Site 2 encompasses a gently sloping ridge that trends NNW-SSE and has 1 to 1.5 m of relief. Based on the sonograph records this ridge is a linear featuremeasuring 1.5 km in length.The northeast facing slope is covered with rock rubble and shell hash. Rocks are ferruginous and rounded, with complex nodular form and sparse to moderate encrustation. Shell materials composed of fresh intact shells of neritic forms, as well as bored and abraded fossil shells including estuarine forms such as oysters.

3) 17 Fathom Hole: This study site is located approximately 37 km south of Mobile Bay (Figure 2), in an uncharted depression with depths of 30 to 32 m. Two features are presently being investigated. One is a large outcrop (reef-like) structure with dimensions on the order of 100 x 35 x 2 m and the other is a mound-like feature of rock rubble covering an area of approximately 300 m^2 and with a vertical relief of up to 2 m.

4) Big Rock / Trysler Grounds: Schroeder et al. (1988) describe two sites from this area; which lies approximately 46 km offshore the Alabama-Florida state line (Figure 2), at water depths of between 30 to 35 m. The first site is known as "Big Rock" and consists of a large mound-like feature with approximately 5 m of relief. The substrate collected to date is a light gray, porous bioclastic limestone upon which a moderate to heavy epifaunal growth occurs. The second site, the "Trysler Grounds", has similar rock on an irregular hummocky bottom.

Mississippi-Alabama Outer-shelf.
1) The Pinnacles: Located 105 km southsoutheast of Mobile Bay and 120 km east of the Mississippi River Delta (Figure 2), in 100 to 180 m of water, these structures are perhaps the most unique hardbottom features on this shelf. Ludwick and Walton (1957) state that a number of the pinnacles stand 12 to 15 m (average height is 8 m) above the surrounding sea floor and are onlya few hundred meters across, measured above the basal talus slopes. Side slopes are steep and irregular; some are vertical. Water depth to the top of the pinnacles averages 99 m and ranges between 89 to 168 m. Some of the conclusions Ludwick and Walton came to are: (1) that these features are part of a more extensive carbonate zone found at the shelf break in many other Gulf of Mexico locales; (2) the pinnacles they studied had a reef origin at a lowered sea-level; and (3) at present, the reef is not growing appreciably and is considered to be dead. Calcareous algae (Lithothamnion), the chief constituent of the reef rock and surrounding sediment, are no longer found living on or near the pinnacles.

2) 40 Fathom Isobath: This well known fishing banks complex is located 24 km northeast of the Pinnacles area (Figure 2). As the name states water depths are around 40 fm or approximately 75 m. Fathometer records indicate that the hardbottom environments associated with this area are often topographic features, with up to 9 m of relief, that are either mound-, pinnacle- or ridge-like in form. Some of these features are included in the "New Areas" discussed below. At this time no substrate samples have been collected from this area.

3) "New Areas": These areas have recently been identified on side-scan sonograph records obtained by Texas A&M University in conjunction with their MMS-Mississippi/Alabama Marine Ecosystem Study. These areas are scheduled to be investigated with u/w TV video mounted on a Remotely-Operated-Vehicle and conventional dredge and grab sampling during the month of July. Some of the features to be studied have distinctive or unusual signatures on the sonograph records and have been preliminarily given names such as "Pox Field", "Boulder Field", "Footprints", "Flat-tops" and "Snake Ridge".

Head of the De Soto Canyon.
This study area lies on the northwestern rim of the Head of the De Soto Canyon approximately 40 km southeast of the mouth of Pensacola Bay (Figure 2), in 50 to 60 m of water. The major isobaths in this region trend southwest to northeast while the hardbottom feature appears to have a WSW-ENE

orientation. The hardbottom is a sheet-like structure, up to 2 m thick, composed of coarse quartose sandstone and pebble conglomerate, which has undergone extensive orthogonal fractioning. The shallow, northwest side is nearly flat with a combination of exposed and partially exposed surfaces mixed in with large areas of sand that are vary often covering hardbottom substrate. On the deeper, southeast side the rectangular blocks, formed as a result of the fracturing, are separating and slumping or creeping down slope as a result of undercutting of the unconsolidated sand layer below. Consequently, a zone of inclined blocks and rock rubble, with a relatively steep face, has been formed.

Shipp and Hopkins (1978) observed a feature composed of one to three ridges (of rectangular blocks), up to 20 m wide, with intervening sand zones. Relief of the ridges varied from barely detectable to 10 m. In addition, fathometer records they obtained suggested the presences of "spire-like" ledges up to 15 m in relief.

4. BIOLOGY

Biological assemblages of the shallow, inner-shelf hardbottom habitat are dominated by the soft corals, Leptogorgia virgulata and Lophogorgia hebes. Less obvious components include hydroids and bryozoans. Mobile invertebrates observed include the urchins, Arbacia punctulata and Lytechinus variegatus, as well as portunid crabs. On the outer-shelf, deep water octocorals dominate the epifaunal community, along with solitary corals and antipatharians. The hard coral, Oculina diffusa, is the only epifaunal species observed to occur across the entire shelf.

Growth rings have been identified in both species ofshallow water soft corals and we are in the process of verifying the periodicity of the banding. Initial field measurements indicate that Lophogorgia are significantly smaller ($\bar{x}$= 14.3 cm) at our 20 m Southwest Rock station than at Southeast Banks, our 25 m station ($\bar{x}$ = 46.7 cm). Too few measurements are available from 17 Fathom Hole (30-32 m station) for comparison.

The Leptogorgia/Lophogorgia community has been reported as common on the inner- to middle- shelf off South Carolina (Wenner et al. 1983) as well as off central western Florida (Bright et al. 1981) and there is evidence that year-to-year variation in the abundance of soft corals results from the seasonal fluctuations in temperature and light characteristics of the continental shelf environment (Peckol and Scarles 1984). Storm waves, current regimes and turbidity also undoubtedly play a role in mortality caused by scour and shifting sediment (Grigg 1977; Farrant 1987; Gotelli 1988). When complete, accurate estimates of age frequency distributions at our different study sites across the shelf are available they should yield valuable information on the chronology of colonization and extinction events in hardbottom habitats; a form of environmental hindcasting.

5. ACKNOWLEDGEMENTS

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VIDEO DOCUMENTATION OF HARDBOTTOM ENVIRONMENTS

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ABSTRACT

Investigators will present underwater video documentation of hardbottom environments along the continental shelf of the northern Gulf of Mexico. A variety of geological features and biological habitats will be illustrated in support of the discussions presented in the three previous papers in the session by Rezak and McGrail, Bright and Gittings, and Schroeder et al. Videos were made from manned submersibles, ship-deployed Remotely Operated Vehicles, and cameras tethered to drifting vessels as well as during scientific SCUBA diving operations.

Footage from the following areas will be shown: (1) Texas-Louisiana outer continental shelf (including the "Flower Garden Banks"); (2) the "Pinnacles" of the L'MAFLA outer continental shelf; (3) Alabama inner continental shelf (including "Southeast Banks", "Southwest Rock", and "17 Fathom Hole"); and (4) the "Head of the De Soto Canyon".

THE USE OF ENCLOSED ECOSYSTEMS FOR THE STUDY OF CYCLING AND IMPACT OF TRACE ELEMENTS

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Phytoplankton play an important role in the biogeochemistry of many trace elements, through incorporation within the cell and direct or indirect chemical transformation. We report on studies carried out in large-volume, continuous cultures maintained outdoors under ambient conditions of light and temperature in which we examined the role natural phytoplankton populations play in the availability and speciation of two toxic trace elements. Silver was readily taken up by phytoplankton, with uptake inversely proportional to salinity. Uptake and incorporation reduced silver availability to other estuarine organisms. Arsenic is modified either by reduction or methylation. These transformations relieve toxicity to phytoplankton, but may serve to increase the toxicity of arsenic to estuarine fauna. It is important that we understand how physico-chemical controls of trace element speciation, algal incorporation, transformation and release are coupled in productive estuaries before we can predict the impact of anthropogenic inputs of trace elements.

INTRODUCTION

The transport and impact of toxic substances are matters of major concern to management of coastal estuaries and oceans. Man's love for the coastline and its attendant water bodies ensures that, as population and industrial growth continue, the loading of toxic substances into estuaries and the coastal ocean will continue to increase. It is imperative, therefore, that society address the potential toxic effect of anthropogenic inputs to these areas.

There are several impediments to successfully addressing these concerns. Society produces an overwhelming number of potential toxic substances. The large number of toxic inorganic compounds and the ever-increasing array of organic compounds require initial, broad assessments of the compound's occurrence, concentration, and toxicity (1) and allow detailed study of only a few, most important substances. Moreover, it is difficult to assess the potential for impact at a community, or worse, ecosystem level. Individual species, particularly species of varying trophic levels, may exhibit vastly differing sensitivity to the same toxic compound (2-4). Thus, populations and communities do not necessarily react in a similar fashion to individuals. In addition, there are indirect effects of altered trophic relationships caused by the disappearance of sensitive species (5-7).

To further complicate the process of assessment, biological processes occurring within organisms can transform the original compound into a new set of compounds that may have quite different chemical and biological properties and different relative toxicity (8).

Over the past several years, we have developed an experimental microcosm system to attempt to address such problems in impacted estuaries. We have largely focused our attention on the cycling, interaction, and impact of low-level contamination on natural phytoplankton assemblages. Phytoplankton have an important role, comprising the base of the aquatic food web in most systems. They lend themselves quite well to such studies because they can be followed at the community level and their rapid growth makes apparent even subtle changes within a matter of days. They are active in the uptake and transformation of a variety of inorganic and organic compounds. From this trophic level, further investigations can build, allowing an assessment of potential impact of trophic relationships within the system and some insight into the transfer of contaminants.

This article summarizes our work with two, quite different inorganic contaminants, silver (Ag) and arsenic (As). Silver is a cation in its biologically active form and behaves in a manner similar to other cations such as cadmium and copper. Arsenic, in its dominant chemical form, arsenate, is a nutrient analogue of phosphate and undergoes a variety of reduction and methylation reactions and can be found in a number of chemical forms. Both are present in elevated concentrations in estuaries and coastal systems such as the Chesapeake Bay. As such, the pair are good models for a wide variety of inorganic contaminants that may be present in a coastal system.

MATERIALS AND METHODS

Location

The studies were performed in the Patuxent River, a subestuary of the Chesapeake Bay, in Benedict MD. River flows within the Patuxent vary widely, with large inputs of fresh water in the spring, and greatly reduced flows in the summer and early fall. This portion of the estuary has an annual salinity range of 10 $^{o}/oo$, from approximately 5-15 $^{o}/oo$, a pH range of 7.5-8.5, and annual water temperature extremes from 0 to about 30^{o} C. Thus, this portion of the estuary is quite dynamic, and undergoes substantial, seasonal variability.

Culture System

A system of large-volume, outdoor tanks was utilized for these studies. Natural phytoplankton from the Patuxent River were cultured in 500 l cylindrical fiberglass tanks, submerged in a raceway to maintain water temperatures to within 1^{o} C of ambient river temperatures. The objective was to operate the tanks as continuous, flow-through phytoplankton cultures using the mesohaline river water without nutrient enrichment as the diluent. The 12 tanks were initially filled with Patuxent River water containing the natural phytoplankton assemblage after passage through 35 μm nylon mesh to remove large herbivores. This initial screening did not remove a significant fraction of the phytoplankton. After filling, the tanks were operated as continuous cultures, diluted with fine-filtered (1 μm) river water. Contaminants were also metered continuously to maintain pace with dilution water. Further details on design and maintenance can be found elsewhere (9-12). The number of tanks allows several different contaminants, or several levels of the same contaminant to be studied simultaneously in replicate systems. The system is quite adaptable and particularly suitable for studies of the cycling and impact of toxic substances because 1) it utilizes whole plankton communities rather than single species or even clonal cultures, 2) environmental conditions under which experiments are performed are quite realistic, allowing most natural biogeochemical reactions to occur, and 3) the inputs of continual, small amounts of contaminants more closely reproduce conditions in a dynamic, natural ecosystem.

Other Experiments

In addition to these studies, numerous experiments were performed in the laboratory using unialgal cultures isolated from the Chesapeake Bay and other coastal systems. Also, a number of studies were carried out on board ship on cruises within the Chesapeake Bay.

Metal Analyses

Silver in water samples was analyzed according to Sanders and Abbe (13). Samples were collected in rigorously cleaned polyethylene bottles (14), frozen and analyzed using graphite furnace atomic absorption spectrophotometry (GFAAS) with appropriate standards and matrix modification, if necessary. Algal cells were collected on acid-washed glass fiber filters and digested in redistilled concentrated HNO_3 in teflon vials (15). Residues were redissolved in 1% HNO_3 (redistilled) and analyzed by GFAAS.

Arsenic was measured within water samples using techniques modified from Braman et al. (16). This technique allows measurement of a variety of chemical forms of arsenic, including arsenate, arsenite, and methylated arsenicals. Samples were collected as above for silver, fast frozen, and analyzed with no further modification. Tissue samples were digested as above for silver, then analyzed as above for total arsenic.

RESULTS AND DISCUSSION

Silver

Silver is readily taken up by phytoplankton. Within 24 h, cellular contents of Ag have increased from control levels of approximately 0.03 $\mu g\ g^{-1}$ to 44 $\mu g\ g^{-1}$ when grown in silver concentrations of 2-7 $\mu g\ l^{-1}$ (6,13). The uptake of Ag is species specific, to some extent, with smaller species such as Skeletonema costatum and Isochrysis galbana incorporating 2-3 times the cellular content of larger species such as Prorocentrum mariae-lebouriae (17). Silver uptake is proportional to Ag concentrations within the water column, which suggests passive uptake mechanisms predominate (13,18).

Silver uptake is also salinity dependent, with uptake inversely proportional to salinity (13). Silver is heavily complexed by chloride in saline systems; the reduction in uptake and incorporation is consistent with the reduction in free silver ion as salinity increases (17, 19, 20). However, there are indications that the uncharged ion, $AgCl^0$, may also be available for algal uptake (17, 20).

Silver levels of 2 to 7 $\mu g\ l^{-1}$ have measureable impacts upon the community structure of phytoplankton (Figure 1). We have noted the loss of some species and attendant increased success of others; however, in our experiments the

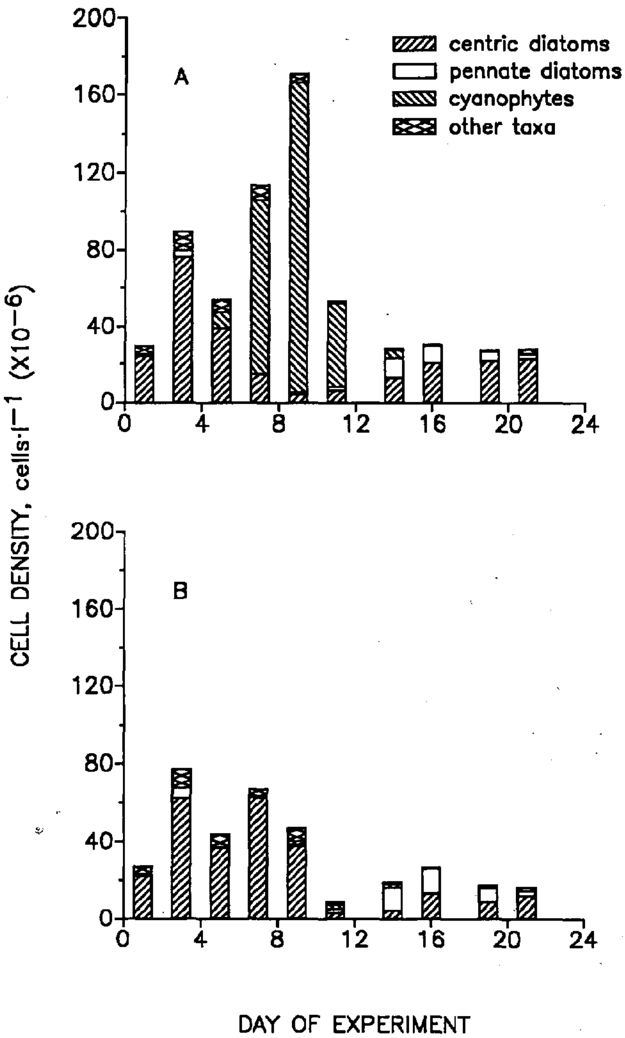

Figure 1. Composition of phytoplankton by taxonomic groups through time. A. Control assemblages. B. Ag-dosed (7 $\mu g\ l^{-1}$) assemblages.

species that flourished in Ag-dosed assemblages were "desireable" ones, mainly centric diatoms (6) possibly as a result of inhibiting less "desirable" species, such as cyanobacteria. Laboratory studies have also shown that diatoms are more resistant to silver than either flagellates or dinoflagellates (17). Therefore, even though the effect on phytoplankton species composition may be large, probable effects to the ecosystem as a whole may not be significant (6).

Perhaps the most important consequence of silver uptake by phytoplankton is the reduction of silver availability to higher trophic levels. Although phytoplankton do not transform silver to a different chemical form, they do actively partition it between the dissolved and particulate phase. Studies with silver and a dominant filter feeder in Chesapeake Bay and other temperate estuaries, the oyster, Crassostrea virginica, have conclusively demonstrated that silver associated with algal cells is not incorporated by the oyster after ingestion and that oyster uptake and incorporation of silver is solely via uptake of dissolved silver (Abbe and Sanders, unpublished data). Therefore, algal uptake and incorporation of silver effectively removes silver from association with higher trophic levels and reduces its potential for impact.

Arsenic

Arsenic in oxidized, aquatic systems is present primarily as an inorganic ion, arsenate (21, 22). Reduced arsenic (arsenite) and methylated arsenicals (methylarsonate, MMA, and dimethylarsinate, DMA) are also present occasionally.

The production of reduced and methylated species is mediated by biological processes (15, 21). The quantity and chemical form of arsenic released, and resulting concentrations of reduced and methylated species, vary between ecosystems. The variation in reduced arsenic is well correlated with primary productivity (5). In addition, the presence of specific chemical forms of arsenic, particularly methylated arsenicals, appears to be correlated with particular dominant phytoplankton species (23).

The transformation of arsenic by phytoplankton is quite variable, however, there is a general pattern to arsenic speciation that can be followed either during the development of a phytoplankton bloom in enclosures such as ours, or in the field as one moves down estuary, essentially moving forward in time.

Arsenate is quickly reduced to arsenite, which, through time, is reoxidized to arsenate. Following the appearance of arsenite are the methylated species, which tend to persist through time and dilute down the estuary into the coastal ocean. An example of such a pattern is illustrated in Figure 2, using both generalized curves and actual data from a cruise in the Chesapeake Bay. Similar data have been collected from our controlled enclosure studies.

The proportion of reduced and methylated arsenic species is of extreme importance to the ecosystem as a whole. Arsenite and methylarsonic species have been shown to be the most toxic arsenic forms (24). Arsenite is unstable under oxidizing conditions and is rapidly reconverted to arsenate (25). However, both MMA and DMA are relatively stable in marine systems, and may persist indefinitely (26). The production, release and persistence of MMA in a coastal ecosystem may be extremely important, not only because it relieves phytoplankton of the inhibitory effects of arsenate but also because it increases the toxic burden to other organisms within the ecosystem. Thus, other biota within the ecosystem may be inhibited by the change in chemical form and resultant increased toxicity.

Arsenic inputs (5-10 $\mu g\ l^{-1}$) to natural communities in general led to declines in the growth rate of most species of centric diatoms, with one exception,

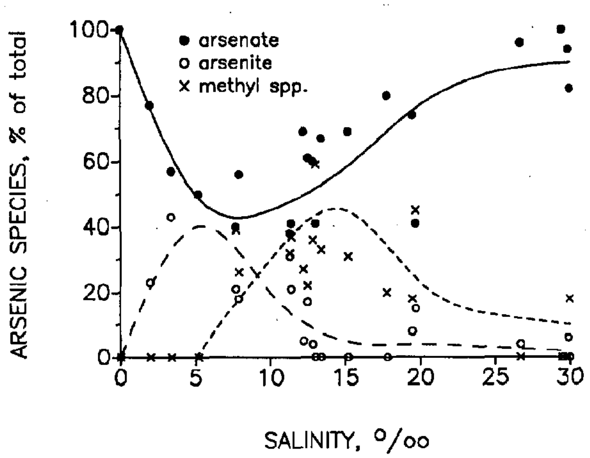

Figure 2. Progression of arsenic speciation, either coincident with the development of an algal bloom, or along an estuarine gradient. Shown are generalized curves for each arsenic species and data collected from Chesapeake Bay, taken from (23).

<u>Thalassiosira pseudonana</u>. In a number of different experiments conducted with arsenic over several years in Chesapeake Bay, we have seen the same result: the decline of larger centric diatoms (<u>Cerataulina pelagica</u>, <u>Rhizosolenia fragilissima</u>, <u>Chaetoceros</u> spp., <u>Skeletonema costatum</u>) and their replacement by the small <u>Thalassiosira</u> sp. and, on occasion, small flagellated species (4, 5, 6, 7, 10). As an example, Figure 3 illustrates the changes in species composition through time in one enclosure experiment. This shift in dominant species is probably caused by replacement of sensitive species by those either resistant to arsenic

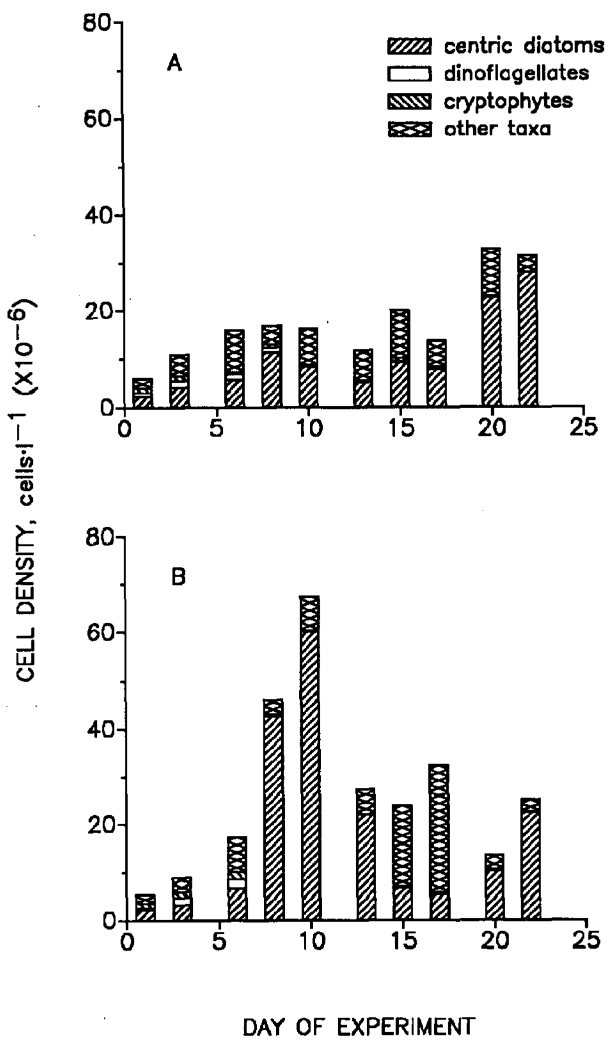

Figure 3. Composition of phytoplankton by taxonomic groups through time. A. Control assemblages. B. As-dosed (10 $\mu g\ l^{-1}$) assemblages.

or those less likely to take up large quantities of arsenic (8). From an ecological sense, the shift in species composition and overall size can lead to significant impact to higher trophic levels which feed on phytoplankton. Dominant zooplankton in the Chesapeake Bay exhibited dramatically decreased survival and fecundity when fed an arsenic-altered phytoplankton assemblage (5, 7). An arsenic-induced shift in phytoplankton not only led to the reduction in importance of copepods but also resulted in an increased abundance of small, noncrustacean grazers such as ciliates and rotifers (7), promoting greater importance of the so-called microbial loop (27, 28).

Although phytoplankton exposed to elevated arsenic concentrations take up arsenic, the quantities are not as large as seen with other trace elements. For example, natural assemblages exposed to 10 $\mu g\ l^{-1}$ (approximately 10-20 times ambient) increased their arsenic content approximately 50%, from 4.2 $\mu g\ g^{-1}$ to 6.2 $\mu g\ g^{-1}$ (6). Thus, biological removal of arsenic from the water column is insignificant, unlike the response seen with silver and other cations.

Summary

There are many ways in which phytoplankton can alter the chemical form of an inorganic contaminant, and not all algae appear to interact as we have discussed. Further study of the biological processes involved in controlling trace ion form, transport, and transformation in coastal water bodies will be necessary in future years. Although all inorganic elements will not react in the same manner as the two discussed here, similar geochemical and biological reactions will occur, leading to the same possible ecological responses.

We must understand how several processes are coupled in productive estuaries before we can predict with confidence the impact of arsenic, silver, or other toxic compounds within affected estuaries and coastal oceans. In some instances the important effect of phytoplankton uptake may be the production of toxic, methylated compounds, because of their persistence, stability, and toxicity to organisms within the ecosystem. Arsenic, and perhaps selenium, tin, mercury, antimony, and lead are elements of this type. In other cases phytoplankton may reduce the toxicity of elements by transforming them into less toxic forms. Reduction of chromium and copper, either directly or by photoreduction or complexation (and detoxification) by DOC are examples of this type of effect. In other instances, selective partitioning, as with silver, may also reduce toxicity. In each instance, however, the modifications mediated by phytoplankton are of significance to the estuarine ecosystem. They must be considered when impact assessments are made.

ACKNOWLEDGEMENTS

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INTERACTIONS BETWEEN INSOLATION AND NUTRIENT LOADING AND THE RESPONSE OF ESTUARINE PHYTOPLANKTON

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The response of natural estuarine phytoplankton communities to nutrient enrichment was investigated using large-volume outdoor continuous cultures. The five-year study in the Patuxent River, MD, revealed a strong enrichment potential for nitrogen (N) during summer/fall, often resulting in tenfold increases in biomass within 48 hr. Largely due to increased centric diatom growth rates, the resulting unstable blooms rapidly declined, leading to successional assemblages quite different in composition relative to unenriched controls. Phosphorus enrichment did not affect individual species growth rates or produce changes in assemblage composition, and produced only weak, delayed response during two winter experiments. Subsequent experiments to investigate the role of light intensity demonstrated a strong potential for light limitation in the river during fall and winter, whether or not a nutrient response was present.

INTRODUCTION

A major problem contributing to the decline in water quality in tributaries of the Chesapeake Bay, one of the United States' largest and most productive estuaries, is increased nutrient loading. In addition to increasing non-point sources, rapid urbanization of the Bay's watershed results in increased sewage effluent, identifiable as a major source of nutrients. When coupled with adequate available light, the resultant increase in phytoplankton productivity yields biomass values which can be beyond the assimilative capacity of the system. This underutilized organic material is eventually deposited to bottom sediments, where subsequent decomposition creates oxygen stress in overlying waters.

The principal nutrient elements requiring regulation in effluent are nitrogen (N) and phosphorus (P). Attempts to control their inputs to levels within the system's assimilative capacity require a knowledge of seasonal variations in nutrient loading and elemental standing stocks (and associated ratios). In addition, a knowledge of the nutrient requirements of dominant phytoplankton and their potential response to increased nutrient concentrations is essential. This requirement is complicated by the complexity of estuarine systems, which contain a diverse group of phytoplankton taxa ranging from freshwater to marine forms, and are subject to seasonal variability and succession.

One technique employed to assess the response by phytoplankton to nutrient addition involves enrichment studies of surface waters in outdoor continuous cultures. These studies are based on the premise that phytoplankton experiencing some degree of nutrient limitation will respond by increased growth when exposed to additions of the limiting nutrient. Replicate phytoplankton cultures exposed to the different elemental forms of N and P can demonstrate which nutrient is limiting, as well as resolve the potential for preferential response to nutrient form.

We utilized the above technique to assess the "nutrient enrichment potential" (operationally defined as increase in biomass of nutrient-enriched treatments over controls) of N and P on natural assemblages of phytoplankton from the Chesapeake Bay, employing a system of large-volume outdoor cultures. Microcosms, in many different forms, have been employed in a number of studies (6, 7, 4, 5) to allow intensive investigation of natural systems in a controlled manner. The experimental system employed in this study was not, by definition, a microcosm. Instead of attempting to replicate a specific ecosystem, we chose to simulate one portion of an aquatic system. Our objectives were to (a) determine experimentally the relationship between nutrient inputs and algal productivity, (b) identify by season which element is most important in stimulating growth, (c) assess the effect of nutrient loading on species composition and community structure. We conducted fifteen experiments over a four year period from 1983-1986. Three subsequent experiments were carried out in 1987 to assess the influence of light quality on the earlier findings. The redundant nature of the study made it possible to include both seasonal and annual variability in parameters such as phytoplankton composition, nutrient chemistry, salinity, turbidity, and insolation.

MATERIALS AND METHODS

The study was conducted in the salinity transition zone of the Patuxent River, a subestuary of the Chesapeake Bay, at Benedict, Maryland. River flows within the Patuxent exhibit considerable seasonal variability. The annual salinity range of the study area is 10 $^{o}/oo$, from approximately 5 $^{o}/oo$ to 15 $^{o}/oo$, and water temperature ranges from 0 to about 30° C. Nutrients also vary seasonally, with nitrogen levels highest in winter and spring, and lowest in summer. Phosphorus concentrations show a distinct summer maximum. Consequently, DIN:DIP ratios vary widely, from low values (1:1) in late summer to very high values (100:1) in late winter/early spring (2).

We utilized an outdoor system of large-volume culture vessels. The vessels were 0.5 m^3 cylinders fabricated from light-transmitting fiberglass and laminated into resin-sealed plywood bases. Twelve such tanks were submerged in a raceway through which river water was circulated to maintain culture temperatures to within 1° C of ambient. Initially, tanks were filled with water pumped from the Patuxent River and screened through 35 μm nylon mesh to remove large herbivores. The tanks were then operated as continuous cultures using 1 μm filtered river water as the diluent at a flow rate of 250 $l \cdot d^{-1}$ (50% turnover/day). This dilution rate was employed as earlier studies (8, 2, 9) indicated that such a dilution rate would maintain algal densities comparable to that of the nearby Patuxent River. Further details concerning the experimental apparatus and design can be found in the references cited above.

Tanks were designated for control and enrichments, with each treatment usually run in triplicate. The experiments routinely achieved the close replication within replicates necessary in these studies to separate natural from experimental variability. Controls consisted of assemblages diluted with filtered river water with no enrichment, whereas enriched tanks were first spiked with the appropriate amount of nutrient (P or N) to achieve desired experimental levels, then diluted with filtered river water plus nutrient stock to maintain additions at these levels. Enrichment concentrations employed in the study were additions of 10 μM PO_4^{-3}, 50 μM NH_4^+, and 50 μM NO_3^-. These values were chosen to provide excess nutrient, at environmentally realistic concentrations. The tanks were mixed by gentle aeration, and maintained for a period of two weeks. Delivery lines for filtered water, nutrient stock, and air were of non-toxic PVC tubing, which were replaced for each experiment. Associated water delivery systems were entirely non-metallic.

Sampling was conducted daily at 1300 hours, and included surface samples for in-vivo fluorescence (a real-time indicator of biomass) (3, 2), phytoplankton species composition, temperature, salinity, and ambient insolation. Samples for dissolved nutrient analysis were taken 2-3 times/week, filtered through Whatman GF/F glass fiber filters, and frozen until analyzed by standard automated colorimetric procedures (11). Phytoplankton samples were analyzed using the sedimentation technique described by Utermohl (12) and enumerated by inverted microscopy.

Experiments performed in 1987 to investigate the effect of different light regimes employed the use of fiberglass screening over the microcosms to manipulate insolation, and a slightly altered design. Three experiments were run during the course of the year; in July near the summer solstice (NH_4^+ enrichment only), in September during the fall equinox (NH_4^+ only), and again just prior to the winter solstice (PO_4^{-3} only). Duplicate control and enriched tanks were subjected to three light levels. In the highest light level the tanks were unscreened, as in earlier experiments; mid-light tanks were manipulated by screening to approximate light penetration in the river throughout the experiment; the lowest light tanks were screened to achieve values approximately 30% of river levels, thus providing levels approaching light limitation. All other procedures were similar to that in other studies.

RESULTS

Experiments conducted over the five-year study period demonstrated definite seasonal patterns in the nutrient enrichment potential of nitrogen and phosphorus in the salinity transition zone of the Patuxent River. The river's natural phytoplankton assemblages exhibited large, rapid increases in productivity in response to N addition in experiments conducted in the summer and early fall months, periods typified by warm water temperatures and low river flow. Nitrogen enrichment during other seasons yielded little or no response. The potential for P limitation during winter months was demonstrated by a weak, delayed increase in biomass during only two experiments, one performed in November and one in February. Otherwise, no response to P was observed. Results of enrichment experiments during the study period are summarized in Fig. 1.

Response to N enrichment was immediate, frequently occurred within 24 hours, and typically resulted in biomass levels an order of magnitude greater than associated controls or P-enriched tanks. In every instance, the increase in productivity was caused by increased growth rates of one or more centric diatoms. The resulting unstable community of artificially high cell densities persisted until limiting conditions again developed (either due to depletion of available N or induced P limitation). The treated assemblages would then experience a precipitous decline in numbers (i.e. a population "crash"), often by the fourth day of the experiment. The result would be an underpopulated system with nutrient levels being rapidly replenished, where opportunistic species with different nutrient/ratio requirements were able to succeed and establish dominance. Control assemblages underwent a more protracted competition for resources, with initial dominants persisting well into the second week of the experiment. The end result of the different successional patterns was radically different phytoplankton communities (Fig. 2). More detailed information can be found in D'Elia et al. (2) and Sanders et al. (9).

In contrast to the typical N response, experiments demonstrating some response by the phytoplankton to P were characterized by a delayed increase in biomass; for example, in the February 1984 study, a P effect was not seen until day 12 of the study. In this instance, biomass levels tripled those of controls and N enrichments, weak in comparison to the 14-fold response to N in August of that year. We believe that the delayed response reflects artificially-induced P limitation caused by tank entrainment and not an actual response to P limitation in the Patuxent.

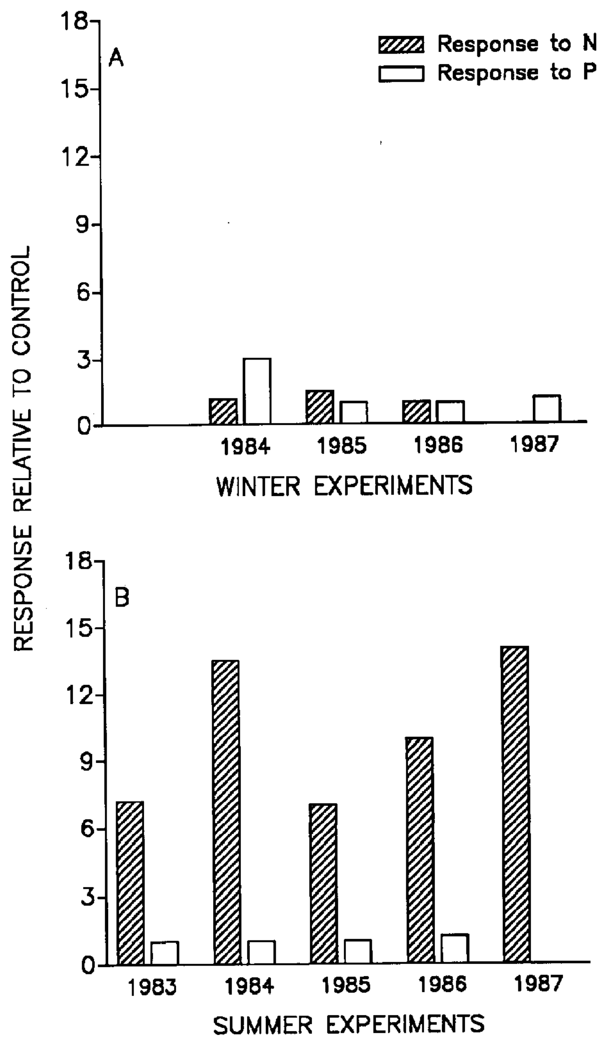

Figure 1. Phytoplankton response (average maximum biomass increase, expressed as % of control ($x10^{-2}$) to N and P enrichment during summer and winter experiments from 1983 to 1987.

Influence of Light on Nutrient Enrichment

A typical response to N enrichment occurred, as in previous years, in July, 1987 (1), regardless of imposed light level. Again, N-enriched tanks attaine biomass levels an order of magnitude higher than controls, even in the lowest light treatment, despite a 60% reduction in available light (relative to river values). Maximum growth occurred in the mid-light treatment, where light levels averaged 80% of river values; unscreened

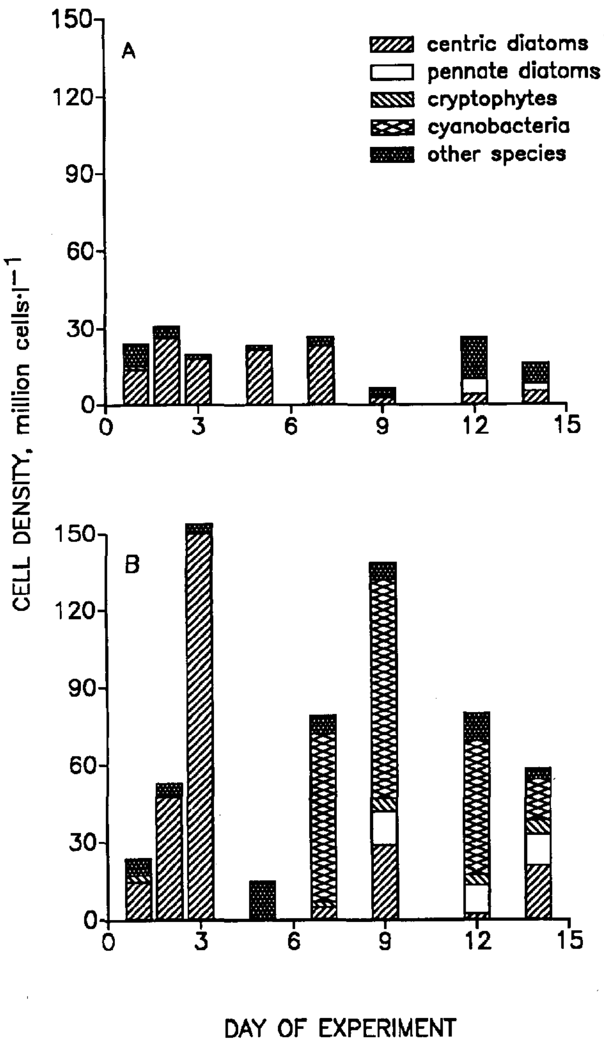

Figure 2. Composition of phytoplankton by taxonomic groups during an experiment performed in summer. A. Control and P-enriched assemblages. B. N-enriched assemblages.

tanks responded in a manner similar to the lowest light tanks.

In the fall experiment, N enrichment did not result in the large increase in biomass found in the July experiment. During September 1987, unlike previous years, ambient NO_3^- concentrations in the Patuxent were unseasonably high, and were utilized by control assemblages as an alternate N source. Demand for nutrients was proportional to available light, regardless of N source.

While nutrient enrichment in the fall experiment did not result in a large biomass increase typical of N additions, light levels did influence species composition and succession. This influence was even more in evidence during the P experiment conducted in December. Additions of PO_4^{-3} had no effect on phytoplankton growth or species composition, but there was a pronounced effect caused by a reduction in insolation. This resulted in both lowered biomass levels and a large shift in community structure (Fig. 3).

DISCUSSION

Results from this study demonstrate that increased N availability in the mesohaline regions of the Patuxent River (as well as in other tributaries of the Chesapeake Bay and similar systems) can profoundly stimulate phytoplankton growth and biomass production. Through five years of study, N loadings controlled algal growth and species composition during summer and fall experiments. Phosphorus enrichment was a factor only occasionally (if at all) during winter. While regulation of P loading due to sewage effluent may help limit autochthonous organic production in the freshwater reaches, the transport of excessive N levels downriver into the estuary can result in levels of organic material beyond the assimilative capacity of the system. The data further indicate that a seasonal strategy of N control may prove effective in many circumstances.

There are two aspects of the present study that must be taken into consideration with respect to management implications.

1. This study shows the response of an isolated component of the Patuxent estuary ecosystem--the upper water column, free of large grazers. Accordingly, if N added upriver is assimilated, denitrified or otherwise removed before it reaches downstream areas, it will not have an effect on phytoplankton growth at times when phytoplankton are susceptible to N enrichment.

2. By removing larger grazers (by screening with a 35-µm mesh) we are allowing the growth of phytoplankton in our cultures to be unchecked by large herbivores. While this may be unrealistic under some conditions, nuisance algal blooms form when phytoplankton production and grazing are uncoupled. Present evidence suggests that zooplankton grazing does not control phytoplankton production in the Chesapeake during much of the year (10). In any case, our assessment yields an estimate of enrichment potential to nutrients, a critical consideration in the management context.

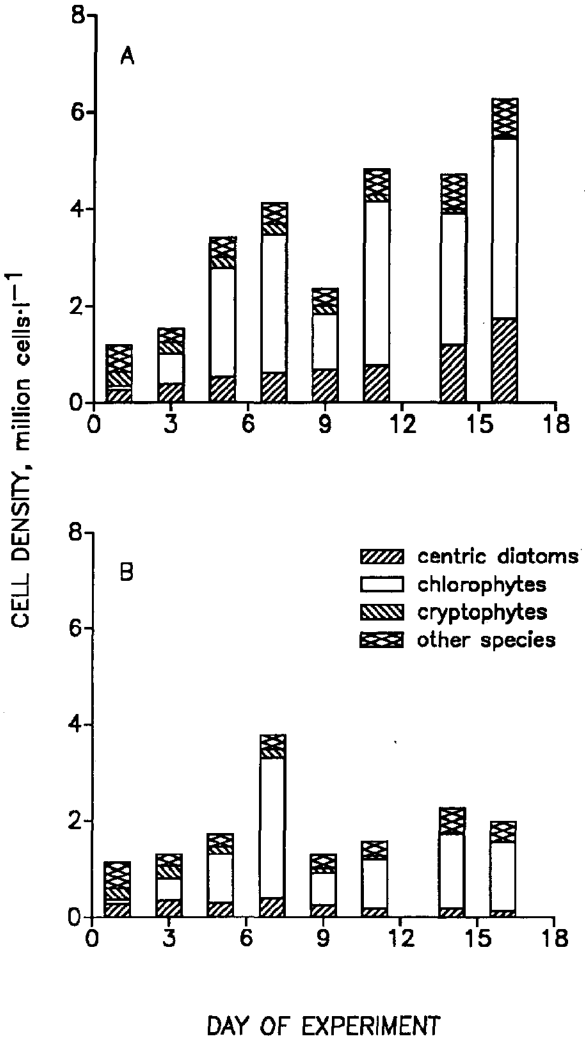

Figure 3. Composition of phytoplankton by taxonomic groups during an experiment performed during winter and subjected to modifications in insolation. A. Unscreened control tanks. B. Screened control tanks receiving 27-30% of total insolation.

In any case, our assessment yields an estimate of enrichment potential to nutrients, a critical consideration in the management context.

Another important factor demonstrated by this research is the strong control asserted by light availability on cell growth during fall and winter in this portion of the Patuxent River. The indication is that light strongly limits productivity and influences species composition. As insolation decreases in the fall, light availability becomes more important and, along with N, may limit phytoplankton productivity. During winter, light appears to be the major limiting factor. Therefore, efforts to reduce sediment loads to estuarine systems through improved land use practices may result in greater light penetration and increased productivity during fall and winter months, necessitating further evaluation of seasonal nutrient strategies.

The large-volume culture system employed here is an excellent tool for the investigation of complex ecological questions. Such systems are well-suited for studies at the community level on the effect and fate of a variety of contaminants, and provide predictive data on the subtle effects of community change. Increasingly, management agencies are employing coupled numerical and hydrodynamic models to assess nutrient strategy and formulate policy. The results of experiments such as those described here can provide the realistic data base for such models, ultimately providing for better management of estuaries and coastal oceans.

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SOUTH CAROLINA'S COASTAL WETLAND IMPOUNDMENT PROJECT (CWIP): RELATIONSHIP OF LARGE-SCALE RESEARCH TO POLICY AND MANAGEMENT

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ABSTRACT

Some 144,000 acres of South Carolina tidelands were impounded in the 1700's primarily for rice cultivation. Today, more than 70,000 of the state's 504,000 acres of wetlands remain impounded, managed for waterfowl and aquaculture. A controversy concerning the restoration and re-use of former rice fields emerged in the early 1970's involving private impoundment owners and managers, regulators, scientists, and concerned citizens. A key ingredient missing from the debate was an adequate base of information upon which arguments could be tested. The Coastal Wetland Impoundment Project (CWIP) was initiated to characterize wetland impoundment systems and compare them ecologically to open, tidal wetlands. Field studies were undertaken on a series of five small, brackish-water impoundments, located adjacent to open tidal wetlands. Although results characterized the ecology of these systems, application of field data to the resolution of policy and management questions has come more slowly.

INTRODUCTION

Coastal wetland impoundments are a distinct feature of coastal South Carolina. Some 70,000 acres of impoundments are located along the tidal reaches of the state's five major drainage (river) basins: the Black-Waccamaw-PeeDee, North and South Santee, Wando-Cooper-Ashley, Ashepoo-Edisto-Combahee, and Broad. Vestiges of old impoundments can be seen on more than 74,000 acres which now have direct hydrological flow with adjacent wetlands and tidal waters.

Interest in the inherent productivity of these systems has waxed and waned during the past 300 years. Over the last three decades, intense debate has occurred regarding the disposition of thousands of acres of impounded and formerly impounded tidelands. Many of the arguments are based on history and tradition.

Coastal wetland impoundments can be traced back to the early 1700's, when rice emerged as a profitable crop (1). Huge plots of tidelands were granted by the King of England (and later, the State) to individuals for rice culture. The conversion of tidal swamps to rice fields improved productivity, but required large initial investments (2). The preparation of rice fields was difficult; swamps had to be cleared, and a series of dikes, water control structures, water reservoirs, and interior beds had to be excavated and constructed. In a number of watersheds, the entire floodplain was modified; the fields extended several miles in width and tens of miles along the river banks (3). All of this was accomplished by slave labor working only with hand tools; it often took years to reclaim these areas.

After the Civil War, South Carolina experienced a major shift away from rice culture (4). The loss of slave labor, several crop failures. coastal storms, and competition from other industries and states led to the industry's ultimate demise by 1930. However, the impoundment resource was not totally abandoned. Many of the rice field plantations were sold to wealthy northerners, who managed the impoundments for waterfowl hunting and other pastimes. Still others were purchased by timber companies for their extensive forest resource (4).

Today, more than 75 percent of intact impoundments are managed to attract waterfowl for conservation and hunting purposes. Others are used for aquaculture; significant acreage has been converted to crawfish culture. The ability to manipulate these systems to meet specific management goals has increased their value, and resulted in a serious ecological debate.

DESCRIPTION AND FUNCTION OF IMPOUNDMENTS

Coastal wetland impoundments are basically managed to control the flow of tidal waters in and out of the system and the level of water inside. Their success can be attributed to a tidal range of 1.0 to 2.5 meters found along the South Carolina coast. The manager's ability to control water movement depends on this and on the structural integrity of the impoundment.

Impoundments consist of a series of earthen dikes equipped with several water control structures. Wetlands and swamps were impounded by the construction of dikes built with hand labor, dragline dredges or hydraulic trackhoes (5). Dike material was taken from a borrow pit located on the inside perimeter of the impoundment (6).

Modern dikes vary in dimension, depending on whether they will accomodate vehicular traffic. Those that allow it will have a top width of 12 feet and a base width of 25 to 30 feet (5). A critical dimension is the height of the earthen structures. Dikes are constructed at least 3 feet above mean high water, enough to withstand all flooding except from storm surges.

Water control structures, called "trunks," remain typical of those used during the rice culture era: interestingly, the structure of these mechanical devices has not varied much in over 300 years. Although they can be constructed from concrete, metal or wood, those built with pressure-treated wood appear to be the most durable in brackish and salt-water environments. Trunks are designed with flap gates at both ends, which can be raised to take in water or lowered to release water at scheduled intervals according to the tides. When managers need water, the flapgate outside the impoundment is raised and during high tide the force of the water pushes open the inside gate. As low tide approaches, the pressure of the water inside the impoundment causes the inside gate to close shut and water is retained. When drainage is desired, the manager raises the outside gate and at low tide waters are released (6).

Today, most water control structures contain a flashboard riser system used to control water levels inside the impoundment: The riser consists of a rectangular trough, about five ft high, five ft wide and one ft deep, built perpendicular to the inside lip of the trunk. The side of the trough facing the pond is made of removable boards, called flash-board risers, placed horizontally in grooves that run the height of the 'riser'. With the inner gate shut, the water level of the impoundment is regulated by adding or removing boards (6).

Water flow and levels are manipulated in impoundments according to specified management goals. Management schemes vary with species of vegetation desired, salinity of the waters, and soil characteristics. The management strategy employed at an impoundment site not only serves the manager's goals, but also dictates how the system functions ecologically. These differences have shaped the controversies arising over impoundment restoration and use.

THE IMPOUNDMENT ISSUE

Over the last 30 years. owners and managers of impoundments have desired more acreage for waterfowl hunting and conservation. The conversion of formerly impounded wetlands into aquaculture systems also seemed attractive. Recently, more than 25 applications were made to state and federal regulatory agencies for re-impoundment and restoration activities. These applications triggered the controversy in which impoundment owners and managers, regulators, scientists, and interested citizens all participated.

DeVoe and Baughman (7) discuss the arguments made for and against these proposed activities: many dealt with impacts on the natural system. Opponents argued that impoundments reduce tidal exchange, limit access to nursery grounds by larval and juvenile fish and shrimp, reduce overall marsh productivity, diminish water quality, and concentrate and store nutrients. Also, they contended that permits to impound formerly impounded wetlands would affect navigation, limit public access, and set dangerous precedents. Proponents felt impoundments to be very productive systems, catering to large populations of waterbirds, reptiles, and mammals (some threatened and endangered). They also argued that tidelands may be conveyed through historical land grants, and that inasmuch as public entities are allowed to re-impound areas, equity should permit private owners the same opportunity.

As the debate sharpened, it became clear that there was a lack of sufficient data and information on impoundment ecology, impoundment management techniques, and policies of the state and federal government,

THE COASTAL WETLAND IMPOUNDMENT PROJECT (CWIP)

This apparent lack of information was the impetus for the Coastal Wetland Impoundment Project, a multi-institutional, transdisciplinary study to characterize wetland impoundment systems in South Carolina and compare results with those collected from simultaneous studies of a nearby open marsh and tidal creek system (8). The overall goal of the CWIP was to obtain data useful for issue resolution and make it available to decision-makers, impoundment managers, and the informed public (9).

Undertaken from 1981-1986, CWIP represents an initial stage of ecological and policy research on impoundment systems in South Carolina. Establishing the structure and objectives of the study involved interaction with physical, biological, and social scientists, landowners, public and private managers, public interest groups, and others. The thrust of the CWIP was also dictated by the characteristics of the study site.

CWIP Study Site

The study site area is located on the Tom Yawkey Wildlife Center, Georgetown, South Carolina. The advent of the rice culture industry in the early 1700's saw the area converted from a pristine cypress swamp to impounded rice fields. During the construction of the Atlantic Intracoastal Waterway (ca 1900), the area was used by the U.S. Army Corps of Engineers as a spoil deposit (10). In 1945, the area was converted from a fresh to brackish environment with the completion of the Santee-Cooper River Diversion Project. In 1967, six impoundments were reconstructed from previously impounded marsh by the S.C. Wildlife and Marine Resources Department to examine the effects of different water management practices on vegetative succession (11). These impoundments have been managed by the state to attract waterfowl since 1970 (10).

The study site consists of five contiguous impoundments, 3.5 to 7.8 ha in size (Ponds 1-5); a 7.9 ha contiguous unmanaged tidal impoundment (Pond 6); a 13.8 ha managed impoundment (Cooperfield); and open marsh located east of the impoundments. Immediately adjacent to the impoundment complex dike is Chainey Creek, the major water source for the impoundments (see Fig. 1).

CWIP Study Design

The initial design for the CWIP was to use the five contiguous impoundments as "replicate" systems, with two of the ponds managed as controls and each of the others under different water management regimes. The intent was to not only characterize a "typical" managed impoundment, but also to identify variations in systems managed under alternative strategies. The study design was to take advantage of these natural aquaria, as recently discussed (12).

However, preliminary field investigations demonstrated that the five systems could not be treated as replicates; natural (temporal and spatial) and artificial (artifacts in water management) variations masked observed differences among management schemes. And because of the pressure to develop an information base quickly, time was not available to first document these variations.

Therefore, each study impoundment was manipulated under a typical waterfowl management scheme. Ponds were dewatered in the spring to expose the impoundment beds and to encourage the germination of _Ruppia_, widgeon grass. After a quick flood and drawdown to remove mosquito larvae, the impoundments were reflooded and the risers set to maintain from 10 to 20 cm of water over the beds. From spring to early fall, water levels were increased in 10 cm increments to allow for _Ruppia_ growth. Water levels were lowered throughout the fall to expose the widgeon grass to waterfowl. The cycle is repeated annually.

CWIP Study Objectives

The CWIP was structured into twelve tasks to address the following objectives:

(1) Determine stratigraphy, characterize hydrology, and identify and compare the major flora and faunal components of the study impoundments;

(2) Characterize the nutrient dynamics and determine primary productivity of the study impoundments and the adjacent open wetlands:

(3) Determine and compare the recruitment, growth rates, and standing crop biomass of commercially and ecologically important species in impoundments with the adjacent system;

(4) Determine the flow of nutrients and biomass between the study impoundments and the tidal creek and wetlands; and

(5) Determine the public policy issues affecting impoundments: ownership, current and proposed uses, management techniques, and federal and state policies.

Field studies were undertaken for a two-year period, beginning in Spring, 1983.

CWIP Study Results

The study area was found to be a very productive and well-integrated system. Based upon the data collected, the impoundments and tidal wetlands were different with respect to the overall community structure of many of their biological components, but, not surprisingly, the basic ecological processes occurring in each were similar. The critical variables that controlled observed differences between the two systems were, in fact, a function of "transfer effects."; due primarily to tidal influences, water level patterns and the degree of water exchange between the systems (13).

The immediate resolution of the controversies surrounding impoundments in South Carolina did not turn on the immediate scientific questions, however.

EXTERNAL INFLUENCES ON THE IMPOUNDMENT CONTROVERSY

The controversies over South Carolina's

impoundments proceeded in many arenas. The CWIP brought together a diverse community of scientists, whose efforts were focused by a common study site and an integrative study agenda. The disputes over specific impoundments continued to unfold elsewhere.

Some private landowners pursued specific claims to title and the right to manage their sites as they wished. These controversies were pursued through the regulatory arena and involved public agencies such as the S.C. Coastal Council, the S.C. Attorney General, and the S.C. Department of Health and Environmental Control, as well as public interest groups such as the League of Women Voters and the Sierra Club, who opposed the claimants. The controversies were further complicated when the U.S. Environmental Protection Agency formally intervened in 1981 to raise additional ecological concerns.

The considerable complexity of these proceedings created a situation in which only the most aggressive and well-funded proponents of rice field restoration could pursue their claim. Thus, public controversy focused on a few cases, One applicant reports that he spent over $200,000 in legal fees during the fifteen years that his case lasted.

The CWIP team maintained on-going communication with these claimants. The CWIP included a survey of all identifiable impoundment owners and claimants. Prior to the beginning of intensive field studies, the S.C. Sea Grant Consortium convened a day-long briefing for the CWIP scientific team, conducted by four of the most prominent impoundment managers in the state.

As a result, diverse, sometimes incommensurate perspectives on the impoundment resource were brought into continuing discussions. Indeed, many environmental controversies manifest themselves in this way and create "failures of discourse" (15). With the impoundment controversy, these boundaries involved the divisions between those interested in aquatic species using coastal wetlands as nurseries and others interested in reptiles, birds, and mammals using the impoundment sites for shelter and feeding. The issues also involved fundamental conflicts over whether these wetland sites represent common pool resources with open access or private lands and therefore appropriable resources.

Ultimately, the policy debate was halted by external events. In 1986, the S.C. Supreme Court took up a critical impoundment case. In response to an appeal from the League of Women Voters and the state's Attorney General, the Court reversed a decision of the S.C. Coastal Council to permit the re-impoundment of more than 660 acres of old rice fields. The strong emergence of the U.S. EPA in the impoundment issue was also felt, specifically regarding water quality and wetlands impacts. The court decision and continuing skepticism of regulatory agencies sent a strong signal: applicants would face a difficult regulatory process if they sought to re-impound rice field sites. Not surprisingly, permit applications for major impoundment restoration projects have subsided: from 1980 to 1983, seven restoration projects were proposed to the S. C. Coastal Council, but from 1984 to the present only two were proposed. The S.C. Coastal Council also received thirteen requests for permits to repair existing sites in the 1980 to 1983 period, but only seven from 1984 to 1988. However, interest in sites further inland has increased, with the S.C. Water Resources Commission, which has permit authority outside S.C. Coastal Council jurisdiction, receiving only nine requests from 1980 to 1983, but seventeen from 1984 to the present.

Whatever interest remains in changing state policy to encourage the restoration of old rice fields has been overshadowed by other events, In 1986, the state formed a Blue Ribbon Committee to examine the controversial questions posed by beachfront development. This effort resulted in 1988 legislation which established beachfront setback lines for construction and reconstruction along the coast. As reflected in the policy making process more generally, state natural resources policy is made by policy-makers whose time and attention is limited (15). Since the beachfront management controversy involved many of the same legislative and regulatory policy-makers, impoundment issues have been bumped off the immediate agenda for public discussion.

IMPACT OF THE CWIP

The CWIP has had only a modest impact to date. The impoundment debate was both defused by the S.C. Supreme Court decisionand displaced by other controversies: actions that have constrained those who would otherwise seek to reimpound old rice fields. While CWIP results had little direct impact on these particular events, they have had other important consequences and have become an important base of information to be drawn on in the future.

Sea Grant played an important role by focusing the effort on a common site (where management schemes were consensually defined), providing a common focus, committing it to a multi-year analysis strategy, and bringing members of the team together periodically to refine task directions. After the field work was done, study results were assembled and integrated, and research team members presented their findings at meetings such as the 1985 and 1987

Estuarine Research Federation Conferences. This process has produced improved communication and understanding among members of the research team. CWIP scientists now provide the state with a diverse resource of experienced and knowledgable impoundment investigators. The research was relevant to impoundment research in other settings as well; the states of Louisiana, Florida, Georgia and Delaware have specifically invited CWIP investigators to participate in conferences and meetings and have requested copies of the CWIP report.

The CWIP highlighted the complex issues that the impoundment resource posed. It became clear, as scientific studies were defined, that multiple, but only partially incommensurate values were at stake. Better management of existing sites clearly had the potential to improve productivity and limit the impact of favored waterfowl management regimes on other valued aspects of wetland ecology. As a result, participants and observers realized that no simple, universally-compelling resolution of conflicts between competing claimants could be reached, while no case for an underinvestment in impounded sites could be made. This emerging understanding attenuated the force of arguments for immediate action on impoundment issues.

Recent discussions with state policy-makers indicate that this controversy is now on the "back burner." However, they all agree that the impoundment issue still has the potential to re-emerge at any time in the future. But, few of them reported having even read the overall study: most decision-makers have limited time and cannot be expected to attend to detailed information unless it becomes relevant to them (16). More likely, when such controversies emerge, they will rely on key staff members, bureaucrats, and lobbyists to synthesize and summarize materials for them.

When we turn to legislative and regulatory staff, whose importance in the policy-making process is often underestimated, a different picture emerges. We interviewed staff people in nine regulatory and public interest agencies and found that most are familiar with the overall project and had, in fact, read the CWIP report. While they, too, view the controversy as one which does not currently demand attention, they also regard it as one which may re-emerge in the future. When it does, they expect CWIP results to play an important role in framing the issues and informing them about the questions which must be addressed.

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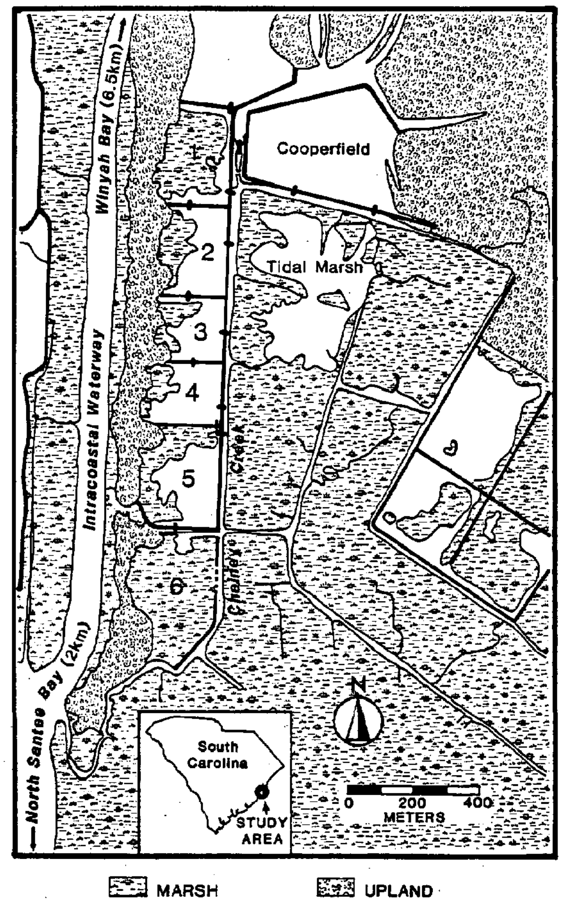

Figure 1: CWIP Study Site

EXPERIMENTAL MARSH MANAGEMENT SYSTEMS IN LOUISIANA

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ABSTRACT

Replicated experimental marsh ecosystems are established and planned for research and management of coastal Louisiana wetlands to (1) test management schemes before large scale implementation, and, (2) discriminate between long-term changes and the cumulative impacts of many other alterations. Water level changes are clearly shown to influence plant metabolism, hence ability to of the marsh to withstand sea level rise and geological subsidence. Animal migration/emigration is influenced as well as sedimentation rates. Soil conditions, especially bulk density and mineral content, influence hydrologic impacts, hence the need for replicated and diverse manipulations.

1. INTRODUCTION

Man's management and impacts on coastal wetland ecosystems is very often a result of how the hydrologic regime is modified. Changes in sediments, plants and soil chemistry are known to be caused by hydrologic changes[4,7,9,16,20], but the direct and long-term consequences of hydrologic modification in wetlands are not well-known. These circumstances arise, in part, because the relationships between parts of the ecosystem and hydrology are better known than the reactions of the whole ecosystem. This situation is not altogether very different from the situation that environmental toxicologists may find themselves in: the results of detailed and short-term (up to 30 days) laboratory experiments of individual species may be precise and predictable, but these same results may not be useful to predict the consequences of the same stress when applied in the field on whole ecosystems and followed for years. An additional consideration in evaluating the cause and effect relationships in wetlands is that the hydrologic changes in one part of the watershed may alter sediments and water regimes as far as 1 km from the initial activity[2,13,15]. This is not a trivial consideration if one is familiar with dredge and fill permitting decisions which typically to not consider off-site or cumulative impacts[5,6,11,14].

Field mesocosms of wetland ecosystems are one approach used to overcome some of the obstacles to learning about wetland management and impacts. This paper includes a description of some mesocosms used in coastal Louisiana to learn about (1) why coastal wetland losses and changes are both large (0.8% annually from 1955 to 1978[15,18]) and extensive (these wetlands include about 40% of the nation's coastal wetlands[12,15], and, (2) wetland development and management options. Three very different experimental field designs will be presented ranging in size from field manipulations of 5 ha impoundments, to 25 m^2 test areas, to field trials in outdoor tanks. These mesocosms include large replicates of whole (or nearly whole) ecosystems are are followed for long periods of time. We have excluded the excellent experi-mental results of Mendelssohn and McKee[10] because they were relatively brief and small (marsh cores less than 20 cm). The studies described here are in salt or brackish marshes, primarily because the vast majority of coastal wetlands in Louisiana are composed of this vegetation type and eroding at very high rates.

2. A BRIEF DESCRIPTION OF SEVERAL EXPERIMENTAL WETLAND MESOCOSMS IN LOUISIANA

It is the purpose of a research program at the Center for Wetland Resources, Louisiana State University, to establish a large-scale experimental study of wetland hydrology to be followed over 10-20 years in direct cooperation with landowners[17]. The planned new study sites would be composed of at least fifteen, 2 ha (5 ac) impoundments fitted with adjustable water control devices. Variability in waterflow, soil, plants, and animals will be determined. The only comparable large-scale wetland manipulations we know of are at the Delta Waterfowl and Wetland Research Station, Delta, Manitoba.

Other studies (in triplicate) are currently underway (3 m circumference) at 5 sites in salt and brackish marshes. These manipulations are meant to replicate, at a smaller scale, the anticipated changes from the larger impoundments, described above. One explicit intent of these smaller studies was to see if the marsh could be made to become open water through, it seemed, rather small hydrologic blockages in either belowground or aboveground flow. In essence, various plastic sheets were inserted around intact marshes between +30 and -60 cm from the marsh surface. If we really knew why the marsh became open water, we reasoned, then we could intentionally create that result, observe the processes and more intelligently determine solutions for stressed, but still intact wetlands.

Smaller studies were completed by Babcock[1]. Babcock transplanted 35 cm marsh cores to field tanks and followed plant growth for one year and the influence of waterlogging, drainage, burning and salinity.

Scale considerations become important if one is interested in the role of large organisms. The nutria (*Myocastor coypus*) and muskrat (*Ondatra zibethicus*) are large herbivorous marsh mammals common in south Louisiana and hunted for their fur. Fuller et al.[8] put fencing around a developing delta island *Saggitaria sp.* marshes in the Atchafalaya river delta. The intent was to study what would happen if these large herbivores were excluded from the marsh.

3. RESULTS

The experience with these three types of mesocosms has been beneficial for the new knowledge about (1) how the plants respond to hydrologic changes, (2) the role of large herbivores in structuring vegetation, and, (3) the difficulties in organizing large experiments. These results, and others not mentioned, would have been unlikely if smaller scale experiments were substituted.

Plant production seems to be indirectly related to soil flooding and we are now beginning to quantify the relationships in a meaningful way for field managers. Plant production is usually higher when flooding is reduced and lower when flooding is increased for *Spartina alterniflora, S. patens and Distichlis spicata* (Figures 1 and 2), but the effect may vary, depending on the species and salinity. Plants contribute to marsh stability through sediment trapping, erosion resistance, and organic contributions to soils. These wetland soils must accumulate enough material vertically to compensate for the rise in water level because of rising sea level, sediment compaction and a geosynclinal tilt in the basement material. Sediment deposition behind hydrologic restrictions (e.g. spoil banks) may decrease leading to a synchronous and synergistic interactions between waterlogging stresses and sediment deprivation. The cumulative result may be a relative increase in water level leading to lower plant production and further stress.

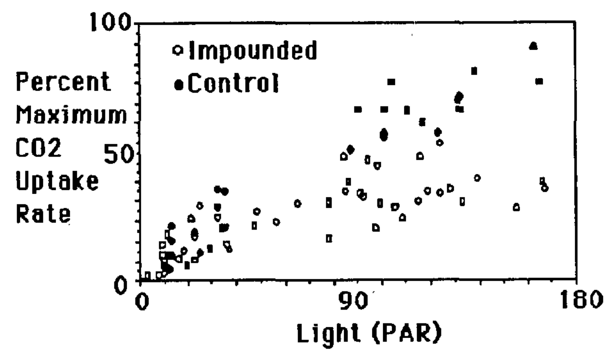

Figure 1. An example of the relative photosynthesis rate for *Spartina alterniflora* (April, 1987) in control and artificially-impounded wetlands (triplicate treatments).

The study of large exclosures on newly deposited delta lands[8] showed a significantly higher plant biomass inside compared to outside and there were indications that plant species composition was affect by herbivory. These results would not have been determined with smaller scale studies.

Attempts to build the large impoundments are being stymied by three factors, none of which are insurmountable. First, the state permitting authority has not issued the necessary permits, in spite of their legal requirement to strongly and quickly favor such scientific work. Second, the landowner, a large oil and gas

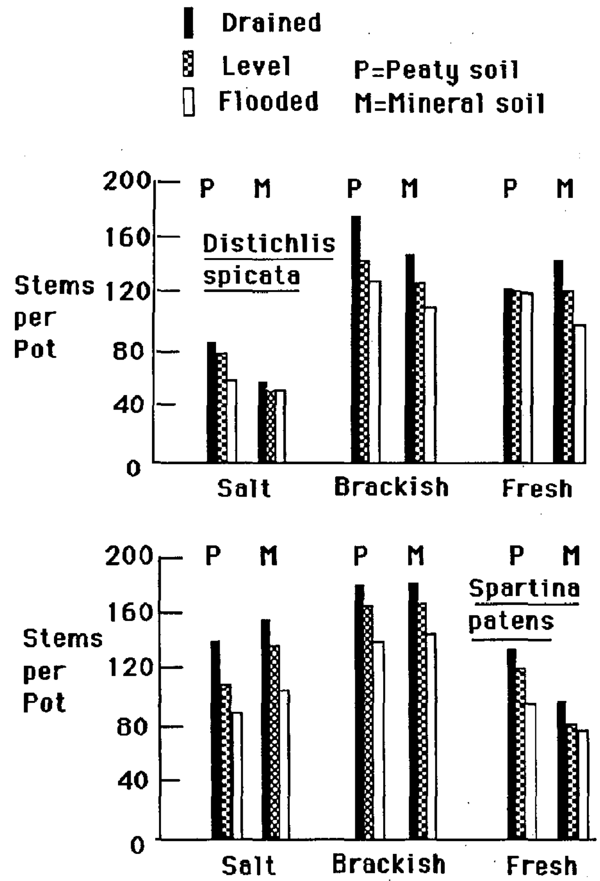

Figure 2. Stem density of *Spartina patens and Distichlis spicata* growth for one year at three water depths (+4, 0 and -4 cm below the marsh and at three salinities in the field[1].

development company, is undergoing divestiture thereby complicating the commitment of funds and acquisition of legal rights necessary to complete the project. Third, the funding necessary for the dredge and fill operation has been difficult to obtain from the company, as initially expected. The company's profits plummeted with a fall in oil prices the last few years and the company found it difficult to fund a large project in the midst of a staff reduction program. A foundation proposal was rated very high in a national review, but not funded when reviewed by within-state representatives of a federal agency. State funds are unavailable due to the extremely dismal state financial situation.

4. DISCUSSION

The use of mesocosms provides a substantial field test of both real-life alternatives field managers face daily and of hypotheses that scientists bring to bear on real world problems, regardless of whether or not they are immediately applicable to management. Our knowledge of natural resources must be scaled to that of our interests, which are for the long-term. In these case of these three examples, the results have not yet provided explicitly clear alternatives for management, but several conclusions are now obvious. First, though seemingly trivial, the old (for Louisiana, at least) piecemeal approach to manage for fish, fur, or fowl interests, must be acknowledged to influence other management interests. For example, hunting groups might wish to attract waterfowl to open water (and create open water from vegetated marshes), but the water control structures used also inhibit fish and invertebrate migration into and out of the marsh and, in the long-term, may cause indirect losses of wetlands; Fur harvest may be enhanced by burning or flooding to control vegetation quality, but waterfowl harvests be reduced. Water management, in other words, is total ecosystem management, not species management, and these conflicting issues must be addressed when public resources are affected.

Second, demonstration plots are useful to (1) illustrate just how long it takes for changes to occur, (2) learn how different soils affect the results, and, (3) let the non-specialist see, for themselves, the consequences of small managementa changes. Changes did not occur as always expected and the scientists' understanding of how fragile some marshes were was challenged.

Third, the larger the mesocosms, the more diligence, perseverance and support is needed to sustain the research team (which is necessarily interdisciplinary), the financing, and the administrative infrastructure. Mesocosms are as rare as the financing is rare.

There is growing awareness of the value of long-term study sites in environmental work[3,19]. However, the design, funding and study of long-term study sites offers several special problems to the researcher: having dedicated leadership (including lead and core scientists), and a unique site offering special advantages, and diverse approaches. Although the combination of growing interest in addressing wetland losses in Louisiana and the proven interest of the university research community will probably overcome these barriers. But, the cooperation of the state and federal agencies is also required. The shortest path to a solution is understanding and that requires a suite of technical approaches, of which mesocosms are a uniquely useful addition.

5. ACKNOWLEDGMENTS

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THE MARSH ECOLOGY RESEARCH PROGRAM (MERP): THE ORGANIZATION AND ADMINISTRATION OF A LONG-TERM MESOCOSM STUDY*

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ABSTRACT

In 1978, the Delta Waterfowl and Wetlands Research Station and Ducks Unlimited Canada developed a joint venture to study the impact of different water levels during a wet-dry cycle on the composition and rate of nutrient cycling (N, P, and C) of prairie, lacustrine wetlands. Changes in water levels associated with wet-dry climatic cycles are a characteristic of all prairie wetlands. An experimental marsh complex consisting of 10 rectangular mesocosms, each with an area of at least 5 ha, was constructed by diking a section of the Delta Marsh, Manitoba, Canada. Each cell is equipped with water control structures and pumps. The hydrology, water chemistry (surface and interstitial) vegetation, invertebrates, and vertebrates (waterfowl, blackbirds, muskrats) of each cell have been monitored during each growing season since 1980. Sixteen short-term projects by graduate students that supplement the main project have also been done as part of MERP. MERP is largely administered by Delta. It is located on Delta property; its full-time coordinator and staff work for Delta; and most field technicians are hired by Delta. Some specialized research is contracted out to other institutions, e.g. water chemistry, plant tissue analysis, and algal production. A scientific team composed of 6 or 7 members, about half from Delta and Ducks Unlimited Canada and half from academic institutions, directs the project and makes all scientific and technical decisions. They designed the water-level experiments; established sampling and sample handling protocols, described in a field manual that is revised annually; and are responsible for publishing the data collected. Delta and Ducks Unlimited Canada jointly fund the project, and they have raised funds for it from a variety of

individuals, corporations and foundations. Recommendations for the design of field mesocosms and conducting long-term studies are also given.

INTRODUCTION

The Marsh Ecology Research Program (MERP) is an experimental, long-term, ecosystem-level study of the impact of water level changes on the composition of, and cycling of nutrients (N, P, and C) in, freshwater prairie marshes. In this paper, we will first discuss why we are using mesocosms, how we designed our mesocosms, and how we sample them. Administrative, organizational and funding aspects of our project will then be discussed. Finally, on the basis of our experience, we give 10 recommendations for conducting a successful long-term study using mesocosms.

WHY USE MESOCOSMS?

This study arose out of a need to develop reliable information about freshwater wetland ecosystems that could be used to improve their management. The ultimate objective of the two organizations, the Delta Waterfowl and Wetlands Research Station and Ducks Unlimited Canada, that developed this project was to improve the management of waterfowl breeding habitat in the northern prairie region.

All palustrine and lacustrine wetlands of the northern prairie region undergo changes in their water levels that are the result of variation in annual precipitation, wet-dry cycles. During a cycle, a freshwater wetland changes from an expanding emergent wetland, the regenerating stage, to a more open system, the degenerating stage, during which a combination of high water levels and muskrats begins to eliminate the emergent vegetation. This is followed by the lake stage during which emergent vegetation is largely absent. With the onset of the next drought, the final stage of the cycle begins, the dry marsh stage, during which there is no standing water in part or all of the marsh. During this stage the seeds of emergent species germinate on exposed mudflats. With the end of the drought, the marsh refloods and enters the regenerating stage again during which emergents spread over the wetland by vegetative propagation. Waterfowl, other birds, invertebrates, and mammals all respond dramatically to changes in water levels and vegetation during wet-dry cycles[3].

We decided to study experimentally the responses of prairie wetlands to water level changes during a cycle. Two features of the cycle were chosen as treatments: the length of the drawdown or dry-marsh stage and the depth of water during the regenerating, degenerating and lake stages. Both have significant management implications. Because it is impossible to control water levels in natural marshes, some type of mesocosm complex had to be established. Such a study would of necessity have to be long-term because a complete wet-dry cycle can take up to 20 or more years. The need to replicate treatments was also considered essential. The limited literature on wet-dry cycles and prairie wetlands was based solely on studies done at one or two marshes[3], and consequently, it was impossible to separate site and year effects from responses to water-level changes. In order to determine the potential variation in the response to a water level treatment, replicates of each treatment would be necessary. Mesocosms make it feasible to replicate treatments.

THE MESOCOSMS

In order to be able to apply the results of MERP directly to other prairie wetlands, the study had to be done in an existing wetland. To do this, a series of marsh mesocosms was created by diking off a part of the Delta Marsh located on property controlled by the Delta Waterfowl and Wetlands Research Station, Delta, Manitoba, Canada. The final size and shape of the cells was determined by four major factors: (1) the area needed to include all five major vegetation types found in the Delta Marsh; (2) the area needed to detect changes in waterfowl, blackbird, and muskrat populations; (3) the area needed to avoid sampling areas disturbed by boundaries (dikes and ditches) and 9 years of sampling; and (4) the cost of constructing dikes.

Annual sampling disturbs about 2,500 m^2 per mesocosm (Table 1 and Figure 1). Only 175 m^2 are disturbed by permanent sampling sites, but nearly 2,300 m^2 by work lanes and sampling sites whose location is shifted each year. Over the 10 year life of MERP, about 2.5 ha of each mesocosm will be affected by sampling. To reduce the annual sampling impact to less than 5% of the total area of a cell, each cell would have to be 5 ha or more. Five hectares also were considered adequate to detect changes in waterfowl and muskrat populations. In order to enclose all the vegetation zones found in the Delta Marsh, mesocosms would have to run about 320 to 340 m from its upper edge into the marsh. In order to avoid boundary effects, no regular sampling would be done within 10 m of any mesocosm boundary. This 10 m wide buffer area around each cell provides an area from which soil, plants and other samples can be collected for experimental purposes. These specifications meant that for rectangular mesocosms their width had to be between 150 and 220 m in order to effectively have a 5 ha cell. Ten rectangular mesocosms of this size, contiguous to minimize the total length of dike needed, were built with the funds available. Having contiguous mesocosms did cause problems with seepage from one cell to another during a few years when some cells were flooded 1.5 m higher than adjacent cells. During these years a buffer zone of 30 m or more was needed to avoid all boundary effects.

Funding to construct the experimental marsh complex was provided by Ducks Unlimited Canada, and the dikes were designed and built under the supervision of their engineers. Dikes were built wide enough so that muskrats could not tunnel through them and high enough so that the cells could be flooded to 1 m above normal. Each cell was equipped with water control structures and an electric pump with sufficient capacity to offset losses due to seepage and evapotranspiration at any water level. Additional information about MERP and the experimental cell complex can be found in references [1] and [2].

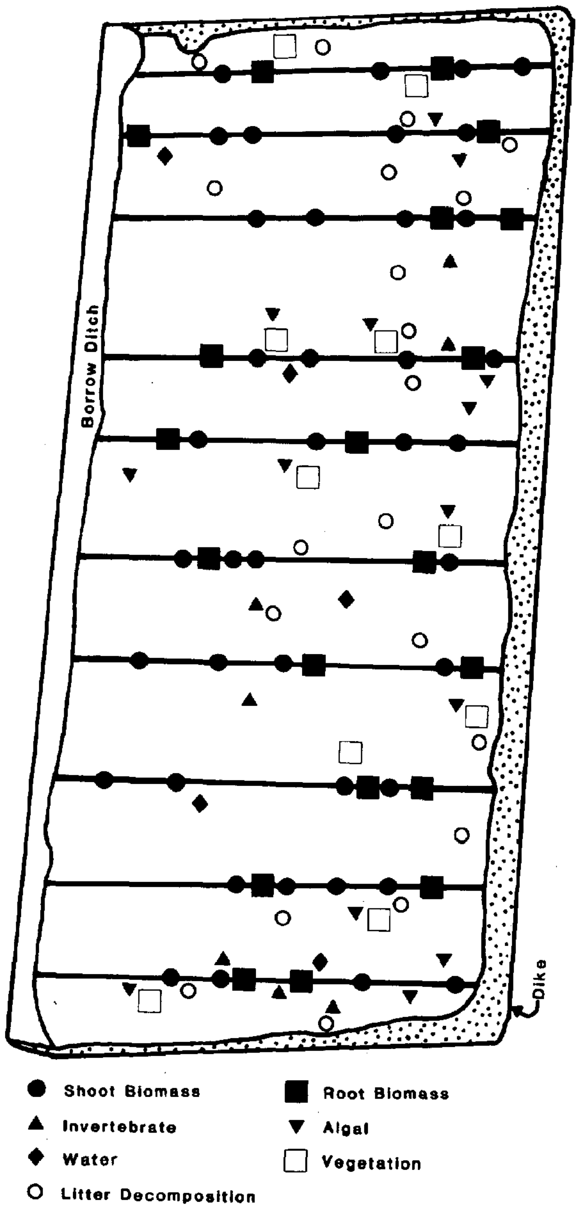

Figure 1. Location of sampling sites in mesocosm 5.

SAMPLING

Education is one of the major missions of the Delta Waterfowl and Wetlands Research Station. It had done this traditionally by funding thesis and dissertation research of graduate students working on waterfowl or wetland research projects. Delta also had a tradition of hiring recent university graduates who planned to go to graduate school in either waterfowl biology or wetland ecology as field assistants to give them practical experience doing field work. Ducks Unlimited Canada was interested in seeing more people trained as wetland ecologists whom they could hire as managers. As a result of these traditions and needs, it was decided that most of the core sampling during MERP would be done by recent university graduates or beginning graduate students.

Table 1. Area disturbed by work lanes and different types of sampling during one year in a mesocosm in the MERP complex.

Sample Type	Area (m2) Disturbed per sample	Number of Samples per cell	Total Area (m^2) Disturbed
Work Lanes	150	10	1,500
	Shifting Sampling Sites		
Shoot Biomass	9	40	360
Root Biomass	9	40	360
Invertebrate	9	7	63
Algal	1	13	13
Subtotal			796
	Permanent Sites		
Litter	9	5	45
Water	4	10	40
Vegetation	9	10	90
Subtotal			175
TOTAL			2,471

The decision to do most of the work with relatively inexperienced personnel who would only work one field season meant having to design the administration of the project in such a way that consistency in the collection and handling of samples from year to year was assured. There was also a need to integrate the day-to-day field operations of the project to ensure that different types of sampling did not interfere with each other. A full-time coordinator with an assistant was hired to manage the project and supervise on-site operations. A methods manual was also written that outlined sampling protocols in detail, how samples were to be handled and stored, and how data were to be entered unto the computer for later analysis. This manual has been revised annually. Changes in the composition of the vegetation, primary production (vascular plant and algal), litter decomposition, secondary production (invertebrate and muskrat primarily), water chemistry (surface and interstitial), and hydrology are all monitored as part of the core study (Fig.1).

It became clear during the early years of MERP that some kinds of sampling and sample analysis could not be handled reliably by people without any specialized training and supervision. This resulted in a partial change in policy and the hiring of people with specific expertise in some areas. The first area in which this was done was water chemistry. After the first year all water chemistry was done by the Freshwater Institute of Environment Canada in Winnipeg, and a full-time technician was hired by Delta to work in this laboratory. Similar arrangements were made to handle algal sampling with the University of Manitoba and to do plant tissue analysis and muskrat studies with Iowa State University.

ADMINISTRATION AND FUNDING

MERP is a joint project of the Delta Waterfowl and Wetlands Research Station and Ducks Unlimited Canada. Administratively and operationally, however, it is run by the Delta Waterfowl and Wetlands Research Station (Figure 2). It is located on Delta property; most operating funds are administered by Delta, the coordinator of the project is a Delta employee; and most of the technicians who work on the project are hired by Delta. Ducks Unlimited Canada, however, through a formal arrangement with the Station, provides a significant share of the annual operating budget of MERP, is involved in the design and conduct of some aspects of the study, supports directly short-term studies, and is the main vehicle for transforming scientific results into day-to-day management recommendations.

Neither the Delta Waterfowl and Wetlands Research Station nor Ducks Unlimited Canada had the in-house expertise to design or carry out an ecosystem study. Consequently, several academic wetland ecologists were recruited to direct various aspects of the research (vegetation, litter decomposition, water chemistry and hydrology). Scientists from the Delta Waterfowl and Wetlands Research Station and Ducks Unlimited Canada and three academic ecologists formed the initial scientific team that designed the study.

All scientific and technical decisions are made by the scientific team (Figure 2). They determine what data are collected and how it is handled. Publishing the results in their areas of expertise is also their responsibility. The scientific team, however, does not play a role in project budgeting, and has been only peripherally involved in fund raising and data collection. The role of an academic member of the scientific team lies somewhere between consultant and principal investigator. The team usually meets twice a year: once after the end of the field season to review how it went, and again before the next field season to finalize sampling plans and make decisions regarding new short-term projects, core data analysis, and future MERP publications.

All short-term studies have to be approved by the scientific team. Sixteen graduate students have done short-term projects. Most of these have been students of members of the scientific team. These studies were established to collect data needed to supplement the information collected by core MERP sampling. Whenever possible, however, they were done outside the MERP complex to reduce damage to it. Several other studies were carried out by scientists from other institutions who were interested in using the complex for their own purposes. These too had to be approved by the scientific team.

RECOMMENDATIONS

Never take on long-term ecological research without a detailed assessment of what it will take (manpower, facilities, funds, etc.) to complete the project successfully. To facilitate this, we provide the following 10 recommendations.

(1) The mesocosms should be as large as is feasible. When we began this project there was little to go on when it came to deciding at what scale we should do our study. Many kins of sampling would have been easier to handle with smaller mesocosms, e.g. algal and invertebrate. In retrospect, our mesocosms are an appropriate size because they encompass the variation found in the natural marsh and are large enough to avoid both edge and sampling effects. Smaller cells would have been too subject to cumulative disturbances Larger cells were not affordable and would have exceeded our ability to sample them adequately because of funding and personnel limitations.

(2) Design your mesocosms carefully and build them to last by using the best materials available. The failure of a mesocosm in the latter stages of a long-term study could jeopardize years of work. All components of the MERP mesocosms were engineered to last 20 years, i.e. twice the length of the experiment. MERP has never had any problems with any of the mesocosms, except some minor dike erosion during high water years. All dikes and other structures were designed to withstand all onslaughts that could be anticipated, and only routine maintenance has been needed to keep the cells fully functional.

(3) Every effort must be made to insure consistency in how data are collected from year to year. Meticulous record keeping is indispensable. Records must be kept about all aspects of sampling and data handling, including a daily log of all activities. It is particularly important to record any uncertainties about, or problems with, the collection, handling or coding of a particular sample or datum. A full time, on-site coordinator is essential for the smooth running of a project during the field season, particularly to insure that different types of sampling do not interfere with each other. MERP has been fortunate that the same person has coordinated the project from the beginning, and core data collection has largely run smoothly and uneventfully.

(4) To carry out a long-term study requires institutional stability. MERP is a 10 year experiment. In reality, the project will take more than 15 years to complete when the pre-experimental planning phase and post-experimental write-up phase are included. This is equivalent to about one half of the career of most scientists. Because people lose interest, become administrators, move to other institutions, etc., a long-term project must be able to survive changes in key personnel that are inevitable over such a period of time In the case of MERP, three members of the scientific team,

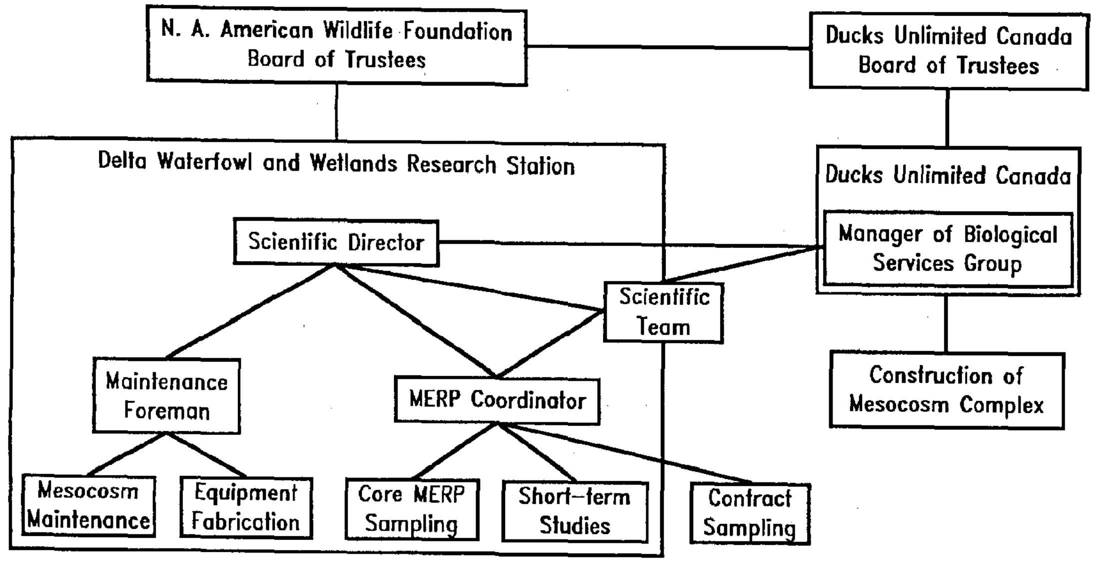

Figure 2. Administrative organization of MERP.

which has had only 6 or 7 members at any time, have changed jobs and left the team. The fact that MERP is largely an in-house Delta project has enabled it to weather this turnover of personnel. Nevertheless, there are fewer members of the scientific team today than earlier,and some aspects of project have suffered because of these personnel changes.

(5) There is a need for institutional flexibility. A large-scale and long-term study like MERP can require significant adjustments for an institution. These may include construction of new laboratory space, offices and other facilities, hiring new staff, and dealing with decisions to redirect funds from alternate uses. For a small organization like Delta, it can change the very character of the institution.

(6) All research scientists whose expertise was needed to develop a project should be involved in all aspects of the study. MERP is unusual in that most members of the scientific team have not been involved in fund raising, have nothing directly to do with project budgeting, and have little to do directly with the collection of their data. Their role, is largely as consultants, leaves them free to become involved in other projects, and they have. This has caused problems, particularly during the first few years when field operations were being worked out, because these scientists were not present at Delta. It has also delayed publication of the data because they were working on short-term projects besides MERP that required their immediate attention. More direct involvement of key scientists in the research and a more formal commitment of their time to the project is desirable than was the case with MERP.

We do not recommend, however, that principal investigators in a long-term project be so tied to the project that they are unable to work on any unrelated activities. Since most of the data collection in a long-term study tends to be standardized, routine sampling, after the first year or two their direct involvement on a day-to-day basis is not needed or even desirable. Being able to work on other activities may keep the principal investigators from leaving a long-term project. It prevents them from becoming frustrated because they do not have to pass up all other professional opportunities. What is essential is that all the principal investigators have sufficient time formally committed to the project so that they can fulfill their obligations to it.

The number of scientists involved in the organization and running of a project should be kept to a minimum, and each scientist's responsibilities should be well defined and overlap as little as possible with those of others. There is also a need, however, to balance the expertise available not only by scientific discipline, but also in other ways. For example, there should one or more scientists who can also contribute as administrators; others as theoreticians, writers or editors; and yet others who can translate scientific results into management plans.

(7) Identify short term studies as early as possible that need to be done to supplement the data being collected by core sampling. This makes it easier to budget for short term studies and provides more lead time to get these studies organized. This is often difficult, if not impossible to do, since the need for some types of data may not be obvious until the study is well underway. Nevertheless, adequate budgeting for

future, short-term studies is crucial for a successful long-term research project (see also recommendation 8). MERP several times had to arrange for short-term studies too quickly, and a few times was unable to find adequately trained personnel on time.

(8) It is going to cost more than expected. MERP's annual operating budget currently is 300% higher than what it was estimated to be initially. Not only does inflation over a ten-year period present a challenge to long term budgeting, but a successful project will unquestionably expand with time. In the case of MERP, it became clear that certain types of data were essential that had not been considered so at the beginning of the project. For example, it became obvious that algal production data were essential after a couple of years. This required hiring three additional technicians to do this work.

If funding is to be provided by more than one organization, as was the case with MERP, carefully consider how to set up a working relationship among funding groups that will remain viable for the length of the project. All organizations funding a project should be involved in developing the overall project budget and its annual operating budgets. Any changes in budgeting should also be made by all the funding organizations collectively. As budgets escalate with the years, conflicts among funding organizations about which is to cover additional costs can develop. A formal arrangement in which each funding organization agrees to cover a certain percentage of the annual operating budget or the cost of some aspect of the project is better than an arrangement in which each organization contributes a fixed sum of money. See also recommendation 10.

(9) It is going to take longer than expected. It will require a great deal of time to design and set up a successful long-term study. For MERP it took more than a year to design the experiment, work out the sampling details, and write the methods manual. It will also require several years of full-time effort to complete the write up. This is longer than foreseen. There are two reasons for this: one, the large volume of data that is collected over a 10 year period and the diverse ways that it can be utilized; and two, the need to interact frequently with other scientists, located at different institutions, who are responsible for various data sets. The final modelling of the nutrient cycles in the case of the MERP project cannot occur until the whole data set has been worked up. This is not likely to be until one year after the last data have been collected. An additional period of one to two years will be required to write the summary monographs. A 10 year experiment will, in reality, last at least 15 years or longer (see recommendation 10).

(10) Finding funding will become more difficult with time. It is much easier to raise money for a new project than to obtain funds for an ongoing one. If at all possible, secure funding for the entire project at the beginning. It seems to be most difficult to obtain funding to support the post-experiment data-analysis and write-up phase of a long-term project. This is ironic because most of the risks associated with long-term research are now over, costs are much lower, and the final product of this phase, usually one or more comprehensive books or monographs, will be its most influential and significant products. Because of the large volume of data and the myriad of ways that it will be used, data analysis and the final write up of the study will require a great deal of time, we estimate a total of 11 man years, 5 for members of the scientific team and 6 for their support staff. This kind of time cannot be easily bootlegged from other projects. Unless release time can be purchased after the completion of the experimental phase of the project, the chances of it ever being fully written up diminish quickly as key scientists get involved in other projects.

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MICROORGANISMS AS A CAUSE OF ECONOMIC LOSS TO THE SEAFOOD INDUSTRY

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ABSTRACT

Direct loss of seafood products is more commonly due to microorganisms or their products than to any other cause. Bacterial spoilage of is probably still the major culprit but contamination by potentially hazardous microorganisms and the presence of toxins derived from microorganisms is a significant problem in shellfish and finfish from warm waters. Freezing raw product reduces traditional bacterial spoilage but new products produced from frozen material such as surimi and seafood analogues may present new and different problems. The focus of seafood scientists' attention has shifted in part to naturally *occurring biochemical change due to endogenous* enzyme systems. Toxins occurring in seafoods which may adversely affect sales as well as posing a direct hazard include scombroid toxin (probably histamine), ciguatera toxins, tetrodotoxin, paralytic shellfish poisoning toxins and a number of others mostly associated with shellfish.

Traditionally, the major negative effects of microorganisms in the seafood industry have resulted from spoilage of raw product. On a world scale it has been estimated that 20-25% of fish harvested from oceans, lakes and rivers are lost due to spoilage by bacteria and by insects. Direct losses to North American fisheries are probably much less than this due to the lower ambient temperatures in much of our fishing areas and the almost universal use of ice or refrigerated and chilled sea water to cool fish after capture. Nevertheless, there are still direct losses due to over long fishing trips, or improper procedures on land and sea. Most losses, however, are undoubtedly due to reduction in value of commodities because of unsatisfactory quality and for the same reason by customer dissatisfaction.

We know a good deal about microbial spoilage of fish in our temperate fisheries and we are learning about quality. Until comparatively recently "quality" has meant simply "not spoiled" and it was assumed that most consumers were unable to distinguish really fresh fish or that they in fact preferred it. Consequently, our major concern was shelf life and much effort was expended by researchers to try to stretch the limits of acceptable storage by using antibacterial ices and dips, antibiotics and other treatments. All of this was done in good faith to extend the distribution range for fish and to improve the average condition of seafoods in our markets. However, while some of the newer methods proved quite effective in preventing or, at least, in delaying spoilage, they had minor effects on intrinsic quality if we define quality as those factors which distinguish a particular foodstuff in the fresh condition from a stored product. We now know that these factors are intrinsic to the fish and that they change mostly in response to endogenous events mainly brought about by the fishes own enzymes after death. Of course, bacteria can affect this but even in their absence the changes will still take place. There has been some interesting recent work with fish from tropical waters which suggests that in some cases endogenous changes may even be the cause of rejection of fish by sensory judges in the absence of significant bacterial activity.[2]

Because consumer attention has recently focused on fish as a desirable food for health and dietary reasons demand for fresh seafoods has increased markedly[12] and the supply system has adapted to this in a number of ways. Air shipment of fresh seafood products on an international scale has increased enormously. This became possible because of technical improvements in chilling methods and packaging and because an upscale market permitted pricing that could absorb shipment costs which themselves showed some decline. Freezing at sea or near the site of capture is a technique widely used to protect the quality of high value fish or fish caught in bulk. The shipboard processes increasingly involve primary processing so that fillets or dressed fish ready for marketing are often the end product. All of this circumvents the bacterial spoilage problem by holding fresh fish as short a time as possible in cold conditions which greatly slow bacterial growth and by freezing which prevents bacterial growth completely. Perhaps of more direct importance rapid processing and handling of products held at low temperatures insures that the endogenous enzyme processes are slowed as much as possible - or halted completely in frozen fish. Thus, the fresh sweet flavor often associated with inosine monophosphate is maintained through the point of sale to the consumer.

Does all this mean that bacterial spoilage is no longer a problem in the industry? Unfortunately, the answer if "no." A large proportion of fish is still caught and landed by smaller fishing vessels with inadequate chilling and handling facilities. Moreover, there are still too may instances of improper practices during distribution of fish which can lead to bacterial growth such as shipment in unrefrigerated vans, holding on loading docks, refrigeration shut downs in trucks hauling fish interstate. Unfortunately, many retailers are still unaware of the special need to hold fish at $0^{o}C$ and may carry product overlong at too warm temperatures. Thus, research is still needed to accommodate the special problems of smaller scale fisherman, transportation and retailing. Such research might logically be focused on antibacterial procedures and bacterial control.

Of course, there are still unresolved problems of bacterial spoilage which merit research. Fish vary greatly in their shelf life when held under comparable conditions and sometimes this can be related directly to bacterial populations as in the example shown in table 1. We really do not understand why this is so.

There are a number of unresolved problems in the case of fish from warm tropical waters. Until recently comparatively little work had been done on the bacteriology of these animals. With the expansion of fisheries in tropical regions resulting from increased world demand, there has been a flurry of work in S.E. Asia and Australia particularly. In addition, the extensive researches of Japanese scientists has been given wider publicity and greater scrutiny. Warm water fish often show greatly extended shelf life when held in ice as compared to temperate water fish. That this is due largely to the rarity of typical psychrophilic spoilage bacteria in their microflora has been confirmed by a number of studies.[7, 14] However, as noted earlier Australian work has indicated that non bacterial antogenous changes due to fish enzymes may also be a determinant factor.[2]

Japanese workers have long emphasized the importance of nucleotides in determining fish quality. They utilize a "K" value which is essentially the ratio of Inosine and hypoxanthine to all other ATP derived nucleotides as the primary index of quality for warm water and temperate region seafoods.[4] This index is largely independent of bacterial activity though bacteria can break down nucleotides[10] and is highly specific for initial (ie. pre-spoilage) quality. Another important factor in initial quality relates to rigor mortis. Japanese buyers place high value on fish in pre-rigor condition. Some fish show more rapid development of rigor mortis at $0^{o}C$ than at higher temperatures and this has led to a suggestion that such fish might be shipped to market at $5\text{-}10^{o}C$ after killing.[6] This phenomenon is related, of course, to the rate of ATP breakdown and lactic acid production and in some cases seems similar to cold shortening in beef except that rigor develops quickly without shortening. The importance of these observations from the microbiologists point of view is that they could lead to practices which would accelerate microbial growth and spoilage. This is particularly important in tropical regions where delays in icing of more than 9-13 hours can shorten shelf life from 15 to 4 or 5 days.[1] Obviously, fish should be cooled at least to $10^{o}C$ as quickly as possible after killing to avoid premature microbial growth.

Rapid cooling to below $15^{o}C$ is also important to prevent growth of undesirable bacteria such as the histidine decarboxylating species on tunas and mahi mahi and enterotoxigenic vibrios. There is no more devastating effect on sales of a food product than publicity concerning its involvement in human disease or a recall associated with such a possibility. Estimates of the economic costs of the canned salmon botulism outbreak which only involved 2 people are in the millions of dollars. Scombroid poisoning is related to the presence of histamine produced by decarboxylation of histidine which is abundantly present in tunas, dolphins, mackerels and blue fish. There seems little doubt that this is due to rapid growth of most mesophilic bacteria on fish which are held at relatively high temperatures. The effect has been duplicated experimentally in tunas, and mackerel and other fish.[5, 17]

Bacteria of the Proteus group seem to be most commonly involved in histamine production giving rise to scombroid poisoning with Morganella morganii most frequently indicted. However, other bacteria can give rise to histamine most notably Photobacterium which has been shown to do so in salt cured herring.[15]

Other bacteria which may cause human disease from consumption of seafoods have been identified earlier by Dr. Colwell and are well reviewed by Bryan.[3] Economic loss arises from each outbreak associated with seafood products and fish.

One aspect of microbial hazard which should not be ignored is that arising from changes in processing methods. We are all aware of the concerns over such novel processes as radiation and vacuum packaging of unprocessed seafoods or controlled atmosphere storage. All of these have been or are being fully studied and effective codes of practice developed. But we should also recognize the potential problem of products made from fish which no longer behave microbiologically like fish. In particular, I refer to the range of products derived from surimi which is rapidly spreading through our markets. These seafood manufactured products do not undergo spoilage in the same way as raw or frozen fish. They are usually given pasteurization treatment and may have very low microbial populations when sent out from the factories. The potential problem lies in the repackaging carried out in supermarkets during which contamination can occur. In the absence of the normal competitive microflora of untreated fish conditions may be good for the growth of undesirable bacteria. Studies reported by Matches et al.[11] and Yoon and Matches[16] clearly indicate the potential for growth of food poisoning organisms on such products if these are exposed to warmer temperatures. Industry must exert every effort to follow good handling practices to avoid such incidents.

Most food borne disease is due to errors in handling, storage and presentation of the food. However, there are some causes of illness which occur due to events early in the handling sequence or to intrinsic problems in the raw material. Scombroid poisoning from tuna is most commonly due to improper handling immediately after capture. However, fish poisoning due to consumption of toxic fish or shellfish is caused by events beyond industry control.[3, 9]

There are three kinds of fish poisoning which are most prominent in addition to scombroid poisoning and these include Ciguatera, Puffer Fish poisoning and Paralytic Shellfish Poisoning. Most of the evidence suggests that these are due to toxins which are accumulated in the animal tissues from feeding on microorganisms that originally produce these toxins. Currently we assume that these original toxin producers are dinoflagellates or cyanobacteria. Recent work mostly by Japanese authors has indicated that certain bacteria may produce one or more of these toxins.[8, 13] The evidence is strongest for tetrodotoxin (puffer fish) which is apparently produced by some rather commonly occurring Vibrio species. The significance of these observations for toxin development in fish and shellfish is not yet clear but they raise intriguing questions which need further research. Work is going on in my own and in other laboratories on methods of detoxifying poisonous shellfish and we have obtained partial success in removing 70-90% of the toxin. Nevertheless, at present the only control measure available to the fish industry is to refrain from marketing toxic fish and shellfish. This raises two problems. It locks up valuable food resources which could be utilized (eg. butter clams in Alaska) and it requires an expensive testing and surveillance program. We urgently need research to develop quicker and cheaper testing methods than we now have available to screen potentially toxic seafoods and keep them off the market. The importance of this becomes apparent if we note that 132 out of 172 outbreaks of food borne disease due to fish reported in USA in the period 1976-1984 were due to fish poisoning.[3]

I have deliberately avoided specific discussion of microbial problems related to molluscs. This is a situation of great difficulty and considerable complexity. Molluscs are largely sessile, they reside in shallow inshore waters and are subject to run off from land.

It is extremely difficult to insure that molluscs harvested from waters adjacent to large urban areas are safe and clean. A major problem is virus contamination and most recent cases of food borne disease from molluscs have been due to Norwalk or Hepatitis viruses. However, there are recurrent problems from human or land animal enteric bacteria and Vibrio species which may be indigenous or introduced. We need to reassess the situation with shellfish in light of our improved understanding of transmission of disease organisms and the growing human populations along the shorelines and modify our control systems accordingly. The economic effect of large scale sickness from molluscs in the shellfish industry could be disastrous.

What then is the message concerning microbiology in the fish industry? First, we are doing much better at controlling bacterial spoilage which was the principal problem. However, there are some aspects of spoilage which we do not understand well enough to control effectively. Newer processing technologies produce safer seafoods which however carry potential problems for the future. We need to research these and develop recommendations on methods to avoid the problems. There are microbiological implications of aquaculture that have not been discussed here but which need research. Food borne disease is probably less of a problem for seafoods than for meat and poultry products but with an increasing consumption of seafoods and widening variety of species and products there will be greater public attention. We must be vigilant both for the recrudescence of old problems and the arisal of new pathogens and new situations. Molluscan shellfish present a continuing microbiological problem which has not been resolved and which deserves additional attention. Finally, in light of the renewed public drive for better food inspection and control we must consider the applicability of new methods of microbial testing to the problems in fisheries. Bacteria and molds are still the number 1 problem of the food industries and fish are no exception to this.

TABLE 1

BACTERIAL COUNTS ON FISH FROM SAME CATCH

Days in Ice	Sole	Hake	Rockfish
	log CFU/cm^2 skin		
0	1.8	1.2	2.1
3	2.3	2.5	1.4
7	5.0	6.3*	5.5
10	6.3	6.3	4.9
14	7.2*	7.3	7.2*

* Indicates spoilage apparent.

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SEA GRANT ADVANCES IN SEAFOOD SCIENCE AND TECHNOLOGY

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ABSTRACT

The failure to express the thermal process rather than a time temperature relationship combined with improper processing and quality control methods, resulted in large product losses and a questioning of the product's safety. Sea Grant personnel developed process methodology, computer based microprocessor control instrumentation, alternative packaging materials, a quality assurance system, and appropriate training materials so that today pasteurized crab meat sales are increasing. Additionally, the pasteurization process has been successfully applied to other shellfish and foods. The development of an integrated (from harvest through consumption) quality fresh fish program has enabled seafood dealers to extend shelf life from 6 - 8 days to 12 - 21 days. This shelf life extension created new higher revenue producing markets.

1. INTRODUCTION

Since its inception, Sea Grant has developed and maintained active research and education programs in seafood science. Programs in Virginia during the last 20 years have been effective in developing new technology and expanding the scientific knowledge within various academic disciplines. As a consequence, consumers have been able to obtain seafood products that are economical, safe, convenient, and nutritious. Examples of successful programs are as follows:

2. PASTEURIZED CRAB MEAT

Meat from the blue crab was first produced as a fresh product in Virginia during the 1860's. In order to prevent product spoilage and stabilize inventories, the meat was marketed as a canned or pasteurized product almost 100 years later. Pasteurized meat was an almost immediate success since: the product retained many of the physical, visual, and sensory qualities of the fresh product; had a relatively long shelf life (over one year); and did not have either the higher cost and reduced consumer appeal produced by a 12 D thermal process. Unfortunately, improper processing, packaging, storage, and transportation resulted in large product losses and the expressed concern over the safety of the product by both the Food and Drug Administration (FDA) and various health regulatory agencies. Eventually, the FDA issued both a Class I and a Class III product recall and several studies were initiated to determine the potential hazard of pasteurized crab meat. As confidence in the product eroded, sales of pasteurized crab meat significantly decreased and the U. S. Defense Personnel Support Center terminated their purchase of the product. The seafood industry became concerned over the situation and in 1971 contacted the state Sea Grant program for assistance.

A comprehensive research and educational program was initiated by the Virginia Sea Grant program to identify the various constraints and issues associated with the production of high quality pasteurized blue crab meat. In order to achieve the goal, the Tri State Seafood Committee (a committee of crab meat processors, Sea Grant personnel, and state health regulatory personnel in Maryland, Virginia, and North Carolina) was reformed. An audit of pasteurization processes and product handling practices was subsequently conducted in several plants. Several major problems were identified as a consequence of the study: 1) the usual process was to process the product to a temperature of 185 F for one minute at the geometric center of the container, irrespective of container size; 2) thermal processing equipment had no temperature regulating, indicating, or recording devices; 3) storage and shipping environments were not properly controlled; and 4) no firms had developed reliable quality control or assurance programs. Microbiological examinations of pasteurized meat revealed that many cans contained obligate anaerob populations exceeding one million per gram.

It was obvious that many changes in equipment and procedures would be required if pasteurized crab meat was to be reestablished as a commercially viable product. The Tri State Seafood Committee established a Good Manufacturing Practice (GMP) for pasteurized crab meat which contained recommendations for equipment and facilities, microbiological quality standards, and handling conditions. The 185 F internal temperature processing was retained as the Committee's interim recommendation. The GMP was submitted to the FDA for consideration, however, no action was taken.

One of the greatest problems facing the production of high quality pasteurized crab meat was the development of a satisfactory thermal process. Under processing results in product spoilage while over processing causes discoloration. If the 185 F internal temperature is used, large cans (16 oz) would receive a greater amount of thermal energy while small containers (12 and 8 oz) would receive considerably less. Several processes were monitored for their lethality with the process being being expressed in terms of f values ($z = 16$, f 185). F values obtained ranged from 22 to 196 with an average of 96 which indicated that some processors were were either under or over processing their product. Unfortunately, it was not possible to recommend a lethal process due to the relative large variation. Laboratory and field research eventually indicated that an f value greater than 35 would provide an adequate process. This research placed the pasteurization process in acceptable scientific terms and permitted processors to use temperatures other than 185 F and helped establish adequate processes for containers of varying sizes and shapes. A computerized data base was established that would enable processors to calculate their thermal processes and compare their process to others. Sea Grant personnel evaluated each firm's thermal process on both the East and Gulf coasts to insure their adequacy. Eventually, foreign countries (as far as Turkey) requested visits by Sea Grant personnel to evaluate pasteurization processes.

A comprehensive crab meat pasteurization manual was developed in cooperation with the National Fisheries Institute, Inc. The publication presented, for the first time, the theory and applications of pasteurization practices on meat shelf life and quality. Eventually the manual was provided to industry on a 5.25 or 3.5 inch computer disk that enabled processors to calculate their process lethalities using normal office equipment rather than having to access a main frame data base.

By this time, pasteurized crab meat was again becoming accepted in the market place since quality could be guaranteed and the longer shelf life reduced losses in retail food stores and food service establishments. Additional developments rapidly occurred. Sea Grant produced 6 forms that would permit a firm to evaluate their process and maintain an accepted quality assurance program. Two color coded forms were developed to assist processors in establishing a can seam evaluation and record keeping program. Additionally, two video tapes were produced in cooperation with the Blue Crab Industries Association on crab meat pasteurization equipment and procedures and can seam evaluations. The tapes have been translated into several languages and are used as training materials in the processing of other Callinectes crab species. To insure that the educational materials were understood by both the industry and regulatory agencies, a series of training courses were held. At the suggestion of the blue crab industry, some states required attendance at the programs before a license to process crab meat would be issued.

Recently, a cooperative venture was initiated with Keltech, Inc. to develop a microprocessor controller that can be used in two modes. One is a time-temperature sequence and the other is the real time calculation of process lethalities. The process controller monitors both the cooking and cooling process variables, terminates the process on pre-set time-temperature of process lethality schedules, and maintains records for quality assurance programs. The equipment is now being used in both the United States and the People's Republic of China.

Several major advances were made when a process was developed for the pasteurization in flexible films and plastic containers. The flexible film is capable of holding up to 6 lbs of product and costs less than 10 cents whereas 6 metal containers would cost over 4 dollars. The plastic container (1 lb) has a cost of 15 cents. These new packaging materials have provided substantial savings to the industry and their use is rapidly spreading and should account for more than 80 percent of container sales within the next 5 years.

The pasteurization concept has been expanded to include further processed foods, institutional food products, and other shellfish species. Virginia Sea Grant has provided sufficient technology to pasteurize seafood stuffings, mixes, sauces, soups, stews, and chowders. A patent has been received for the process and new marketing opportunities developed as a consequence. Prior to the introduction of the bulk pack, pasteurized meat could only be purchased in metal containers. The relative cost of the container and the cost of opening a one pound container made purchase of the meat unattractive. Consequently, many crab based products were not produced during the winter when crab catches are at their lowest level. The ability to process the product and store it in an appropriate container provided alternative marketing opportunities. Recently, pasteurization has been successfully applies to crawfish tailmeat, shrimp, and oysters.

Today, pasteurization is emerging as the preferred market form and accounts for approximately 30 percent of the market share. Within a few years, pasteurization has been transformed from a questionable to a respected product.

3. FRESH FISH MARKETING

In 1983, a cooperative research project was initiated with Virginia Sea Grant, the Kroger Co., and the Mid-Atlantic Fisheries Development Foundation, Inc. to develop and implement a high quality fresh fish marketing program. Initial studies revealed that mid-West markets were willing to pay higher prices for quality fresh fish products than East coast residents and that most fish firms on the East coast were only capable of producing products that had a shelf life between 6 to 8 days. An integrated program was initiated that included fishermen, processors, distributors, and retailers.

Several species of fish were boxed, short shelved, and bulked stored. Boxed fish generally produced higher quality products than the other methods since the fish had a greater cooling rate and were not physically damaged. Day of catch did effect the quality and shelf life of boxed fish. Bluefish and mackerel had the shortest shelf life. Blue fish caught on the last day had an average shelf life of 10 - 11 days, third day caught fish lasted 7 - 8 days, and first day fish lasted only 4.5 - 5.5 days. Bleeding and gutting by either a one or two stage process did not significantly extend shelf life. The effect of delayed processing produced interesting results. Fishermen and processors believe that the quicker you process fish the longer the shelf life. Bluefish which were processed immediately had the lowest sensory scores after 9 days of storage and the shortest shelf life. Bluefish that were stored on ice for a period of 4 and 7 days before processing lasted approximately 11.0 to 13.0 days. A longer shelf life can therefore be obtained, at least for bluefish, by holding fish on ice in cold storage and processing prior to marketing.

The shelf life of Atlantic mackerel was shown to be dependent upon a specific market form. Based on taste sensory scores, with a score of 5 or less as the cutoff, the following shelf lives were obtained: dressed - 12 days; skinless fillet - 10.5 days; steak - 8.5 days; and skin-on fillet - 8 days.

The temperature at which tray packed fish fillets were stored significantly affected quality and shelf life. Foe example, boxed bluefish were processed under sanitary conditions into skinless fillets, tray packed, and stored at the following temperatures: 29 F; 29 F for 2.5 days with subsequent storage at 33 F; and 33 F. Storage at 29 F resulted in an increase in the shelf life of approximately 3 days over the 29 - 33 F combinations stored bluefish and 5 days over the 33 F.

Since the primary mechanism of fresh fish spoilage appeared to be microbiologically related, a high pressure washer (up to 1,000 psi) was developed and tested. The washer was different from other washing devices on the market in that it contained three separate sections. A high pressure pre-wash, high pressure wash (with or without additives), and a low pressure post-wash containing sanitizing solutions. Fish which were high pressure wash prior to processing, demonstrated a reduction in microbial counts over the unwashed fish. Evaluations of the raw fish for odor and cooked fish for taste, demonstrated that the high pressure washed fish were superior throughout the storage study. the high pressure washer was also tested on processed fish. Traditional methods of washing fish have been shown to actually increase the number of spoilage bacteria. Fresh fish which were boxed at sea were processed at two typical East coast fresh fish processing plants. One plant washed the dressed fish by passing them through an ice water wash tank while the other utilized the high pressure wash. Microbial counts of dressed mackerel, sea bass, and porgy which were passed through the conventional wash tank were more than two logs (100 fold) higher than the high pressure washed fish. The high pressure washed fish also had a substantially lower coliform counts (240 vs <3 per g). The shelf life of the high pressure washed fish can be extended by as much as 5 days.

When the various treatments were combined, boxing at sea, sanitary processing with high pressure washes, and superchilling, the shelf life was extended from the customary 6 - 8 days to 12 - 15 days. This shelf life extension made possible a market expansion from the East coast to the mid-West. When modified atmospheres were used, the shelf life was extended from 17 21 days depending on the species. While this extra shelf life time was potentially useful, the added expense and potential hazard form consumer and distributor abuse was not worth the benefit. Additionally, the food retailers did not want longer than absolutely necessary shelf lives since profitability is increased when greater product turnover occurs. Long shelf lives encourages retail department managers to inventory product rather than purchase on realistic projected needs.

The culmination of the project was a two phase marketing effort conducted incooperation with the Kroger Co. The marketing effort was divided into two phases. Phase I was held from April 14 to May 24 in six stores in the Dayton, Ohio area. These stores, which were classified according to their consumer income level profile, included one low income store, four middle income stores, and one high income store. During phase II, November 17 - December 20, the project was expanded to include 17 stores (three low income, seven medium income, and seven high income) in the Cincinnati-Dayton, Ohio area. Training programs were held, before each phase, for the seafood managers of the participating stores.

This project was unique, in respect to being vertically integrated. Several of the activities tested, during parts I and II, were implemented in part III to ensure quality. Aboard the vessels the fish were handled quickly to ensure rapid and adequate icing. Storage methods such as boxing and short-shelving prevented damage from crushing or bruising. In the processing plants sanitation personnel were trained on the proper use of sanitizing equipment and chemicals. All employees were trained to use proper hygiene and sanitary practices, including washing hands prior to entering a work area, use of hairnets and clean attire, elimination of eating and smoking in the work area, use of bactericidal hand and utensil dips, and use of gloves that can be sanitized. A rotation system whereby product totes and cutting boards were scrubbed and sanitized routinely was implemented. All fish processed for this marketing effort were high-pressure washed to reduce spoilage microorganisms and to ensure at least 12 days of quality shelf-life. Temperature control was also closely monitored to ensure rapid and adequate cooling throughout processing. Tray-packing equipment enabled product to be held at 29 F rather than 33 F thereby extending fresh shelf-life. Packaging, shipping and distribution of the product was executed to ensure rapid delivery without temperature or handling abuse. Upon arrival at Kroger, the fish were checked for proper temperature and quality before the shipment was accepted.

Retail Marketing Phase I - The mid-Atlantic species marketing during phase I were Atlantic Mackerel (skin-on fillets), Whiting (dressed), Porgy (dressed), Bluefish (skin-off fillets), Black Sea Bass (dressed), Atlantic Croaker (dressed), and Gray Seatrout (skin-on fillets). These species were chosen based on availability and quality.

Among the service seafood stores, the low and high income stores reported the best sales. Low income store "A" had sales of 90% or greater for Croaker, Sea Bass, Bluefish, Whiting, and Mackerel. High income store "O" reported sales of 100% for Seatrout, Croaker, Sea Bass, Bluefish, and Whiting. In comparison, the medium income service stores (stores E, G, and I) were not as successful. These stores reported sales of 38-59% for Mackerel, 33-70% for Whiting, 45-49% for Porgy, 25-50% for Bluefish, 20-87% for Sea Bass, 0-100% for Croaker, and 25-50% for Seatrout. Overall, high income store "O" reported the highest sales with 93.6% of the product sold. Low income store "A" had sales of 91.1%, while the medium income service stores (stores E, G, and I) had the lower sales of 54.7%, 39.4%, and 50.9%, respectively.

On a percentage basis, the amount sold was very similar for all the mid-Atlantic species which were marketed. The sales ranged from a high of 75.6% sold for Sea Bass to a low of 62.4% sold for Porgy. Bulk packed fish outsold the tray-packed fish by 15%.

Retail Marketing Phase II - The mid-Atlantic species marketed during phase II were Black Sea Bass (dressed), Atlantic Croaker (dressed), and Gray Seatrout (skin-on fillet). These species were chosen based on availability and quality. The success in selling these fish was highly variable. Sales of sea bass ranged from 0 - 100% of the product sold with an average of 46.1%. Sales of croaker ranged from 0 - 98% with an average of 36.6% and seatrout sold from 0 - 95% with an average of 56.9%. If the sales data from three of the middle income stores, which displayed very little active participation (stores D, E, and H), were omitted these averages would increase: sea bass 54.1% sold, croaker 43.0% sold, and seatrout 65.5% sold.

Sales of these fish, broken down into store income profile levels, indicated that the low income stores had the greatest sales for all three species. Dressed sea bass sold at an average rate of 73% for the low income stores, 50% for the medium income stores, and 31% for the high income stores. Average sales of dressed croaker were 56%, 38%, and 27% for the low, medium, and high income stores, respectively. Even the higher priced seatrout fillets ($3.59 - 4.99 / lb.) sold best in the low income level stores. They had an average sale rate of 77%. The high income stores were next with 62% sold, followed by the medium income stores with 43% sold. Overall, seatrout fillets sold best during phase II. Out of 1190 pounds marketed, approximately 715 pounds or 60.0% were sold. The dressed fish, sea bass and croaker, did not sell as well. They sold at rates of 45.9% and 36.6%, respectively.

During phase II, 48.2% of the fish were sold. If we again omit data from stores "D", "E", and "H", the average increases to 56.2% sold. The percentage of fish sold per store ranged from 6.8% to 96.4%.

On a percentage basis, the sales of mid-Atlantic fish during phase I were higher than during phase II. In phase I an average of 68.5% of the product was sold versus 48.2% for phase II. One factor which may have influenced sales, was the greater variety of fish marketed during phase I. In phase I, seven different species were available. Only three species were available during phase II. Another probable contributing factor was the higher retail price of the fish during phase II. Sea bass, croaker, and seatrout sold for approximately $1.00/lb. higher during phase II.

It should also be noted that the phase II marketing effort occurred during the off season for finfish sales (November - December). One could surmise therefore, that if you can sell almost 50% of your product during the holiday season, even with the limited availability and higher pricing, that the sales potential at other times of the year would be much greater.

In-Store Demonstrations - Evaluation of the in-store demonstrations indicated that they were beneficial to sales of mid-Atlantic fish. The majority of the seafood managers stated, that they believed the in-store demonstrations were beneficial to sales of not only mid-Atlantic fish, but other seafood products as well. The quality of the mid-Atlantic fish that they received was rated from average to excellent; with most of the fish in the above average to excellent range. Many of the managers stated that they preferred the fish which were packed in bulk over the tray-packed product.

Store Management - With respect to future marketing of mid-Atlantic fish, the majority of the seafood managers, from the low income profile stores, stated that they believed they could sell the following species and market forms; filleted Atlantic mackerel, dressed or filleted whiting, filleted bluefish, dressed sea bass, filleted gray seatrout, and filleted flounder. The seafood managers, from the middle income profile stores had the following preferences; filleted whiting, filleted bluefish, dressed or filleted sea bass, filleted gray seatrout, and filleted flounder. The managers from the high income profile stores stated that they could only sell fillets. These included filleted mackerel, bluefish, sea bass, seatrout, and flounder.

Some of the overall comments on the project included: "Would like to do it again!", "Are we going to get any more mid-Atlantic product?~, "Did better with bulk pack...", "Customers liked the variety", "Send more fillets and less dressed fish.", "Bad time for project, too many other things going on.", "Waste of money at this store...too high income level.", "Liked the fish we received, but definitely prefer fillets.", "Tough to sell prior to the holidays", "Program was excellent...very little problem with product overall".

FLAVOR CHEMISTRY AND SEAFOOD QUALITY FACTORS

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ABSTRACT

Recent advances in the understanding of the health-related benefits of omega-3 polyunsaturated fatty acids have enhanced the consumer image of fish and seafoods. While future markets for seafoods appear extremely bright, this great potential will be realized only of products with fresh, mild flavors are provided to consumers. New discoveries about the chemical nature of fish flavors have provided important insights into the processes which yield delicate fresh fish and seafood flavors as well as those which are associated with staling and seafood spoilage. This information is needed to guide the development of safe new preservation technologies, such as modified atmosphere packaging of fresh refrigerated fish. Loss of traditional spoilage odors is encountered in modified atmosphere packaged fish, and potential hazards arise from botulinal food poisoning in temperature-abused products. Thus, alternate means of detecting handling abuse is a requirement for the introduction of this new technology. Measurement of aroma compounds for this and other purposes are discussed in relation to spoilage and fishy flavors.

INTRODUCTION

Consumers have dramatically increased their consumption of fish and seafoods in recent years, and many now project that the demand will continue this upward trend into the future. In addition to benefits from attractive low calorie and low cholesterol images, fish and seafood sales have significantly benefited from the emerging knowledge about the health benefits of the omega-3 long-chain, polyunsaturated fatty acids contained somewhat uniquely in fish lipids (1,2). Currently, fish, especially fatty species, provide the only major source of omega-3 long-chain fatty acids to the food supply.

Freshly-harvested fish and seafoods are characterized by very mild flavors that are particularly lacking in fishiness, especially after cooking. Distinct and objectionable fishiness most disliked by consumers arises as the quality of either fresh refrigerated or frozen fish and seafood deteriorates during handling and storage encountered in usual contemporary distribution systems. Many consumers, particularly those in inland regions, have experienced only seafoods with pronounced fishy flavors, and generally have little attraction to seafoods. Others are aware of the delicate, mild flavors of fresh fish, but prefer not to risk the purchase of fish and seafoods that in all likelihood will have a flavor quality less than their expectations. Therefore, in order to realize the potential for fish and seafood sales, it is essential to strive to provide fish that lack fishiness and have the highly acceptable quality characteristics of freshly caught fish.

In recent years fish oils have also been sold widely as supplemental sources of omega-3 fatty acids to the food supply. However, many consumers refrain from purchasing fish oils because of cautions from the medical community that the consequences of heavy consumption of oils are not understood at the present time. Assuming, however, that moderate consumption of fish oils will not be found harmful through research, it follows that many consumers will not tolerate the pronounced fishy flavors now found in various fish oils. Much interest has also been expressed recently about the incorporation of omega-3 fatty acids and fish oils into usual foods much the same as other animal or plant fats are used. However, in most instances very pronounced fishy flavors result, and major technological hurdles face scientists and technologists as they strive to overcome these difficulties. In any event, without solutions to off-flavor problems foods fortified with fish oils will be rejected by the majority of consumers.

SEAFOOD QUALITY FACTORS

Consumers generally use several quality factors in decisions about fish and seafood purchases (3). However, the species of fish often serves as a basis for an initial concept of the quality, and this is supported by several other considerations, including form, composition, nutritional value, texture and flavor. When little-known species of fish are involved, consumers have little basis for a perception of quality without some persuasion by the marketer. Color, texture, and flavor properties in these fish become the most important factors for quality perceptions.

Many consumers object to the tough or dry textures that are often encountered in frozen fish. Prevention of tough textures in some species of fish dur-frozen storage is difficult, but rapid freezing and storage below -20°C after dipping in polyphosphates generally lessens the severity of the problem (4).

Application of polyphosphate dips reduces the drip formed when fish is thawed and held, and this is attributed to an increased water-binding capacity of proteins. The use of polyphosphates can lead to slight phosphate flavors and requires labeling as a food additive.

Freshness of flavor, however, very frequently is the quality factor that determines acceptance of fish and seafoods. This is especially the case currently where there is a great demand for freshness in all forms of foods. Perceptions of freshness by consumers includes several quality factors. However, the odor quality of either fresh or pre-prepared seafoods plays a pivotal role in the perception of freshness. Odors or aromas are produced by volatile organic compounds when they reach the olfactory epithelium in the nasal cavity, and thereby provide a major portion of the integrated flavor sensation that is perceived when a food is consumed. Aromas associated with seafoods and fish include not only those that are present in freshly-harvested products, but also those that are associated with fish quality deterioration.

There are several very general means by which fresh aromas and flavors of seafoods deteriorate. The traditional aerobic spoilage of fish by microorganisms proceeds through a series of aroma stages that have been described as stale, sweet, ammoniacal, and finally putrid (5). Some quality deterioration can be attributed to autolytic enzyme action in fish, but these effects are often subtle to the average consumer. Autolytic processes yield free amino acids and are responsible also for the early degradations of the 5'-ribonucleotides. The loss of 5'-ribonucleotides lessens fish freshness because they are flavor enhancers which provide some of the delicious or umami taste sensation that is highly prized in fish, crabs, and other seafoods. The disappearance of 5'-ribonucleotides often parallels the loss of fish freshness (6,7), and their measurement is sometimes used as an indirect index of fresh fish quality. Another major mechanism for deterioration of flavor quality in fish stems from the oxidation of polyunsaturated fatty acids in fish lipids which yields oxidized fishy flavors or rancidity. Often in the past it has been impossible to discern which of the mechanisms were most responsible for flavor quality deterioration in a specific circumstance.

CHEMISTRY OF FISHY FLAVORS

Trimethylamine is believed by many to be the compound that is responsible for fishy flavors because it is found in fish, and it exhibits fishhouse-like aromas when present in ppm concentrations. However, it occurs only in significant concentrations in marine species of fish, and it is not present in these fish when they are freshly harvested (8). Its precursor is trimethylamine oxide which is odorless, and this substance functions in osmoregulation of marine fish. Many spoilage bacteria associated with fish are capable of reducing trimethylamine oxide to trimethylamine, and hence its development in refrigerated marine fish has long been used as a chemical index of fish freshness (8). However, trimethylamine measurements frequently do not parallel sensory assessments of fish flavor quality because other fishy flavor compounds also contribute to these flavors.

Dimethylamine is frequently found in marine fish also, and especially in frozen marine fish that have not been held at suitably low temperatures. This alkyl amine also exhibits an ammoniacal, fishy aroma that is somewhat similar to trimethylamine. Instead of having its origin through microbial degradation of trimethylamine oxide, dimethylamine is formed via endogenous enzyme action in fish muscle (8). The enzyme action releases both dimethylamine and formaldehyde from the oxide, and the formaldehyde molecule is believed to cause some of the toughening observed in frozen fish muscle through cross-linking of proteins.

Research that began a few years ago in our laboratory on the chemical definition of seafood and fish flavors addressed the compounds that contributed fresh flavors rather than those that appear when fish is sufficiently deteriorated so as not to be considered in the very fresh stage. This research led to the discovery that specific carbonyls and alcohols that were enzymically generated by lipoxygenase activity accounted for the fresh, marine-green aromas which characterize very fresh fish (9). Lipoxygenases position hydroperoxides at specific sites on polyunsaturated fatty acids, and these hydroperoxides then serve as direct precursors for the alcohols and carbonyls.

Various species of freshwater and marine fish produce differing quantities of 6-carbon, 8-carbon, and 9-carbon carbonyls and alcohols from the polyunsaturated fatty acid precursors, and this difference accounts for the different aromas observed in the various species of fish and shellfish (10,11). Cleavage of hydroperoxides that are produced by the lipoxygenases at specific sites yields specific aroma compounds, and this appears to be carried out by lyase-type enzymes. This research has also shown that the profile of carbonyls and alcohols can change with the stage of life cycle of fish. For example, salmon from saltwater exhibit different profiles of volatile aroma compounds that similar fish taken later during spawning runs in freshwater. This shift appears to reflect a change in the cell level regulatory mechanisms for osmoregulation and slime productions which appear to be mediated by hydroxy-fatty acids or leukotrienes that are also derived directly derived from the hydroperoxides formed by the lipoxygenases.

In refrigerated fresh fish, the very delicate marine-green aromas are often lost during the first day or two of holding. This has been found to be largely the result of microbial conversion of the cucumber-like compound, _t,c_-2,6-nonadienal, to a lesser potent aroma compound, _t,c_-2,6-nonadienal. Thus, the loss in fresh aroma can be traced to a simple alteration of compounds in the fish (12). Continued aerobic storage results in the microbial production of various esters whic- provide sweet aromas, and finally sulfur compounds are produced which along with phenols and certain fatty acids give rise to spoiled or putrid aromas (12).

Until recently it was presumed that the lipids in fish and seafoods rapidly became oxidized because the autoxidation process was initiated by light and then was promoted by the presence of metals, and particularly iron from heme. However, the discovery of enzymic generation of flavor compounds via lipoxygenase activity (9) combined with observations that non-site-directed enzymic lipid oxidations (13) occur in fish muscle places emphasis on means for potential control of the development of oxidized flavors in seafoods in a different light than formerly. In effect these enzyme activities provide a seeding of hydroperoxides into fish muscle very soon after death. Thus, the processes that are responsible for the desirable aromas of fresh seafoods and fish must be controlled somehow because they are also responsible for initiating the random oxidation reactions that soon lead to the expression of fishy oxidized flavors.

Fish lipid oxidation produces, perhaps, some of the most objectionable fishy flavors known, and these are particularly pronounced in fish oils, such as cod liver oil. However, these flavors are equally influential in causing fishy flavors in aerobically held fresh fish and frozen fish. Among the products of lipid oxidation, two isomers of 2,4,7-decatrienal provide the most potent undesirable fishy flavors. These compounds are derived from the autoxidation of long-chain omega-3 fatty acids, and because of their low thresholds they become dominant in the aromas and flavors caused by lipid oxidation products (14). Recently, we have continued research on these compounds, and have found that some hope lies in devising means to alter the course of autoxidation in fish oils so that the 2,4,7-decatrienals are not favored as products of oxidation. In the presence of high levels of tocopherol-type antioxidants, greater amounts of 1,5-octadien-3-ol are formed at the expense of the decatrienals, and the alcohol has less flavor impact and is not fishy in character. Thus, the use of natural antioxidants and other mediator compounds may have potential for reducing the flavor impact of lipid-derived fishiness. However, considering the flavor potency of these compounds from lipid oxidation, it appears that a difficult task lies ahead in solving this highly significant problem of the seafoods industry.

PRESERVING SEAFOOD FRESHNESS THROUGH TECHNOLOGY

Based on the discussion of the chemistry of fishy flavors and other deteriorated flavors in seafoods, it might appear that the task of controlling flavor quality might be a relatively simple matter of preventing microbial growth and eliminating oxygen from contact with the product. Indeed, much of the traditional processing of seafoods, such as drying, salting, or pickling, addresses directly the prevention of microbial growth. Certainly, the frozen fish industry also provides control of microbial growth, but freezing does not control oxidation. Further, frozen forms of seafoods are not highly desired by consumers, and sales have not increased similarly to fresh fish.

Ideal frozen fish technology, including rapid freezing, storage below $-30^{\circ}C$, and vacuum packaging in barrier film, can preserve much of the quality of fresh fish. Some argue currently that this is the means by which seafoods should be marketed, but the costs combined with quality deterioration that occurs from inevitable mishandling continue to make the option less attractive than improved fresh fish systems.

Modified atmosphere packaging with carbon dioxide or vacuum packaging of fresh fish also has been explored significantly as a means for preserving the fresh quality of refrigerated fish (15,16). This technology also provides means for exclusion of oxygen from contact with fish provided that a barrier package is employed, and it retards the growth of traditional aerobic spoilage bacteria. Under ideal conditions, it has been shown that the usual shelflife of 4-8 days for refrigerated fresh fish can be extended to 14-18 days. Such an extension does not imply, however, that fresh-from-the-water quality is retained throughout the period, but instead implies that the products remain acceptable for that time. The freshly-caught quality characteristics can be extended significantly, however, under modified atmosphere packaging compared to usual aerobic holding.

Desires for implementation of modified atmosphere packaging systems for fresh fish distribution have been expressed by the seafoods and retail supermarket industries for some time now. However, a major technological hurdle has arisen in the path of development of these systems for fresh fish, and this very simply is a potential hazard from botulism poisoning from mishandled fish. *Clostridium botulinum* type E especially is widely distributed in freshwater and marine environments, and it is capable of growth at moderate refrigeration temperatures (16,17,18). The reduced oxygen environments in modified atmosphere and vacuum packages slightly favor the outgrowth of the botulism organism compared to aerobic environments. But more importantly, the presence of carbon dioxide and the absence of oxygen inhibits the growth of usual spoilage microorganisms that cause the putrid odors which prevent the consumption of potentially hazardous seafood products that have been temperature-abused. Thus, the spoilage signal has been lost with the new technology. Similar lengthy holding of traditional aerobically packaged fresh fish also will yield botulism toxin if spores or cells of *C. botulinum* are present, but consumption would be prevented because of the offensive aroma.

Thus, the implementation of modified atmosphere packaging for fresh fish has been held back because it is likely that somewhere a consumer will abuse fish by not keeping suitably refrigerated. Abusive handling of modified atmosphere packaged fish that can lead to toxin formation, however, must involve exposure to elevated temperatures for several hours.

Besides aroma signals that fish may not be suitable for consumption, visual signals such as drip, tissue disintegration, and bleaching, may also provide information that the product is spoiled. However, visual ques are generally considered not strong enough to deter consumption of marginally safe fish products. Further, after washing in cold water the fish may again appear quite acceptable for consumption.

The most promising solution to providing consumers with a fail-safe signal appears to be the use of time-temperature indicators which provide a very strong visual que that the product must not be consumed if it has been abused. The appearance of a red color in an enzyme solution-based time-temperature indicator tab after abusive temperature exposure is one commercial approach to this need. Another commercial system employs the travel of a low-melting colored wax along a wick which is positioned along a quality scale, and the wax travels towards a danger zone as the product is exposed to abusive temperatures. These products have great promise for use in making the modified atmosphere packaging technology safe for fresh seafoods.

However, the high cost and some lack of adequate flexibility to cover all circumstances of abuse have precluded their adoption by the fresh fish industry. More research is needed to improve the functionality of these devices, and to lower the cost to levels that make them affordable.

At this time interest in modified atmosphere packaging systems for fresh seafoods appears centered on master-package systems which can be controlled adequately in the distribution system so that essentially no threat of undetected temperature abuse exists. These systems utilize large containers to hold consumer-size packages under modified atmosphere conditions. The consumer-size packages contained in the master packages then can be removed from the systems just before sale, and they will spoil in the usual manner. Thus, the shelf-life extension is provided in the distribution channels, and potential hazards are not encountered by allowing consumers to temperature-abuse the product while it is under carbon dioxide.

QUALITY-RELATED RESEARCH NEEDS

Consumer demands for high quality fresh fish and fishery products in general are projected to continue in the future, and ever increasing demands for better preservation of fresh flavor quality will also result. Assuming that the health benefits of moderate consumption of omega-3 long-chain polyunsaturated fatty acids continue to be supported by on-going research, additional demands will be encountered for fish oils. Currently, only fish and seafoods are viewed as viable sources of the omega-3 fatty acids in the diet. However, research activities towards the incorporation of omega-3 fatty acids into foods other than seafoods has already begun. Fish oils are currently the only source of omega-3 fatty acids for these uses, but alternate production from genetic engineered aquatic plant-based sources are likely to compete with the fishery industry for this market. Therefore, research on the means for preservation of high quality fresh fish and seafoods remains high to assure maintenence of seafoods as highly sought-after foods. Particularly needed are continued research programs on developing means to control development of fishy flavors in seafoods as well as research on the development of safe fresh fish packaging and distribution systems that are compatible with contemporary retailing of fish. Additionally, research is needed on methods that can be used to determine fish freshness quality when they have been held in new preservation systems that obscure the traditional quality indices.

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TECHNICAL PROBLEMS AND OPPORTUNITIES RELATED TO UTILIZATION OF OUR SEAFOOD RESOURCES

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ABSTRACT

The primary macronutrients obtained from seafoods are proteins and lipids. Their chemical and physical instabilities, however, are a major drawback to full utilization of our marine resources. Fish proteins have a unique ability to form protein gels, even in the absence of NaCl. These proteins, however, denature readily during storage and processing, thus changing the physical properties of the fish tissue or products derived therefrom. Current nutritional interest in fish lipids relates to their high concentrations of n-3 fatty acids. Oxidation of these fatty acids produces off-flavors and odors and unacceptable products. A lack of understanding of the basic processes involved in these deleterious changes has prevented utilizing many of our marine resources. Muscle tissue recovery processes involving tissue disruption exacerbate these problems. Due to their living in an unusual environment, marine poikilotherms have enyzmes with unique and unusual properties. Commercial exploitation of these enzymes awaits further research and development.

INTRODUCTION

The living resources of the oceans have produced food for mankind for thousands of years and the lore and challenge of the sea have prompted many a brave soul to choose fishing as a career. Fishing is still a process of hunting and in many respects the search for the wild animals in the ocean today is comparable to the relationship of humans with land animals and birds some 10,000 years ago. This has significance because variations in populations are greater than with species which have been carefully bred for hundreds if not thousands of years. Part of the challenge of fishing as a livelihood stems from the fact that often the roughest of waters provide the highest yields of the sea due in part to the upwelling of the water in those areas which distribute nutrients from the bottom of the ocean.

Fishing is unique in another respect in that while the primary species of land animals and birds consumed by humans were also prey in the wild to carnivorous species, most of the fish that is consumed by humans are themselves carnivores, thus greatly limiting sustainable yields from the sea (Lorentzen, 1981). Perhaps an even more important difference between the catching of food fish and obtaining food from domestic animals and birds is that we are dealing with a common resource in the case of the fisheries. It is a case of "first come, first serve" and makes management particularly difficult. During the 1960's fish catches increased, and it was thought by many that the living resources of the ocean were inexhaustible. However, yields from the sea have long since leveled out and research scientists now recognize the limitations on the resource. This imposes the necessity of our wise use of the resources that are available on a sustainable level.

There are many unique problems associated with the use of fish and shellfish from the marine environment. There are a wide variety of species with very different characteristics, including odd shapes, sizes, or unattractive names. Even with species which are considered desirable, approximately 50% of the edible flesh is not recovered in normal processing, and there has been slow development in the commercialization of byproducts of the fish processing industry. In this short paper, I will concentrate on three areas which illustrate both the problems and opportunities that challenge us in utilizing finfish. The areas are proteins, lipids and enzymes. The unique characteristics of these materials from fish compared to other food sources stem from the fact that most of the commercial species are poikilothermic organisms taken from a low temperature, aquatic environment.

PROTEINS

As is the case with the proteins of most animal tissues, fish muscle protein is of high nutritional quality. Indeed, it is the primary nutrient provided by this type of product. The major problem associated with fish muscle proteins is to keep the product containing the proteins in a form that people wish to consume.

The texture of fresh fish is, in general, acceptable to the average consumer. The low content of collagen and its relatively low tensile strength produce a generally tender product. The nature of fish muscle collagen is a consequence of the fact that the fish lives in a medium (water) which supplies much support to the animal. The ease of degradation of fish muscle collagen on cooking is a reflection of the fact that fish live at low temperatures and have proteins which are unstable at high temperatures.

It is the low temperature environment from which the fish is derived, however, that does bring about one of the major problems related to fish texture. The contractile proteins which primarily determine the texture of fish flesh and the functional properties of the muscle proteins are more unstable during handling and storage, e.g. frozen storage, than the same proteins from land animals and birds. It appears that this is due to the greater flexibility required for these proteins to function at the low temperature at which the fish lives. To obtain this flexibility, stability at high temperatures must be sacrificed (Low and Somero, 1974; Tsuchimoto et al., 1988). This great sensitivity to denaturation when the proteins are stressed is the reason that adequate storage temperature for fish flesh is considered to be -30°C rather than the -20°C recommended for the muscle tissue of warm-blooded animals.

The situation with many marine fish is complicated by the fact that they have an enzymic system that degrades the osmolyte trimethylamine-N-oxide (TMAO) to dimethylamine and formaldehyde. The products of this reaction increase the rate of denaturation of the fish muscle proteins greatly. Although it had been suggested that formaldehyde functions by crosslinking the proteins, other evidence indicates that the primary function of formaldehyde may be to increase the rate of denaturation by side chain modification (Ang and Hultin, 1988). The susceptibility of fish muscle proteins to denaturation following side chain modification has broad implications. Many components of the cytosolic fraction of the muscle cell could react directly or produce compounds that would react with the proteins. Also, there is the possibility that free radicals produced in the aqueous phase can modify proteins leading both to their denaturation and hydrolysis (Davies, 1986). Fish muscle proteins would be particularly susceptible to these changes due to their natural instability.

Preventing these changes while recovering functional fish muscle proteins from minced fish prepared from underutilized species or fish racks poses a major challenge for future research. Some physical properties of fish muscle proteins are unique. One of these is their ability to form highly elastic gels. This property is the basis of the process of surimi manufacture which has become an important economic venture recently in the United States. It appears that the physical properties of fish proteins may be even more unique than originally thought. We have recently shown that very good gels can be produced from some species of fish without the addition of NaCl (Hennigar et al., 1988), usually believed to be necessary to solublize the contractile proteins prior to their formation of gels. This offers a great potential for a whole new range of products catering to the desire, or even need, for people to restrict their intact of sodium. From a food product point-of-view, it could allow the use of these proteins in products which are not compatible with NaCl for reasons of flavor. In related work, we have evidence that components of species which can form good gels in the absence of NaCl can be used to confer this ability on fish species which ordinarily require NaCl. Further work is required in this area, but it may eventually lead to the ability to get desirable physical properties from the proteins of a wide variety of fish species which currently have limitations in their use.

LIPIDS

Fish lipids are currently the center of much research attention because of epidemiological studies which have shown a correlation between the consumption of n-3 fatty acids and a lessening of various human physiological disorders, especially atherosclerosis and immune functions (Kinsella, 1986). Oxidation products of the n-3 fatty acids appear to modify the effects of the products of the arachidonic acid (an n-6 fatty acid) cascade. The principal n-3 fatty acids found in seafood are eicosapentaenoic (C20:5) (EPA) and docosahexaenoic (C22:6) (DHA) acids. Fatty acids are unstable because of their 1:4 conjugated diene systems. DHA has five of these systems while EPA has four. Thus, they are extremely suscepible to oxidation. Hydrogen is extracted from the conjugated system forming a free radical which reacts readily with molecular oxygen. This peroxy free radical can extract hydrogen from another fatty acid propagating the chain reaction while forming a lipid hydroperoxide. The latter are unstable and will break down producing off-odors and flavors.

Due to the high degree of unsaturation of the fish n-3 fatty acids, they have not made convenient model systems. Thus, insufficient information is available about the rates of deterioration and mechanisms of oxidation occurring in fish lipids in bulk. The situation in fish muscle tissue is even worse because of the location and structural arrangement of lipids in biological tissue, the large number of prooxidants and antioxidants in the tissue, and the great complexity of all of these interacting factors. To utilize oxygen, biological tissues have a large number of systems for activating molecular oxygen to participate in necessary reactions in the cell. That uncontrolled oxidation can sometimes be a problem is indicated by the extensive antioxidant systems present in the same tissue. It is perhaps not unreasonable to consider lipid oxidation as a process waiting to happen with a small change in the balance of very strong prooxidative and antioxidative forces. Some of the problems related to this have been recently discussed (Hultin, 1988).

Oxidation of fish lipids is important from two points of view. Due to their nutritional significance, loss of substantial quantities of n-3 fatty acids would have a detrimental effect on the nutritional quality of seafoods. We have found, however, that in a number of normal processing operations as may be practiced both commercially and in the home, chemical loss due to oxidation of the n-3 fatty acids is not a significant nutritional problem (Xing et al., 1988). However, wherever heat is used, as in cooking or canning, there is a rendering of lipid and a concomitant loss of the n-3 fatty acids. This physical loss of n-3 fatty acids was substantial, and in a number of different thermal processes ranged from 30-50 per cent of the total. The loss is dependent on temperature, size and shape of the portion, and fat content, among other variables. Improved methods of heating may reduce this loss.

Although it may not cause a significant nutritional loss, oxidation of the n-3 fatty acids is important from the standpoint of development of off-flavor. The off-flavor components are detectable by the human nose at very low levels. Thus, off-flavor changes can occur even when there is only a very small loss in these unsaturated fatty acids. Progress has been made in understanding the nature of lipid oxidation as it occurs in fish muscle tissue. Transition metals, especially iron, in the presence of molecular oxygen are primary causes for the changes observed. These transition metals may be complexed to small molecular weight components of the muscle tissue, such as amino acids and nucleotides, or may be associated with proteins, either those containing hemes such as myoglobin and hemoglobin or as yet unidentified nonheme proteins. The presence of compounds which can reduce or oxidize the iron are also critical factors. Some success has been achieved in developing antioxidant systems to suppress some of these changes, but the number of prooxidants is large and at times competing factors are operative. For example, ascorbate activates ionic iron but is an inhibitor of the iron associated with heme proteins. Ascorbate levels in muscle decrease with postmortem age. This may play a role in changing the active prooxidant from ionic to heme iron. Many cellular membranes contain prooxidants or are capable of reducing molecular oxygen to superoxide or hydrogen peroxide. Superoxide or hydrogen peroxide can interact with iron to produce the hydroxy free radical which is capable of initiating lipid oxidation. Mincing, grinding or other mechanical disruption of the muscle tissue greatly accelerates oxidative reactions by providing more molecular oxygen as well as distributing the prooxidant systems more widely in the tissue. Antioxidant systems of the cell may also lose their potency during postmortem aging of the muscle tissue. A major challenge of the future is to control these changes to allow the most poorly utilized of our ocean species, fatty fish, such as Atlantic mackerel, herring, and especially the menhaden, to be used directly as human foods.

Another challenge facing the food scientist is to duplicate what has been done in the soy bean industry, namely, the extraction of lipid from fish, especially those with a high content, and incorporation of the extracted lipids into a variety of nonfishery products. It will be absolutely essential to control lipid oxidation and its accompanying off-flavors for this to be successful. Unfortunately, it appears that extracted lipids are less stable to oxidation than the same lipids when present in fish tissue.

ENZYMES

Fish are poikilothermic organisms. Most commercial species are from waters of low temperature. Due to their low temperature environment, fish have enyzmes which function well at low temperatures. This makes storage problems of fish muscle tissue different from those of warm-blooded land mammals and birds. Refrigeration of the latter would be expected to slow enzymic reactions normally occurring, whereas typical refrigeration temperatures are very similar to the normal body temperature of a fish. It should not be surprising that fish undergo autolytic degradation at a much faster rate than does the muscle tissue of warm-blooded animals at low (refrigerated) temperatures. These properties of fish enzymes have often not been given proper consideration in the storage and handling of fish muscle tissue.

Indeed, there is a lack of good, fundamental information on the response of enzymes from fish to temperature. This is of greatest consequence with those enzymes which have important effects in controlling postmortem properties of the muscle tissue, i.e., those that control the breakdown of nucleotides to produce hypoxanthine, cellular proteases, glycolytic enzymes which control pH changes and rigor, lipolytic enzymes, etc. We have demonstrated that enzyme-catalyzed lipid oxidation in membrane fractions of muscle tissue is much more rapid in fish than in birds and mammals. In fact, the lipid peroxidation system of the sarcoplasmic reticulum of fish catalyzes a rapid reaction at temperatures as low as -20°C (Apgar and Hultin, 1982). Obviously, more information is required in this area to prolong top quality in fish products.

On the other hand, enzymes from marine organisms offer unique properties which potentially have use in commercial operations. Enzymes that have been adapted to function at low temperature may differ from similar enyzmes from warm-blooded animals in a variety of their properties including the Michaelis constant, molecular activity, activation energy, stability to low and high temperatures, and specificity (Hultin, 1980). It is possible that enzymes could be recovered from what is now a low value material which could have interesting advantages in commercial processes. For example, the enzymes may be better equipped to carry out a reaction at low temperatures. This could be important in having a process that restricts microbial growth and prevents chemical side reactions from occurring. Enzymes with lower Michaelis constants at low temperatures could function more efficiently in processes where substrate concentration was limited due to solubility problems or cost of the substrate. Lower thermal stability of these enzymes could be important in eliminating them after their function has been carried out, that is, they could be destroyed at a lower temperature causing fewer side reactions than comparable enzymes from warm-blooded animals.

A current theory suggests that enzymes from low temperature environments have greater flexibility in their structure which allows them to function in an environment of low thermal energy (Low and Somero, 1974). It is this greater flexibility which also makes them more susceptible to denaturation. This greater flexibility may be reflected in broader substrate specificities of the enzymes. We have studied in detail specificity against a variety of proteins of a chymotrypsin prepared from the dogfish (Squalus acanthias) and compared the results with those obtained with the bovine enzyme (Ramakrishna et al., 1987). The fish enzyme was able to hydrolyze a greater number of bonds in a number of protein substrates, usually at a considerably faster rate. It was observed that dogfish chymotrypsin could even hydrolyze about 10 per cent of the peptide bonds of corn gluten, a substrate almost completely resistant to the action of the bovine enzyme. In testing for possible use in cheese making, it was observed that the clot formed more slowly in milk treated with the fish enzyme but had a much longer life than the similar one formed by the bovine enzyme. Even though the fish enzyme hydrolyzed more bonds in the casein molecule, the specific sites of hydrolysis must have been different and allowed the clot to remain formed for a long period of time. Although these data are interesting, they only scratch the surface of the potential for a wide variety of enzymes that exist in marine organisms and may have unique properties.

SUMMARY

The major nutrients of fish are its proteins and lipids. The primary challenge of food science is to maintain the quality of the product so that the consumer wishes to consume these high quality nutrients. This is true whether the fish is consumed directly, restructured as in a fish gel, or the components are used as ingredients for non-fish based products. The unique properties of fish muscle as food are due to the nature of the animal and its habitat. These are the reasons for the instability of protein to denaturation, the highly unsaturated nature of the lipids with the concomitant susceptibility to chemical oxidation, the low content of collagen, high concentrations of some osmolytes in the cytosolic fraction, and the high activity of fish enzymes at low temperatures. Too often, the assumption is made that fish muscle tissue is very similar postmortem to that of land animals and birds. Although in terms of fundamental physiological functions, there is a lot of truth in this, the behavior of the tissue as a food during storage and processing is, in fact, quite different. In the future, it is going to be necessary for researchers to learn more about the nature and chemistry of fish muscle tissue, understand the changes they undergo during storage and processing, build a broader and more detailed data base, and develop better means of preventing quality changes. In the past, efforts have not been made with fishery products comparable to what has occurred with red meats and poultry. To fully utilize this excellent nutritional source, greater efforts must be made.

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MICRO-COMPUTER BASED DESIGN OF RECIRCULATING SYSTEMS FOR THE PRODUCTION OF SOFT-SHELL BLUE CRABS (CALLINECTES SAPIDUS)

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ABSTRACT

Use of recirculating shedding systems in the soft-shell blue crab industry continues to increase as the capabilities of existing in-shore production facilities expand. This industry significantly contributes to the value of the near-shore fishery. Recent advancements in water treatment capabilities have been based on fluidized bed and upflow sand filters to support growth of desirable waste-consuming bacteria and to remove solids. The filters' superior treatment capabilities permit a reduction in system construction costs while reducing mortalities resulting from water quality degradation. System designs, however, are complicated by the specific hydraulic requirements of the filter beds. A micro-computer program has been written for the Louisiana Sea Grant College Program to assist crab fishermen with sizing filters, reducing flow requirements, and selecting pumps. The distribution of the software is expected to accelerate the adoption of this new filter technology and strengthen the blue crab shedding industry.

INTRODUCTION

The blue crab (Callinectes sapidus), like all crustaceans, derives its body shape from a shell (exoskeleton) which completely encases and protects the vital organs and muscle tissues. Periodically, immature crabs undergo ecdysis (or molting) by which the old shell is replaced. During this growth process, the crab expands the new inner shell while dissolving and cracking the old shell until it can work itself free. For a few hours after ecdysis, the new exoskeleton is soft. Crabs captured in this condition are commonly known as "soft-shell" crabs. Commercial production of this seafood delicacy depends on capturing crabs that approach ecdysis, keeping these animals healthy until they molt, and harvesting them before their shell hardens.

The holding and shedding of crabs has traditionally been accomplished by pumping water, in which the animals naturally live, into a holding facility and discharging the wastewater back into the body of water from which it was taken. This method of shedding, known as a flow-through system, succeeds only when the water source is consistently of acceptable quality and temperature to facilitate the high loading density in the crab holding trays. The most common examples include saltwater facilities located in, or near, brackish bays and estuaries. Unfortunately, not every crab shedding facility can be located near a suitable water source. As an alternative, recirculating systems are often employed. These systems typically reuse the same water throughout the season replacing only evaporation losses. Water quality is maintained by using filtration components which break down the nitrogenous crab wastes, thus maintaining a suitable environment for the organisms. Without mechanical and biological filtration, the water in a recirculating system would soon become toxic to the crabs, resulting in high mortalities. Therefore, the quality of the environment supporting these organisms is most important when considering the economic viability of a crab shedding system.

BACKGROUND

Overview

A Sea Grant research project at Louisiana State University, initiated in 1982, found that the major threat to crabs in a recirculating system was toxicity due to nitrite (6). This knowledge permitted rational design of low-rate biological filters (submerged rock filters) for nitrification of the system water. Following further research and development, interim design criteria were released for commercial producers of soft-shell crabs (5).

Because these filters' have limited support capacity in relation to their size, and have a tendency to clog, research efforts were directed toward developing and testing high-rate biological filters, principally the fluidized bed and the upflow sand filters (2). These filters were much smaller and more efficient than the submerged rock filters, and, therefore, effort concentrated on developing design criteria for these new filters (3,4).

High rate filter design is complex. Commercial operators found the hydraulic requirements difficult to master, leading to many poorly designed filters in early facilities. Consequently, a computer program, OPTIMUM, developed to assist research, was modified for industrial application. This software is to be distributed through the Sea Grant Marine Advisory Service network to promote the new filter technology and accelerate its implementation in the blue crab shedding industry.

Recirculating Systems

Recirculating systems typically reuse the same water throughout the shedding season. These systems reduce the costs associated with water acquisition and heating while providing complete control over water quality. Components of a typical recirculating system (Figure 1) include holding trays, screens, a reservoir, a sump, pumps, and filters. A brief discussion of each component is presented below.

Screens are used to remove large solids that may damage the pump or otherwise degrade water quality. The reservoir provides a large volume of water which buffers the system while the sump serves as a collection point for the recirculating water. An additional pump is recommended to expand (or clean) the upflow sand filter, as well as providing backup in case of pump failure. Water quality control is provided by employing a filter system which treats crab wastes.

Ammonia is the most critical type of metabolic wastes produced by the crabs. With the aid of biological filtration, ammonia can be removed. Two specific types of bacteria, Nitrosomonas and Nitrobacter, are cultivated in the biological filter. The former converts ammonia to another toxic compound known as nitrite while the latter converts nitrite to relatively non-toxic nitrate (1,7). This series of events is known as nitrification.

Two types of filters modeled by OPTIMUM include the fluidized bed and upflow sand filters (Figure 2). A fluidized bed is an attached-growth microbial filter in which bacteria grow in a film on the surface of sand grains. The filter medium consists of 8/16 (1.2-2.4 mm) filter sand, which provides a large specific surface area for the bacterial growth. The bacteria consume the crab wastes and convert ammonia to nitrate.

The fluidized bed filter operates in a continuous upward stream of water. The drag caused by the water's upward velocity expands the filter bed, keeping the sand particles in suspension. Because of the continuous fluidization of the filter bed, the filter will not capture solid wastes, and thus must be accompanied by a solids removal system. Collisions of the sand particles abrade bacterial growth, which is flushed out by the upflowing water. Consequently, the filter never clogs.

In the second filter, the upflow sand filter, the media remains packed during normal operation. The packed sand traps solids as the water flows upward through the filter. The filter is cleaned daily by increasing the flowrate through the filter, expanding the sand bed, and diverting the cloudy, solids rich effluent to a drain line. Once the solids are removed, the filter resumes normal operation.

Although the sand in this filter is not fluidized except during the cleaning cycle, it provides sufficient surface area for nitrifying bacteria growth. Thus, the upflow sand filter can serve the dual function of solids removal and crab

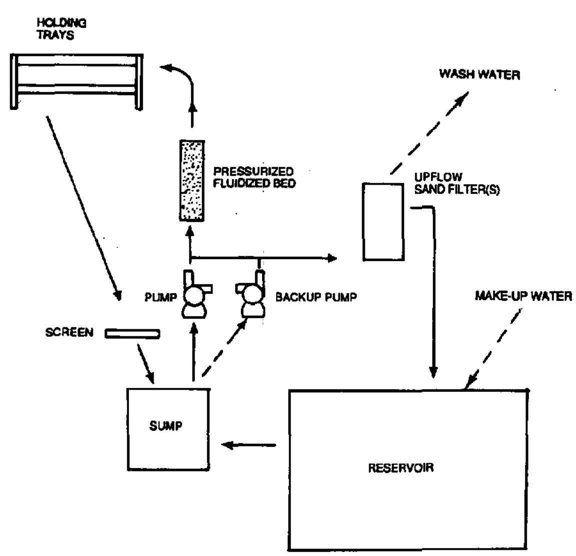

Figure 1. System 2: Parallel operation of upflow sand and pressurized fluidized bed filters.

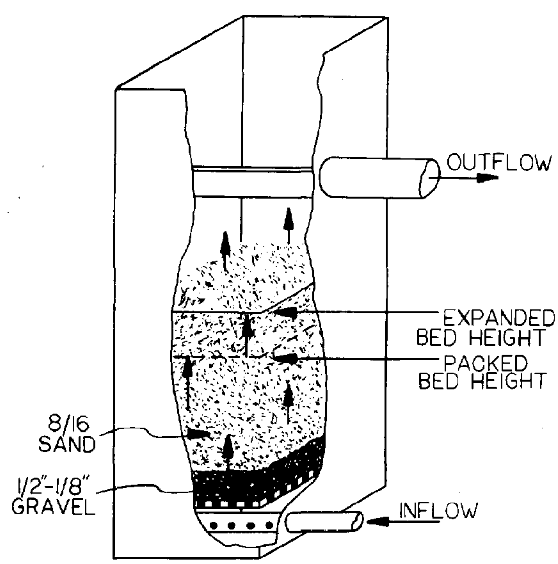

Figure 2. Simplified view of an unpressurized fixed film nitrification filter bed.

wastes reduction. Therefore, the upflow sand filter can be used alone or in combination with the fluidized bed.

Interim design criteria for fluidized bed and upflow sand filters were recently released by Malone and Burden (3) for commercial soft-shell blue crab producers. A summary of these criteria, used in developing OPTIMUM, is presented in Table 1. Summarizing, the surface area requirement for trays with a five-inch water depth is 0.16 ft^2/crab while the volumetric requirement of the system is one gallon per crab. The sand volume in the filters, 0.00067 ft^3/crab, is based on a 15-inch media depth. Flowrates are dictated by the cross-sectional area of each filter. Normal operation of the fluidized bed and expansion of the upflow sand filter requires a flowrate of 65 gpm/ft^2, based on using 8/16 filter sand. Normal operational flowrate for the upflow sand filter (no expansion) equals 10 gpm/ft^2. Tray flowrates are based on a flushing requirement of 0.015 gallons per minute per crab.

COMPUTER MODEL

The program OPTIMUM was developed by the authors as a research tool to aid in designing fluidized bed and upflow sand filters and was modified to assist in technology transfer to the industry. The program is currently equipped to handle unfed crab and fed crawfish recirculating shedding systems.

Three system configurations (filter combinations) are supported by the computer model (Figures 1, 3, and 4). System sizing is based on the desired amount of animals (in pounds) to be held in the system. Filters are designed to be compatible with the pumps for a given system configuration while meeting secondary objectives such as energy conservation and/or ease of operation. A brief discussion of each system configuration followed by a description of the program is presented below. Table 2 presents the advantages and disadvantages of each configuration.

<u>System 1: Upflow Sand Filters with a Combined Sump/Reservoir (Figure 3).</u> The unpressurized upflow sand filter serves the dual purpose of solids removal and nitrification while providing filter media access for inspection and maintenance.

Only one pump is necessary, but a backup/expansion pump is recommended. The circulation pump supplies water to the trays and the filter at normal flow, while the backup pump is used to boost the flowrate to the upflow sand filter for cleaning. This two pump system economically reduces power requirements by reducing the size of the pump which must be operated continuously.

<u>System 2: Parallel Operation of Upflow Sand and Pressurized Fluidized Bed Filters (Figure 1).</u> This system configuration optimizes pump use, thus reducing continuous pumping costs. The system includes a pressurized fluidized bed filter for high-rate waste reduction coupled with an upflow sand filter for solids removal. This configuration takes advantage of the low head loss through the fluidized bed by placing the filter in series with the water line supplying the holding trays. The upflow sand filter can be pressurized or unpressurized and is operated in parallel with the fluidized bed. Only one pump is required for this system, but a second pump for expansion and backup is recommended.

<u>System 3: Parallel Operation of Fluidized Bed and Upflow Sand Filters (Figure 4).</u> System 3 consists of three parallel flow loops. One loop flushes water to the holding trays, another to the fluidized bed, and the last to the upflow sand filters.

Filters used with this configuration include the unpressurized fluidized bed and upflow sand filters. The open top on these filters allows access to the filter media for routine maintenance and inspection. The fluidized bed filter returns the treated water to the sump for tray distribution, while only the upflow sand filters return water to the reservoir--thus keeping the reservoir free of solids. A two-pump system is also recommended for this configuration to reduce continuous pumping costs.

The program OPTIMUM begins by prompting the user for the species and number of pounds to be supported by the facility and the filter shape desired (square or round). The program then graphically displays each system configuration supported and prompts the user to select the one to be analyzed. Once a system configuration is selected, OPTIMUM calculates the filter dimensions, the number of filters required, and the required pump flowrates. A generalized flow diagram for program OPTIMUM is shown in Figure 5 and a sample output is presented in Table 3.

Experimental prototype filters were designed using an early version of OPTIMUM. Following the success of these filters, 15-20 commercial facilities in southern Louisiana and Mississippi were designed with the aid of OPTIMUM and have operated successfully since 1986. Custom design of shedding systems is facilitated by this program because OPTIMUM allows the user to make as many changes as desired while instantaneously producing design recommendations. OPTIMUM was written in Turbo Pascal version 4.0 and will be available for IBM compatible micro-computers using DOS version 3.0 and later through the Sea Grant Marine Advisory Service network. Copies of program OPTIMUM will be obtainable from local marine extension service agents.

ACKNOWLEDGMENTS

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Table 1

Summary of Interim Design Criteria for Blue Crab Shedding Systems Employing Sand Filtration

Parameter	Value	Comment
Tray Area	0.16 ft^2/crab	Normal loading density for trays
Water Depth	5 inches	Recommended water depth in trays
Sand Size	1.2-2.4 mm	Diameter of 8/16 filter sand
Bed Depth	15 inches	Assumed bed depth in sand filters
Sand Volume	0.00067 ft^3/crab	At least 50% of sand volume must be in upflow sand filter
Total Volume	1 gallon/crab	Total of operational volume of all components
Flowrates	0.015 gpm/crab	Minimum flowrate to trays
	65 gpm/ft^2	Normal operational flowrate for fluidized bed
	10 gpm/ft^2	Normal operational flowrate to upflow sand filter
	65 gpm/ft^2	Expansion flowrate for upflow sand filter

Table 2

Advantages and Disadvantages of Each Recirculating System

System	Advantages	Disadvantages
System 1: Upflow Sand Filters with a Combined Sump/Reservoir	High solids processing capabilities Uses small recirculating pump Filters are accessible	Limited carrying capacity Large expansion pump required
System 2: Parallel Operation of Upflow Sand and Pressurized Fluidized Bed Filters	Low continuous pumping requirements High animal loading capacity	High construction cost for pressurized fluidized bed
System 3: Parallel Operation of Fluidized Bed and Upflow Sand Filters	Filters are accessible for cleaning and inspection High animal loading capacity	Moderate energy cost associated with large recirculating flows

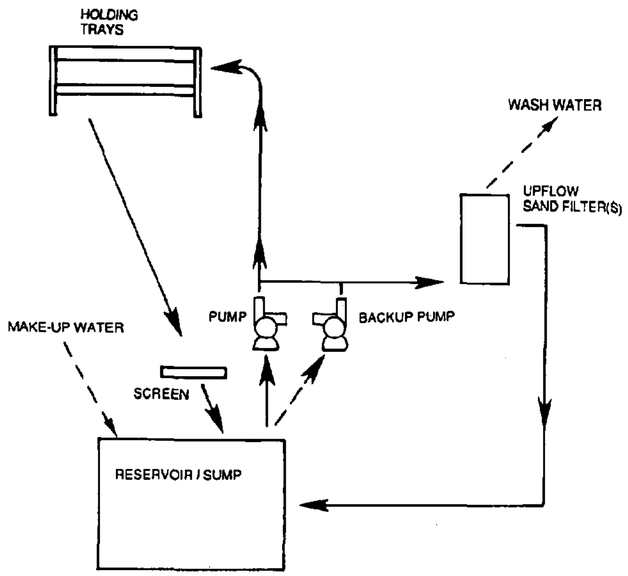

Figure 3. System 1: Upflow sand filters with a combined sump/reservoir.

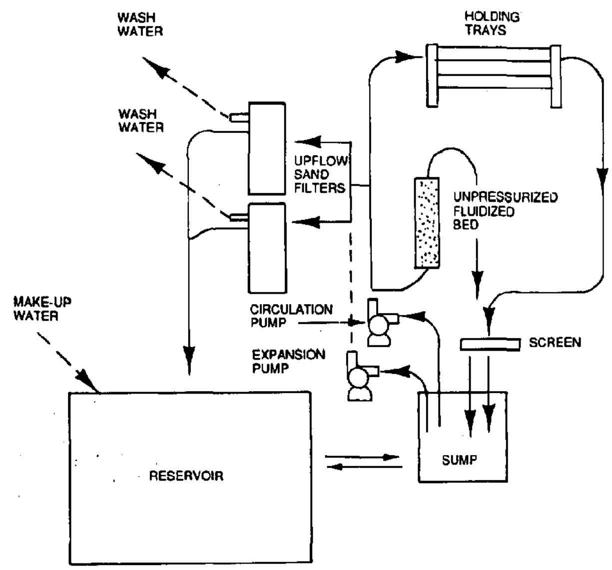

Figure 4. System 3: Parallel operation of a fluidized bed and upflow sand filters.

Table 3

Sample Output from OPTIMUM

Type of System:	Unfed Blue Crab Shedding System
Actual Total Capacity:	1069 pounds
Filter Media Grain Size:	8/16 sieve analysis
Depth of Media:	15 inches
System Configuration:	Parallel Pressurized Fluidized Bed and Upflow Sand Filter
FILTER SPECIFICATIONS:	
Number & Type of Filters:	1-Pressurized Fluidized Bed Filter
Shape of Filters:	Cylindrical Filter
Diameter:	14 inches
Number & Type of Filters:	2-Unpressurized Upflow Sand Filters
Shape of Filters:	Cylindrical Filter
Diameter:	14 inches
Required Output from Pump:	80.00 gallons per minute

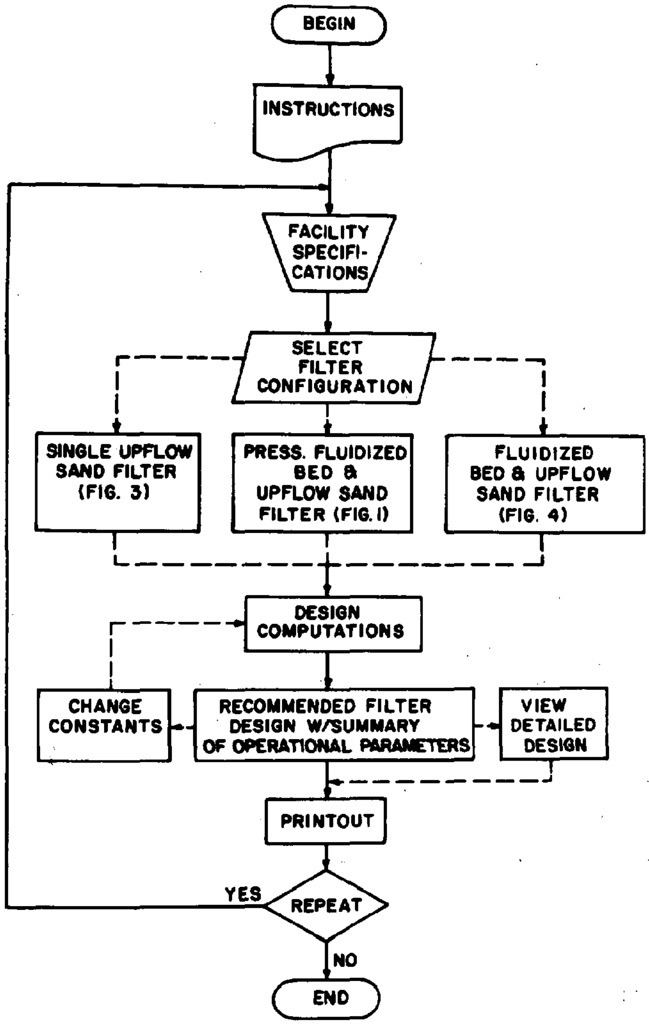

Figure 5. Generalized flow diagram for program OPTIMUM.

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COMPUTERIZED RAPID MEASUREMENT OF AMMONIA CONCENTRATION IN AQUACULTURE SYSTEMS

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ABSTRACT[1]

The response of an ammonia gas sensing electrode was measured automatically via a simple FET (field effect transistor) operational amplifier (op-amp) circuit, a data acquisition and controls system (Cyborg ISAAC 2000[2]), and an IBM-PC. It is possible to measure the chemical concentrations of various solutions faster and more conveniently using the system described than by using conventional methods that involve a pH/digital voltmeter. This system permits development of automated ammonia concentration control, a particularly valuable attribute in recirculating aquaculture systems.

1. INTRODUCTION

Automated Water Quality Measurement and Control

The ability to reliably, and automatically measure and control water quality parameters such as temperature, pH, and dissolved oxygen, nitrite, nitrate and ammonia (NH_3) concentrations are attractive prospects to operators of recirculating aquaculture systems. In industry, automation would reduce labor requirements and allow more efficient system management. This system could eventually lead to higher productivity at lower costs. In research, automation allows certain studies to be performed faster with better repeatibility, and allows experiments to be conducted that would otherwise be impossible with manual methods.

There are two main approaches to automated water quality control. One approach is to design individual control systems for each unit operation, which requires many separate microprocessors. The The other is to control all of the unit operations from one central processor (e.g. a personal computer). The latter approach is taken in the research system described in this paper. Many different ion or gas sensing electrodes, temperature sensors, flowmeters, etc. can be connected to the same computer through a single data acquisition device (i.e. an analog to digital (A/D) converter) so that the data is easily stored and ready for processing. This approach avoids the need for excessive data handling and the use of many different meters, manually switched multiplexers, recorders, etc.

The personal computer (PC) possesses useful features that provide a good basis for a central control processor. Two of these features are the graphics and audio functions that provide the user with valuable tools for analyzing information. For instance, a graph of multiple interrelated inputs (raw and/or processed) can be displayed concurrently in real time. This is far more informative than separate displays from digital millivolt (mV) meters. Also, graphics and audio functions can signal the execution of certain procedures, or alert an operator to unfavorable conditions. The decision making feature of the PC forms the basis of a feedback and control system. The PC can compare sensor inputs to predetermined selected levels and signal for an appropriate compensating action, such as opening a valve to add a chemical.

Unfortunately, computer measurement and control of water quality is not as straightforward as it may first appear. Many problems in automation involve sensors. Interfacing sensors with the computer, sensing element limitations, and other problems must be considered before reliable computer based monitoring and control of water quality will become a reality. Such problems are illustrated in this paper using the automated measurement of ammonia as an example.

Automated Ammonia Measurement Using an Ammonia Gas Sensing Electrode

Ammonia gas sensing electrodes are convenient to use but have several limitations. They exhibit high internal resistance, tend to drift quite rapidly over time, are slow to stabilize in low ammonia concentration solutions and have a limited

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[2]Use of trade names is for clarity only and does not imply endorsement by the University of Maryland.

life.

High Internal Resistance. Like thermocouples, gas and ion sensing electrodes produce low level electrical signals of only a few mV. However, unlike thermocouples which have a fairly low internal resistance, the gas and ion sensing electrodes have very high internal resistances. For this reason, these electrodes require special measurement devices that have a very high input impedance (see Appendix section Impedance Mismatch Problem). Few, if any A/D converters (needed to interface external analog inputs to a computer) have a high enough input impedance for direct connection of the electrodes. Therefore, an interface is needed. Currently, pH/ISE (ion selective electrode) meters are used for measuring signals from these electrodes. However, these meters are expensive and are designed so that only one electrode can be connected to the meter at a time. There are manually operated electrode switchboxes that simultaneously connect up to 7 electrodes with a pH/ISE meter; however, they are of no use in a computer automated system. An inexpensive, high input impedance FET op-amp circuit is presented as an alternative interface between the electrode and the A/D converter. This circuit can also be used in other applications to interface ion and gas sensing electrodes directly to recorders.

Drift. Because of drift, the ammonia electrode must be calibrated hourly to obtain the most reproducible electrode measurements (+/-2 percent)(Orion, 1986). An automated calibration procedure is presented that allows hourly calibration of the ammonia sensing electrode.

Stabilization Time. The faster a measurement can be made, the faster a control response can be implemented which can provide a more stable control. Likewise, fast measurements permit many variables or systems to be monitored by the same computer, thus reducing cost. Before a reading can be taken, the ammonia sensing electrodes must be allowed to stabilize after first being immersed in a new ammonia solution. The lower the ammonia concentration, the longer the electrode takes to stabilize (5 to 10 minutes for concentrations below 4 X 10^{-6} M ammonia (Orion, 1986)). An unsuccessful attempt to predict the stable ammonia electrode response in a shorter time is presented.

2. EQUIPMENT AND PROCEDURES

Experimental Configuration

Figure 1 illustrates the overall experimental configuration. An Orion (Cambridge, MA) ammonia gas sensing electrode (Model 95-12) was mounted in a sample chamber of clear, acrylic plastic pipe with a volume of about 500 ml. The electrode was connected to a high input impedance amplifier circuit via a shielded coaxial cable. The amplifier was then connected to a Cyborg (Newton, MA) I-140 analog input card through a Cyborg I-160 card, a 16 channel multiplexer. The I-140 amplified the mV signal to +/-5 volts, which was then transmitted to a Cyborg ISAAC 2000 I-130 card where the A/D conversion took place. Calibration of the system provided the following relationship for digital numbers between 0 and 4095:

Digital number = 2022.43 + 15.335 (mV)

A digital number of 0 corresponds to approximately -132 mV and 4095 corresponds to approximately 135 mV. Thus, each integer increment respresents 0.065 mV; or, approximately 15 digital values represent 1 mV. The digital value sent by the I-130 card was read into an IBM-PC by a BASICA program statement.

Liquid flow in the system is controlled by solenoid valves and electrically actuated ball valves. Each valve shown in Figure 1 is connected to a separate channel of the relay unit. The relay unit contains 16 solid state relays corresponding to 16 channels. These can be switched on or off from the IBM-PC through an I-120 binary output card which is mounted in the ISAAC and connected to the 16 relays through a cable. Any relay or combination of relays can be turned on by sending a command to the I-120 card through a BASICA program statement. When a relay is switched on, 120 VAC is delivered to a set of three sockets, thus powering the valve(s) plugged into the socket(s). When a relay is switched off, the 120 VAC is no longer delivered to the sockets. Each solid state relay has a maximum current rating of 3 A which is sufficient for the valves in this system.

Calibration Procedure

The following four NH_4Cl standard solutions were prepared by mixing measured amounts of NH_4Cl with distilled water to produce 25 L of each solution:

Standard 1 - 5.88 X 10^{-5} mol/L (1.0 mg NH_3/L)
Standard 2 - 4.12 X 10^{-4} mol/L (7.0 mg NH_3/L)
Standard 3 - 4.70 X 10^{-4} mol/L (8.0 mg NH_3/L)
Standard 4 - 5.88 X 10^{-4} mol/L (10.0 mg NH_3/L)

These were placed in the four tanks as shown in Figure 1. A 10 M NaOH solution was placed in another tank beside the standards. A computer program was written to perform the following procedures automatically:

1. The tap water solenoid valve was opened and the sample chamber flushed for about 1 minute with water. After flushing, the valve was closed and the chamber allowed to drain.

2. The sample chamber was flushed with 500 ml of standard 1 by opening the standard 1 solenoid valve, B.

3. The ball valve below the sample chamber was closed.

4. The NaOH solenoid valve, A, was opened to allow at least 5 ml to flow by

gravity to the sample chamber, then it was closed.

5. The standard 1 solenoid valve, B, was opened and approximately 500 mL flowed by gravity to the sample chamber where it mixed with the NaOH. The purpose of adding the NaOH was to raise the pH of the sample to above 11, thereby converting the NH_4^+ ions in the standard to NH_3 gas which is measured by the electrode.

6. The electrode response as a function of time was recorded for up to 6.6 minutes. Trial tests indicated that with a new electrode, this provided sufficient stabilization time to produce readings with less than 4 percent error for concentrations between 1.0 and 8.0 mg NH_3/L.

7. The ball valve below the sample chamber was opened and the sample discharged.

8. Steps 1-7 were repeated for each of the remaining NH_4Cl standards.

Analytical Procedures

Calibration Equations. When the electrode was initially immersed in a sample solution, a waiting time was required before stable readings were possible (see Figure 2). The lower the solution concentration, the longer the stabilization time interval. Normally, when pH/ISE meters are used, the stable electrode reading (read as mV) is recorded at three different standard concentrations. Since mV verses log ammonia concentration is linear in the range of about 0.1 to 1000 mg NH_3/L (Orion, 1986), a calibration curve of mV verses log ammonia concentration may be calculated using linear regression. Similarly, using the computer, linear regression was used to calculate a calibration curve of digital number (linearly proportional to the mV output of the electrode) versus the log of the ammonia concentration using the stable readings for three ammonia standards: 1.0, 7.0, and 10.0 mg NH_3/L. A reading taken at 6.6 minutes was considered stable.

Error Estimate. The fourth standard solution (8.0 mg NH_3/L), bracketed in concentration by the other three standards, was treated as an 'unknown' in order to estimate the error of the calibration relationship. This was done by comparing the actual concentration of the 'unknown' to the concentration predicted by the calibration equation at 6.6 minutes.

In order to observe the errors expected if readings were taken before the stabilization time, two additional calibration equations were calculated, one for the readings obtained at 2.2 minutes and the other at 4.4 minutes for the same three standards. Again, each equation's error was estimated by comparing the actual concentration of the fourth standard to the concentration predicted by the equation.

Tables 1 and 2 give an example summarizing this procedure using the readings obtained during one calibration trial. Regression equation's in Table 1 were used to predict the 'unknown' concentration from the observed digital number of the 'unknown' as illustrated in Table 2.

Table 1. Digital numbers observed at three times for three different ammonia standards and the calculated calibration equation.

Time (min)	Ammonia Concentration (C) (mg NH_3/L)			Regression Equation Digital # = A+B (ln C)		
	1.0	7.0	10.0	A	B	R^2
2.2	889	242	126	890	-339	.9990
4.4	1032	336	219	1032	-361	.9997
6.6	1021	354	252	1021	-344	.9999

Table 2. Estimated calibration error.

Time (min)	Observed Digital #	Observed Concentration (mg NH_3/L)	Predicted Concentration (mg NH_3/L)	% error
2.2	172	8.0	8.30	3.5
4.4	273	8.0	8.20	.9
6.6	303	8.0	8.05	0.7

Early Prediction of Stable Electrode Reading. When the electrode was new, its response as a function of time appeared to be exponential (see Figure 2). For this reason, an attempt was made to predict the stable reading (i.e. the 6.6 minute reading) by fitting to an exponential curve, data taken between 2 and 4 minutes after electrode immersion in each new solution.

The purpose for employing this technique was to allow faster NH_3 measurements while still maintaining or possibly increasing the accuracy of the measurement.

The exponential equation that was fit to the data obtained when the electrode was new is of the form:

$$C = C_f \left(1 - e^{(-K(t-t_o))}\right) \qquad (1)$$

where,

t = measurement time
t_o = the time at which the concentration measured = 0
C = concentration measured at time t
C_f = actual concentration of solution
K = rate constant

Solving equation (1) (see Appendix section Solution of the Exponential Equation) gives:

$$dC/dt = K\,C_f - K\,C \qquad (2)$$

Thus, plotting dC/dt verses C gives a straight line, Figure 6, with $C_f(K)$ as the intercept and K as the slope. dC/dt was numerically determined from the raw data by using the slope between each two consecutive readings and plotting this value against the average concentration of the two readings. Figure 7 illustrates how one such data pair was obtained. A straight line was fit to these data pairs by the method of least squares in order to determine Cf, the predicted final concentration, and K.

A measure of deviation of the data from the fitted curve was calculated for 1.5 minute time intervals with 45 readings each as follows:

$$D = (\Sigma\ (Y_{obs} - Y_{pred})^2)\ )^{1/2} \qquad (3)$$

where,

Yobs = Observed Digital Number at time t
Ypred = Digital Number Predicted from equation 2.
D = Deviation: the smaller the D, the better the curve fits the data.

3. RESULTS AND DISCUSSION

Impedance Matching

The amplifier circuit shown in detail in Figure 8 provides the high input impedance required for measuring a small voltage produced by an electrode with a high internal resistance.

Electrode Accuracy

Tables 3 through 5 contain the results of three sets of calibrations. The percentage error shown was calculated as described previously. Figures 2, 4 and 5 show a typical set of response curves obtained from each calibration set. The four curves on each graph represent the electrode response at four different NH_3 concentrations: 1.0, 7.0, 8.0, and 10.0 mg NH_3/L.

Electrode Aging Affects. Figures 2 through 4 illustrate the observed electrode response as the electrode ages. It appears that initially, the electrode response over time after immersion in a solution is exponential as seen in Figure 2. After months of use, however, this response tends to flatten out more quickly after immersion as seen in Figures 3 and 4. It would seem reasonable to assume that when the response flattens out more quickly, indicating that the electrode stabilizes more quickly, that more accurate readings could be taken sooner. However, this is not necessarily the case as can be seen by comparing Table 3 and Figure 2 to Table 4 and Figure 4. It is true that at 2.2 minutes the 2-month old electrode gave less maximum error (7.7%) and standard deviation (1.5%) than the new electrode (10.2% and 2.35%, respectively). However, at 6.6 minutes, the 2-month old electrode gave roughly twice the maximum error and about 1.5 times the standard deviation of the new electrode. Also, the mean error of the new electrode was always less than the mean error of the 2-month old electrode before cleaning. After the 2-month old electrode inner body was cleaned according to the procedures

Table 3. Results of automated NH_3 electrode calibrations - New Electrode.

Calibration	% ERROR ESTIMATED 2.2 min.	4.4 min.	6.6 min.
1	3.45	1.92	0.71
2	6.13	1.96	0.28
3	3.28	1.70	0.13
4	7.17	3.19	1.17
5	0.84	0.89	0.34
6	5.28	2.65	1.50
7	5.24	1.29	0.67
8	6.67	4.30	2.58
9	2.14	0.45	1.11
10	5.79	2.11	0.19
11	10.16	4.59	3.95
12	6.65	4.30	3.66
13	8.55	3.05	2.17
14	5.93	1.50	0.67
15	7.13	4.40	3.50
16	6.88	2.86	2.13
17	3.24	0.80	0.40
18	4.20	2.30	0.88
19	1.19	0.37	1.33
20	4.66	1.35	0.03
21	6.44	2.04	0.25
Maximum error observed	10.16	4.59	3.95
Mean % error	5.29	2.29	1.32
Range	9.32	4.22	3.76
Standard Deviation	2.35	1.31	1.23

Table 4. Results of automated NH_3 electrode calibrations - 2 month old electrode before cleaning.

Calibration	% ERROR ESTIMATED 2.2 min.	4.4 min.	6.6 min.
1	3.50	2.40	0.35
2	3.80	3.90	3.70
3	7.03	6.36	5.07
4	4.34	6.17	4.83
5	7.20	7.04	7.03
6	4.33	5.62	4.90
7	4.22	4.06	5.03
8	6.40	7.10	7.40
9	5.30	5.90	6.40
10	5.70	5.90	6.40
11	7.70	7.90	6.50
12	7.06	7.90	8.10
Maximum error observed	7.7	7.9	8.1
Mean % error	5.55	5.85	5.48
Range	4.2	5.5	7.8
Standard Deviation	1.50	1.67	2.05

Table 5. Results of automated NH_3 electrode calibrations - 2 month old after cleaning.

Calibration	% ERROR ESTIMATED 2.2 min.	4.4 min.	6.6 min.
1	.74	2.10	0.80
2	1.98	1.69	1.13
3	2.67	2.10	1.94
4	1.24	0.76	1.82
5	2.16	1.50	0.99
6	2.60	1.60	3.30
7	2.60	1.40	1.80
8	2.30	1.80	1.07
9	2.12	2.40	1.25
10	3.60	8.88	3.50
11	0.83	0.21	2.88
12	0.43	0.33	0.41
13	3.85	4.30	0.88
14	2.18	1.58	4.12
15	3.50	2.80	1.43
16	1.37	0.86	2.40
17	1.46	1.12	1.36
18	1.89	2.33	0.61
19	1.00	1.45	1.67
20	0.99	0.27	1.12
21	3.11	3.50	3.12
Maximum error observed	3.85	8.88	4.12
Mean % error	2.03	2.05	1.79
Range	3.42	8.67	3.71
Standard Deviation	0.99	1.87	1.04

specified by the manufacturer (Orion, 1986), it gave maximum error readings of 3.85% at 2.2 minutes as compared to 3.95% error at 6.6 minutes for the new electrode. The mean errors of the new electrode and the 2-month old cleaned electrode after 4.4 minutes were comparable. This indicates that the 2-month old electrode, after cleaning, stabilizes more quickly than the new electrode while giving comparable accuracies, standard deviations and ranges. However, more tests are needed to determine how often the electrode must be cleaned to maintain good accuracies, and how long the electrode will last under these conditions.

Early Prediction of Stable Electrode Reading. When the electrode was new (see Figure 2), it exhibited an exponential increase in readings over time and then approached a stable value. As can be seen in Table 3, the accuracies achieved were quite good if measurements were taken for 4.4 minutes or longer after immersion of the electrode in the new solution. However, an attempt was made to fit the data points between the time of 2 and 4 minutes to see if perhaps as good or better accuracies could be achieved in less time by calculating new calibration curves using the predicted stable value for each standard obtained by fitting data to an exponential curve. The objective was to fit data from a few 1.5 minute intervals between 2 and 4 minutes (i.e. 2.0-3.5, 2.1-3.6,..., 2.5-4.0 min.) to exponential curves. Then, the deviations of the data from the curve would be calculated for each fit. The hope was that the curve with the smallest deviation D would best fit the overall curve as well. Unfortunately, this was not the case. Figures 9 and 10 illustrate the problem. The electrode's response to standard 1 (1.0 mg NH_3/L) is shown in both Figures 9 and 10. This is the overall curve referred to above. Figure 9 also shows the exponential curve obtained by fitting a piece of the overall curve, the data acquired between 2 and 3.5 minutes, to an exponential function. Likewise, Figure 10 includes the curve obtained by fitting the data acquired between 2.2 and 3.7 minutes to an exponential function. The deviations (D) calculated indicate the deviation of the data points within the fitted time interval from the exponential curve to which they were fit. While the curve in Figure 9 (D=1100) fits the overall data better than the curve in Figure 10 (D=541), it does not fit data in the fitted interval as well, as is indicated by the higher deviation, D. Since, of course, in practice, the overall data is not available because the objective is to use data obtained in less time to predict the future response, it remains to be seen how to find the interval which provides the best overall fit that could, in turn, be used to predict the final stable value.

4. CONCLUSIONS

Computer automation and calibration of an NH_3 sensing electrode that allows measurements with less than 4.2 percent error is possible in relatively interference free, fresh water samples. This system allows for automatic calibration to be performed hourly (necessary to obtain the best accuracies) and for the development of NH_3 controls. For instance, water from a tank containing NH_3 can be pumped to the sample chamber for testing, and the computer can then respond to the condition of water by switching on a pump or valve that would add an appropriate amount of compensating chemical.

5. REFERENCES

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Schmidt, B. 1986. Engineer, Cyborg Corp. 55 Chapel Street, Newton, MA 02158. Personal communication.

6. APPENDIX

Impedance Mismatch Problem

Figure 11 illustrates the impedance mismatch problem. When the electrode, which has an internal resistance of 200-600 megohms is connected to the input of the I-140 card, which has an input resistance of about 22 megohms (Schmidt, 1986), the voltage appearing across the I-140 card is:

$$V(I\text{-}140) = \left(\frac{Ri}{Ri+Re}\right)(Ve) \qquad (4)$$

where,

Ve = Voltage produced by the electrode
Ri = Input impedance of the I-140 card
Re = Internal resistance of the electrode

If, for example, the electrode is producing a 50 mV signal, then:

$$V(I\text{-}140) = (50\ \text{mV})\left(\frac{22\ \text{Megohms}}{600\ \text{Megohms}+22\ \text{Megohms}}\right)$$
$$= 50\ \text{mV}\ (0.0354)$$
$$= 1.77\ \text{mV}$$

Thus, the I-140 would only measure about 1.77 mV even though the electrode's response is 50 mV.

An Analog Devices' AD545KH FET (Field Effect Transistor) Op-Amp has an input impedance of about 1 X 10^{13} Ohms. Therefore, the voltage output from the amplifier is:

$$V(\text{amp circuit}) = \frac{(10^{13})(Ve)}{(10^{6} + 10^{13})}$$
$$= (0.99999)\ Ve$$

Or, the voltage output from the circuit should be approximately equal to the voltage input to the circuit by the electrode.

Solution of the Exponential Equation:

$$C = C_f(1 - e^{(-K(t-to))}) \qquad (1)$$
$$e^{(-K(t-to))} = 1 - C/C_f$$

thus, $C = C_f - C_f\ (e^{(-Kt)})(e^{(Kto)})$

where, C_f and $e^{(Kto)}$ are both constants.

$$dC/dt = K\ C_f\ e^{(-K(t-to))} = K\ C_f\ (1 - C/C_f)$$

thus, $dC/dt = K\ C_f - K\ C \qquad (2)$

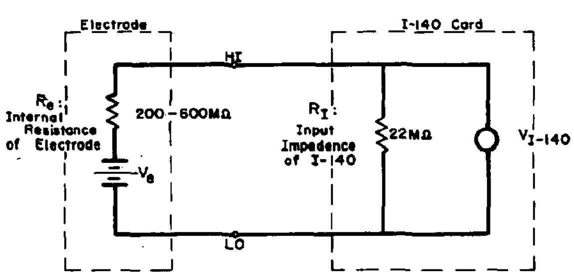

Figure 11. Effects of loading on voltage measurement accuracy.

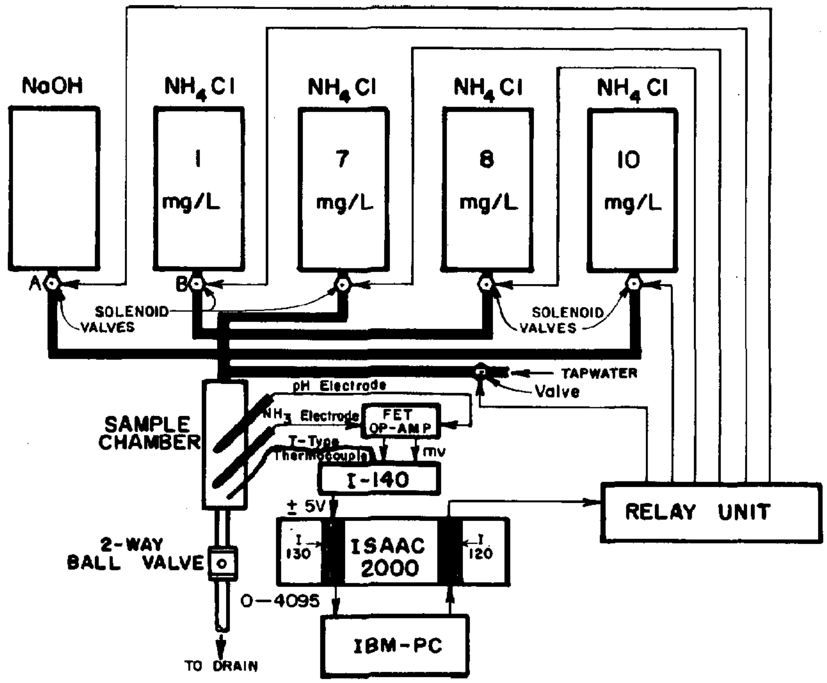

Figure 1. Schematic representation of overall experimental configuration.

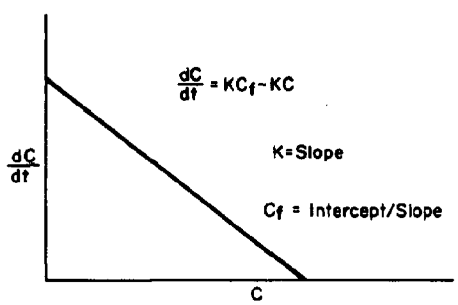

Figure 6. Plot of dC/dt versus C_{avg}, a method of determining K and C_f of an exponential.

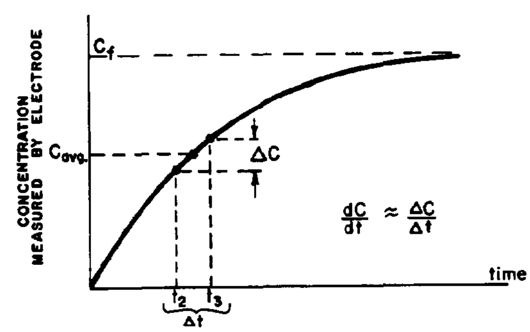

Figure 7. Plot of concentration measured by electrode versus time, a method for determining dC/dt.

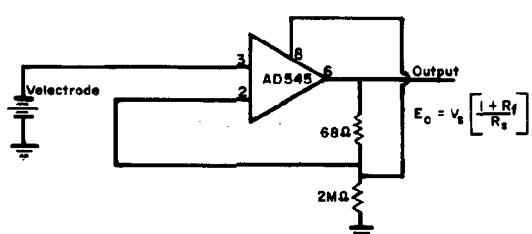

Figure 8. Amplifier circuit using an Analog Devices, precision, low drift FET Input Operational Amplifier (AD545K).

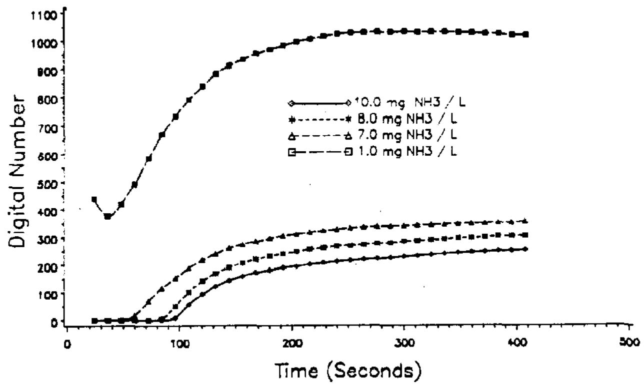

Figure 2. New NH_3 electrode response to four ammonia standards.

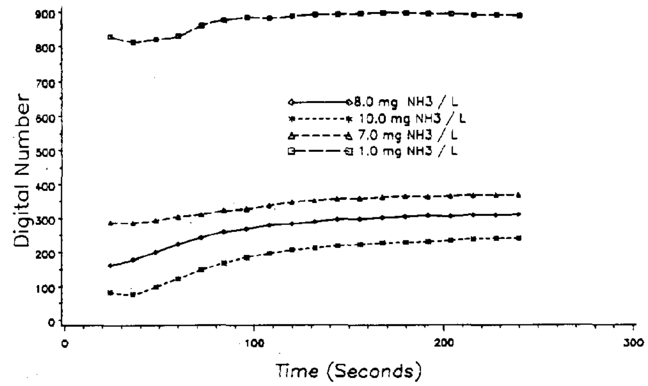

Figure 3. One-month old electrode response to four ammonia standards.

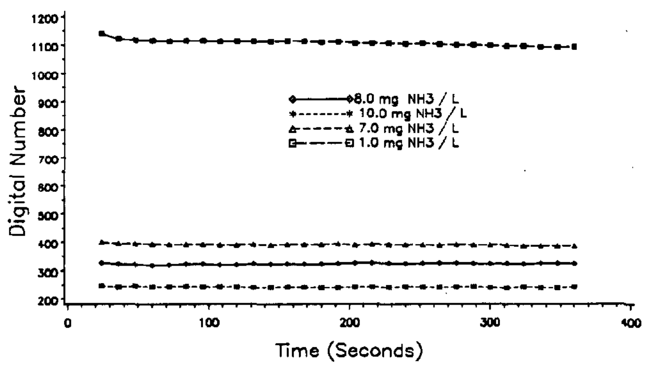

Figure 4. Two-month old electrode response to four ammonia standards before cleaning.

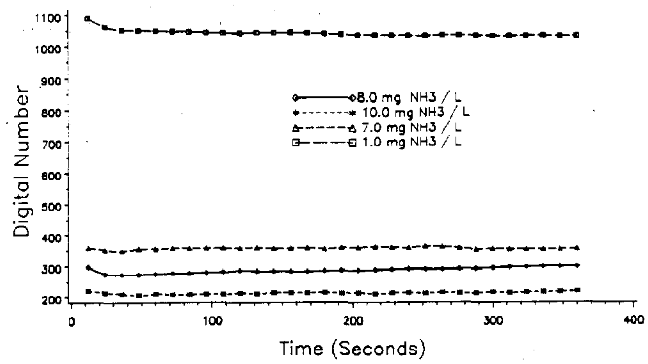

Figure 5. Two-month electrode response to four ammonia standards after cleaning.

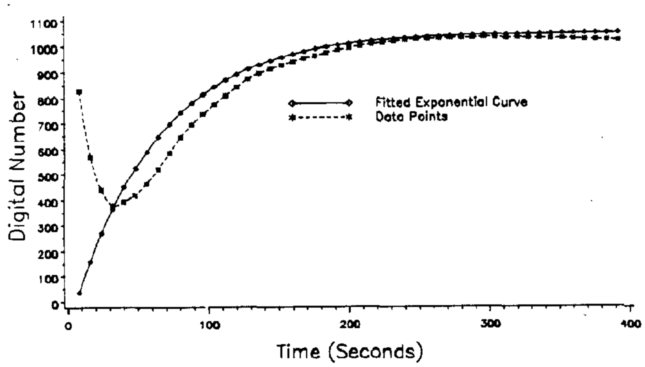

Figure 9. Electrode response over time after immersion in 1 mg NH_3/L solution. Exponential curve fitted to data between 2 and 3.5 minutes.

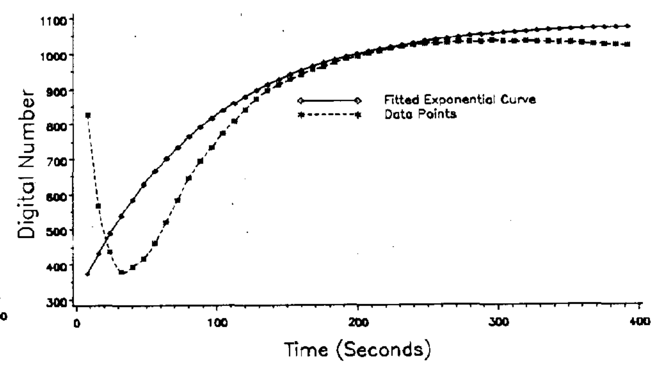

Figure 10. Electrode response over time after immersion in 1 mg NH_3/L solution. Exponential curve fitted to data between 2.2 and 3.7 minutes.

USE OF AUTOMATED HOLDING SYSTEMS FOR INITIAL OFF-FLAVOR PURGING OF THE RANGIA CLAM, RANGIA CUNEATA

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ABSTRACT

The brackish water clam, Rangia cuneata, is widely distributed in coastal waters of the Gulf of Mexico. The use of rangia clam as a high value food product remains largely unexploited due to an off-flavor detected occasionally in the steamed product. Initial tests indicate that the substance is closely associated with fatty compounds and will not be removed quickly. Initial engineering system analysis suggests the use of recirculating technology involving fluidized bed and upflow sand biological filters, chemical feed for pH and alkalinity control, UV/ozonation, and foam fractionation, for maintaining critical water quality parameters in the clam holding system. An algal chemostat system integrating controlled air/carbon dioxide ratios, mixing, photoperiod, harvest, and disinfection modes is used to provide a uniform feed. The operation of the clam holding system and the algal chemostat is linked by microcomputer control and all major processes are automated.

INTRODUCTION

The Louisiana road clam, Rangia cuneata, is a brackish water (0-18 ppt) bivalve found along the Gulf of Mexico coastline from northwest Florida to Laguna de Terminos, Campeche, Mexico (6). In addition, these clams are found along the Atlantic coast as far north as Maryland (6). Presently, the economic importance of rangia clams stem from using it as roadbed material and for the manufacture of many industrial products (17). The estimated 24-48 billion clams, found in the Western Louisiana waters alone, are largely an untapped food resource. While the clam is occasionally canned and eaten in New Jersey, Texas, North Carolina, and Mexico, the Louisiana rangia clam exhibits a muddy/earthy musty odor or off-flavor when steamed or micro-waved. The cause of this off-flavor problem has been identified as geosmin (4).

Economically, rangia clams can be an important food source if the off-flavor can be removed. Presently, these clams are relayed into a natural water environment in anticipation that the clams would purge themselves of the off-flavor causing chemical. But to date, relaying has not been effective in consistently removing the geosmin; however, relaying may be an economical step to assure bacterial quality. Alternatively, using computer controlled, recirculating systems for holding and purging clams provides an environment free of seasonal variations and does not require a constant water source. The use of recirculating systems allows for complete computer control of all processes such as pH, salinity or feedsource that directly affect the release of clam off-flavors.

This paper describes the preliminary development of a microcomputer-based system to hold fed and unfed clams to determine specific factors for enhancing the removal the off-flavor causing compound, geosmin.

BACKGROUND

The marketability of Rangia cuneata in the state of Louisiana depends on removing geosmin from the meat. Geosmin, chemically known as trans-1, 10-dimethyl-trans-9-decalol, creates problems in potable waters as well as in many aquatic organisms. Reports of earthy odors were documented as early as 1891 when researchers described the odors associated with soil (20). A few years later, in 1895, research centered on off-flavors and odors began when cultures of actinomycetes producing "earthy" odors were identified by Rullmann (18). Studies involving aquatic organisms were initiated when salmon caught from rivers in England were contaminated with this "earthy" odor/taste (18,19). Experimental studies showed that the taint in fresh water fish did not originate from mud associated with the source water, but from an odoriferous species of actinomycetes found in the water column (9,19). This study was the first of many attempts to identify the chemical responsible for the odor.

In the late 1960's, Gerber (2,3) and associates isolated and identified a compound from actinomycetes which they named geosmin. This substance is a saturated tertiary alcohol which is unstable in the presence of acid. Gerber's findings, consequently, stimulated more research as other possible sources of the compound were identified (10,11,13,15,16).

During the 1970's, more attention was paid to the problems associated with the aquatic life found in tainted waters. Originally, Thaysen and

Pentelow (19) presented evidence that geosmin was primarily taken up by the gills of salmon thus causing taste and odor problems. Fish species known to have taste and problems include rainbow trout, Salmo gairdneri, bream, Abramis brama, walleye, Stizostedion vitreum vitreum, lake herring, Coregonus artedii, and northern pike, Esox lucius (1,5,12,21). Pond raised channel catfish Ictalurus ictalurus have also been shown to uptake geosmin from the surrounding water (7). Even though fish readily take up geosmin, research has shown that removal is fairly rapid if the fish is separated from the source. Several methods have been tried to eliminate the odor problem in the water industry. Oxidation by ozone/H_2O_2 along with activated carbon seem to produce the most effective results thus far.

Little is known about the uptake/release of geosmin in rangia clams; however, based on the evidence of geosmin removal from fish, it was concluded that relaying the clams would facilitate purging of the off-flavor causing compound. This process takes two weeks to accomplish and is subject to highly variable environmental conditions, and even under ideal conditions may not produce a consistently reliable product.

Moving the clams to a controlled recirculating system equipped with a properly designed filtration unit, the exact purging conditions (temperature, salinity, pH, alkalinity, etc) can be determined and maintained. To design a treatment unit for a recirculating system, the characteristics and amount of wastes excreted by the clams must be known. Prior research on geosmin, waste characterization data, and known effective treatment methods are essential in designing the various treatment components for a recirculating clam holding system. For Rangia clam feeding requirements, additional information about optimum algae species, temperature, salinity, feed rates and other factors must be determined to design a system capable of producing a consistent feedsource.

SYSTEM APPROACH

Factors contributing to the release of the off-flavor causing substance in rangia clam meat are highly complex and interrelated. Testing even the simplest methods for purging the clam requires strict maintenance of all influencing parameters. Computer controlled recirculating holding systems provide an environment which allow continuous monitoring of water quality parameters of any given test condition. In addition, several different control strategies can be tested quickly by simply changing appropriate parameters in the software program. The experimental system used to conduct these complex studies consists of two subsystems: the clam holding system and the chemostat or algal production unit.

Two basic approaches were used to determine the best purging methodology. The first employs a short test sequence that involves altering parameters such as salinity, pH, temperature, and particulates. Each of these factors were varied independently and geosmin levels were monitored in the clam meat and water before and after the testing. Additional taste panel evaluations were used to determine product marketability. All testing was carried out using the clam holding system.

The second sequence of tests assumed that longer periods of time were required by the clam to purge the geosmin to acceptable levels. These longer holding periods require that the clams be fed to maintain a good product. Feeding may also stimulate the release of geosmin in the gut and surrounding tissue as well as enhance the flavor and texture of the clam and thus, provide added value. A green algae, Chorella, was used as a feedsource. This feedsource was provided in large enough quantities to feed up to 1000 clams daily for several weeks. Other parameters associated with the feed such as physiological state and growth phase were also be controlled.

Clam Holding System

The recirculating holding system designed for purging rangia clams consists of the following components: holding trays, fluidized bed and upflow sand filter, foam fractionator, sump, UV/ozone/activated carbon loop, and a pumping system.

Holding Trays. The clam holding trays are multiple stacked trays with internal racks to hold clams in the water column. This arrangement allows food and oxygen to be evenly distributed among the clams while heavier waste solids accumulate at the bottom. Removal these solids is facilitated by several inverted bottom-draw manifolds located between the clam racks. Surface outlets remove any suspended solids, scum or foam that may accumulate. Recirculated water is introduced to the trays via sprayheads for aeration and circulation.

Filtration Design. Adequate water quality in a holding system requires a filtration unit to maintain total ammonia nitrogen and nitrite nitrogen levels below a concentration considered critical to rangia clams. Due to the lack of research on rangia clams, the critical concentrations causing fatality or lowered product quality are unknown, consequently, values for crawfish and blue crabs were used (0.5 mg-N/l for nitrite and 1.0 mg-N/l for ammonia). Filtration designs (fluidized beds and upflow sand filters) developed by Malone and Burden (8) are used for controlling ammonia and nitrite levels. The main purpose of a fluidized bed filter is for nitrification of highly toxic ammonia and nitrite to the relatively non-toxic nitrate form.

Upflow sand filters, on the other hand, are used for solids removal, but also have the capacity to perform nitrification. Recirculated water laden with waste solids flow upwards, penetrating deep into the sand bed, but as more solids are captured the flow rate is reduced. To restore filtering capacity, the sand bed are backwashed or expanded and the backwash flow is diverted to completely remove the captured solids from the system. The computer controls the duration and frequency of this backwash process. Based on our initial waste characterization studies for Rangia clams, solids removal from the system will effectively reduce the BOD_5 loading exerted on the filters by 47 percent. For these carefully controlled studies, the clam shells were washed to remove excess solids. Rangia clams are usually harvested from muddy sediments and can be expected to carry high levels of solids, which in effect, add to the BOD_5 loading of a recirculating system. Thus, solids removal is critical to maintaining adequate water quality.

Foam Fractionation. Based on visual observations of the clams during our waste characterization studies, foaming was a significant problem for both short and long term clam holding. Inclusion of a foam fractionation unit was necessary to alleviate the foaming problem created by the aeration of excreted organics. The foam fractionation loop may be replaced in part, by the UV/ozone/activated carbon process loop. The UV/ozone/activated carbon loop is being tested for destruction of geosmin and fecal coliform bacteria purged from the clams. Control of frequency and duration of the UV/ozone dosing rates by the computer will insure economical and efficient operation of the UV/ozone generator.

Pump System. The total recirculating holding system is tied together by the pumping system. This system consists of a sump which is the pickup point for the pump. The pump circulates water to the holding trays, the filters, and the UV/ozone/activated carbon loop. Computer monitored, water level indicators are located in the sump and water can be added as needed.

Algae Chemostat System

While the rangia clams are held in the holding system, they will be fed a monoculture of algae produced by a semi-continuous culture chemostat. The success of the chemostat depends on the interrelationship between the following components (Figures 1 and 2): (1) growth chambers, (2) air/CO_2/light system, (3) nutrient system, (4) disinfection system, and (5) the computer control/monitor system. Each component will be discussed, in depth, in the following sections.

Growth chambers. The system consists of three algal growth chambers made of fiberglass reinforced with polymer sheet (tradename, SUN-LITE HP). The layout of the chambers is shown in Figure 1. Each chamber is 12 inches in diameter, four feet in depth, and contains a total volume of 23.5 gallons. These chambers have a light transmissivity of 92 percent. The bottom is reinforced fiberglass while the top cover is a friction-fit cap allowing for venting. Additions and withdrawals from the chamber are made through a 3/4" thru-hull fitting in the

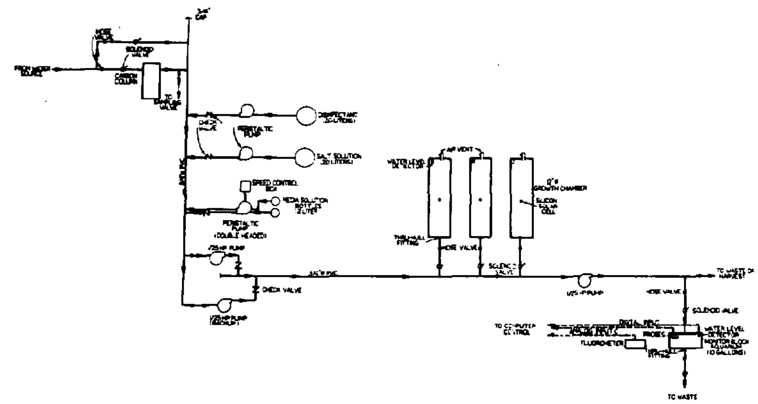

Figure 1. Layout of the nutrient and disinfection loops for the algae chemostat system.

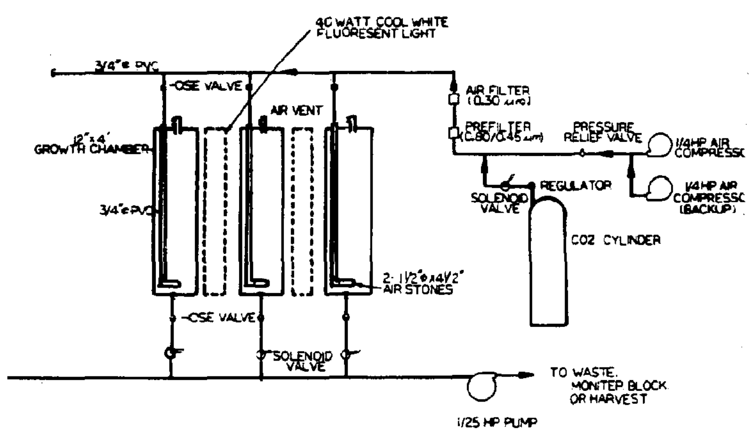

Figure 2. Layout of the air supply loop for the algae chemostat system.

bottom plate and is controlled by a selonoid valve. Air and CO_2 enter the chamber through 3/4" fittings in the cover. In addition, another 3/4" fitting is in the cover for venting and inoculating purposes. Placed five inches from the top of each chamber is a water level detector (two stainless steel wires positioned at a specified distance from each other) used as a prompt to signal the computer to turn off pumps and close selonoid valves when the chamber is full. Positioned on the backside of each chamber is a solar cell for detecting relative densities of algal cells. The three chambers are housed in an open front stand lined with foil to focus and increase the light intensity.

Air/CO_2/lighting system. Air and CO_2 (Figure 2) are introduced into the growth chambers through 3/4" PVC fittings attached to the cover. The air/CO_2 mixture is dispersed by two low pressure, fine bubble air diffusers (average pore size of 35 u). Each diffuser is 5.5 inches long and attaches to standard 3/4" PVC fittings. A 1/4 HP Thomas air pump rated for continuous duty supplies the air while CO_2 is introduced from a gas cylinder. The CO_2, injected into the air line, is controlled by a selonoid valve which opens every ten seconds for a five second period. Before the air/CO_2 combination reaches the growth chambers, it is passed through two filters; a mini capsule with 0.80/0.45 um pore size used as a prefilter and then a HEPA capsule with 0.3 um pore size.

Illumination is produced by two banks of lights (40w cool white fluorescent) situated in front of the chambers facing the back panel. Due to the foil covering the inside of the stand, the light reaching all sides of the chamber should be the same. Presently, the lights are left on in a continuous state, but any sequence of photoperiod can be programmed.

Nutrient system. The nutrient cycle, activated every time a chamber is emptied and disinfected or harvested, is illustrated in Figure 1. The system consists of two-2 liter media bottles, a 20-liter brine solution carboy, two peristaltic pumps (one fixed rate and one variable rate), a 1/25 HP chemical feed pump, and an activated carbon column connected to a water source. The activity of the pumps is controlled by the computer through the use of BSR units. The tap water used to dilute the nutrient media and create an environment for algal growth is passed through an activated carbon column (bed volume of 0.28 ft^3) via a selonoid valve to remove chlorine. The monoculture algae, in this case Chlorella, is grown in an environment as closely related to that of the clams as possible. Rangia clams are being held at a salinity of 10 ppt, thus, the nutrient water in the chambers must be at 10 ppt. In order to maintain a constant salinity within the growth chambers, artificial sea salts must be added every time fresh media and water are added. The amount to be added is determined by conductivity readings taken intermittently throughout the day.

Disinfection system. Weekly, each chamber is emptied and disinfected to insure the growth of pure cultures of Chlorella. Figure 1 depicts the disinfection in relation to the nutrient system and growth chambers. This system consists of a tap water source (bypassing the activated carbon column) controlled by a selonoid valve, a 20-liter disinfectant carboy, a fixed rate peristaltic pump, and a 1/25 chemical feed pump (the same one used in the nutrient system). Once the chamber has been harvested, it is filled with a 4 percent chlorox solution and allowed to soak. After 7 minutes, the chlorox solution is discharged and the chamber rinsed twice with tap water. The tap water is discharged and wasted. Once this procedure has been completed, the chamber is once again inoculated by the nutrient cycle described previously.

Computer Control/Monitor System

The two sub-systems (chemostat and clam holding system) are controlled and linked using a Kaypro model 2X micro-computer interfaced to the monitoring devices with a Remote Measurements Systems ADC-1 data acquisition and control unit. The ADC-1 interface allows for 16 analog inputs, 6 digital outputs, 4 digital inputs, and 32 BSR outputs.

The control program, written in TURBO Pascal (Borland, 1985), is a user friendly menu driven program using a supervisor stack sequence to implement procedures to monitor probes, turn equipment on and off, and collect and record data. The flow diagram (Figure 3) indicates that the subsystems are controlled via separate stack sequences. Direct linkage of the subsystems occurs during the harvest and feed modes when algae is removed from the chemostat and fed to the clam holding trays. Manual override procedures are also provided for system startup and testing of individual components during operation.

All pumps and selonoid valves were controlled using a BSR Type X-10 remote control system connected to the ADC-1. These units use a transmitter which generates a digital code superimposed upon standard house current lines to control up to 255 separate remote relay modules. The BSR units are relatively inexpensive ($20), and minimize the need for hardware connection and lengthy cable runs in a wet environment, thus reducing equipment failure and operator hazards. The pumps were directly connected to the BSR units. The selonoid valves use 24 volt AC current, and thus, a series of transformer were required between the BSR X-10 modules and the valves in order to decrease the line voltage from 110 to 24 volts.

Temperature probes, level detectors, light sensors, conductivity probes, pH and other measurement devices are wired to the ADC's analog inputs which are then converted to digital signals and relayed to the computer through a RS-232 serial line.

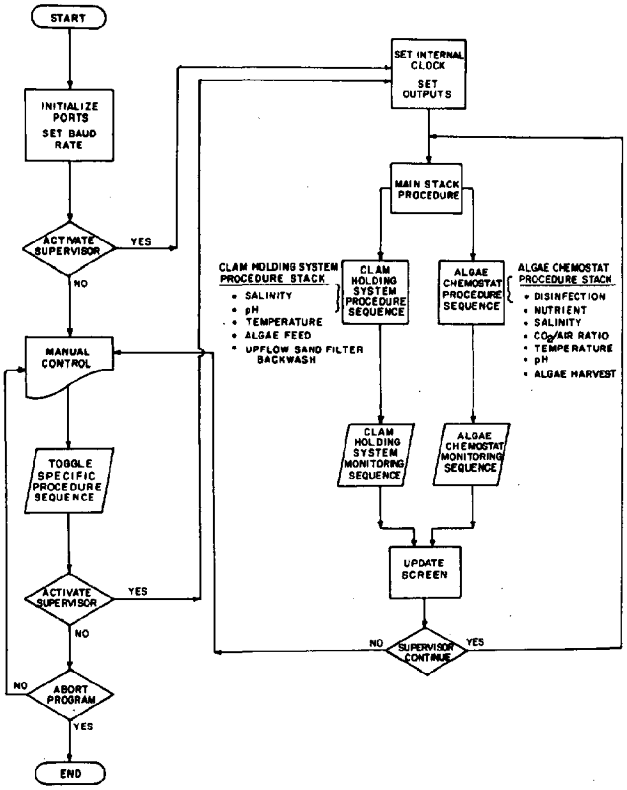

Figure 3. Flowchart of the linked control program for the clam holding system and algae chemostat system.

SUMMARY

The microcomputer based experimental clam holding and algal chemostat system described in this paper provides a valuable tool for the determination of the complex factors contributing to purging off-flavors from the Rangia clam. The control system as designed, allows for the collection of water quality data on a continuous basis for extended periods of time. The autonomous nature of the program frees the operator from the distraction of day-to-day maintenance activities and allows more sophisticated control strategies and fine tune adjustments to be explored with relative ease. Data collection frequency can be selected and data reduction techniques integrated into the program procedures provide succinct output. Control of voltage shifts of output from remote sensory probes are provided by set points and predetermined constants making the system self adjusting. Changes in control sequence or value ranges for a specific probe can be rapidly performed by inputing new constants.

The supervisor control and specific stack sequences for both the algae chemostat and clam holding system outlined in this paper, allow each of these subsystems to independently evaluated and optimized. Thus, investigations into kinetics of algae growth can be evaluated while a purging test sequence is under way. As more specific factors are determined about each system, the closer the two system can be linked. If high salinities enhance purging and the algae species is grown at a similar salinity then feeding and salinity adjustments can be integrated. Other such refinements can be implemented as the study develops.

When the exact conditions that result in a satisfactorily purged clam are identified, simplifications of the process can be developed to make eventual commercialization less dependent on sophisticated control systems. Through this research, the specific control requirement limitations can be defined and an economical design developed for the commercial sector.

ACKNOWLEDGEMENTS

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GULF OF MEXICO CHEMOSYNTHETIC COMMUNITIES AT OIL SEEPS: ESTIMATING TOTAL DENSITY

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ABSTRACT

Chemosynthetic communities occur on the continental slope of the Gulf of Mexico at sites where liquid oil and methane gas can be observed escaping from the substrate. Video and still photographs taken from submersibles suggest that seep mussels (Bathymodiolus-like: Mytilidae) are, together with the vestimentiferan, Lamellibrachia sp., biomass-dominants in these communities. The mussel forms irregularly shaped beds that range in area from 1 to >20 m^2. Length frequency distributions of three collections of mussels show distinct size cohorts. Published length-weight relationship curves for mytilids are used to estimate the mean weight of the collected mussels. Large-area-imaging techniques are used to estimate the total area and mean density of mussel beds at one of the seep sites. These estimates will be combined to give a first order estimate of the mussels' standing-stock biomass.

1. INTRODUCTION

On the sea floor of the continental slope and abyss, the distribution of larger, sessile animals is intriguing because they are generally both rare and diverse. Carney et al. (1983) note that animal zonation in the deep sea is not only due to the great physical gradients present, but also to interaction between animal communities. However, despite some successes in describing characteristic patterns of deep-sea fauna (Grassle et al., 1975), the prevalent conclusion is that few generalizations are possible regarding the causes of the spatial patterns observed (Jumars and Eckman, 1983).

A notable exception to this occurs where inorganic compounds seep into the water at the deep-sea floor. Specially adapted tube worms and bivalves are able to utilize these chemicals through the mediation of internal symbionts and therefore enjoy an unusually abundant food supply (Cavanaugh et al., 1981). The resulting communities are denser, by orders of magnitude, than the normal deep-sea fauna (Hessler et al., 1985) and exhibit distinct patterns that can be directly attributed to the geological processes controlling seepage (Sibuet et al., 1988).

We have examined the spatial distribution of tube worms and mussels at oil seeps on the Gulf of Mexico continental slope using a large-area imaging system developed by the U.S. Navy. The system provides relatively low image resolution, but very precise spatial control of sampling. This is the converse of the usual imagery data obtained by research submersibles. In this paper, we describe our attempts to extend the understanding of distribution processes in chemosynthetic communities by these means.

2. STUDY SITE

Oil and gas seepage on the continental slope south of Louisiana is associated with subsurface faulting, diapir networks and the *in situ* formation of authigenic carbonate and sulfides (Brooks et al., 1986; Behrens, 1988). Oil stained cores and/or chemosynthetic fauna have been collected from over 40 locations (Kennicutt et al., 1985). Six of these sites have been sampled by submersibles and/or by photographic sleds (Brooks et al., 1986; Rosman et al., 1987). These results, and our unpublished observations, suggest that seep communities are spatially discrete, ovoid or linear in shape, and restricted to areas less than 500 m in maximum dimension.

Video data have been collected at portions of four communities using the large-area imaging techniques described below. One of these data sets has been processed in preliminary form. This site was an area of mussel beds located at 27°47.5'N and 91°15.5'W at a depth of 640 m (Fig. 1). The topography of this site is quite uniform; the bottom is mostly free of surface irregularity and the total variation in depth across the site is less than 10 m. Sediments are silty clay; however, cores collected by submersible demonstrated that there is often a layer of carbonate immediately beneath the surface (< 30 cm depth).

3. FIELD METHODS

Single frames of monochrome video were taken from the submarine USS NR-1. The camera was mounted vertically at a location 1 m from the submarine's view-ports. Video frames were simultaneously

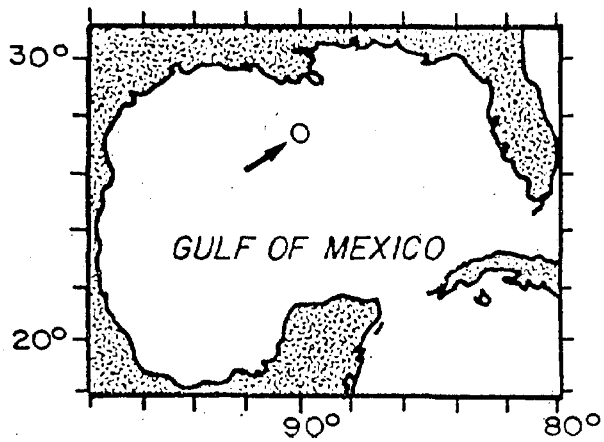

Figure 1. Map showing location in the Gulf of Mexico of oil-seep community sampled using large-area imagery techniques. This site is at a water depth of 640 m and is located near the center of a region characterized by numerous oil and gas seeps.

recorded on laser disk and on 1/2-in video tape. The time and date was overprinted across the bottom of each frame and an observer recorded a continuous narrative describing what he saw through the view-ports as the the frames were being recorded. The submarine's latitude, longitude, and altitude were logged by an on board computer every second (as were CTD readings and other data).

Extensive reconnaissance of the study site indicated that seep mussels were generally restricted to a region approximately 60 by 250 m in size. A series of transects was established across this region and the precision navigation capability of the NR-1 was used to guide the submarine along the transects while video images were recorded (Fig. 2). Spacing between transects was approximately 3 m, mean altitude of the submarine was 3.8 m, its mean speed was 0.2 m per sec, and video frames were recorded every 5 sec. A total of 3923 frames were recorded within an area of 16500 m^2. A 3.5-kHz precision depth recorder provided a record of the sub-bottom profile along the transects (Fig. 2).

Additional observations of seep mussel beds at this site and other sites in the vicinity were made from the submersible JOHNSON SEA-LINK I. A vertically mounted 35-mm camera equipped with a short-range altimeter was used for quantitative photography. Collections of seep mussels were made with a scoop mounted on the submersible's manipulator arm.

4. ABSOLUTE MOSAICS

Large-area images of selected portions of the mussel aggregation were created by constructing a mosaic of adjacent frames and eliminating the overlap between frames (Fig. 3). Photo-negative prints of the video frames were made by a three step process in which the images were first digitized by a video capture board (Data Translation®, model DT2211) installed in a Macintosh II® micro computer, then saved as PICT format files, and finally printed with a laser printer (Apple Laser Writer®). Photo-negative prints were produced because they were found to show light-colored shell material more clearly than positive images.

As the submarine traversed the transects, its altitude tended to vary slightly. This caused the scale of the video images to vary. These differences tended to be most pronounced between transects. For this reason,

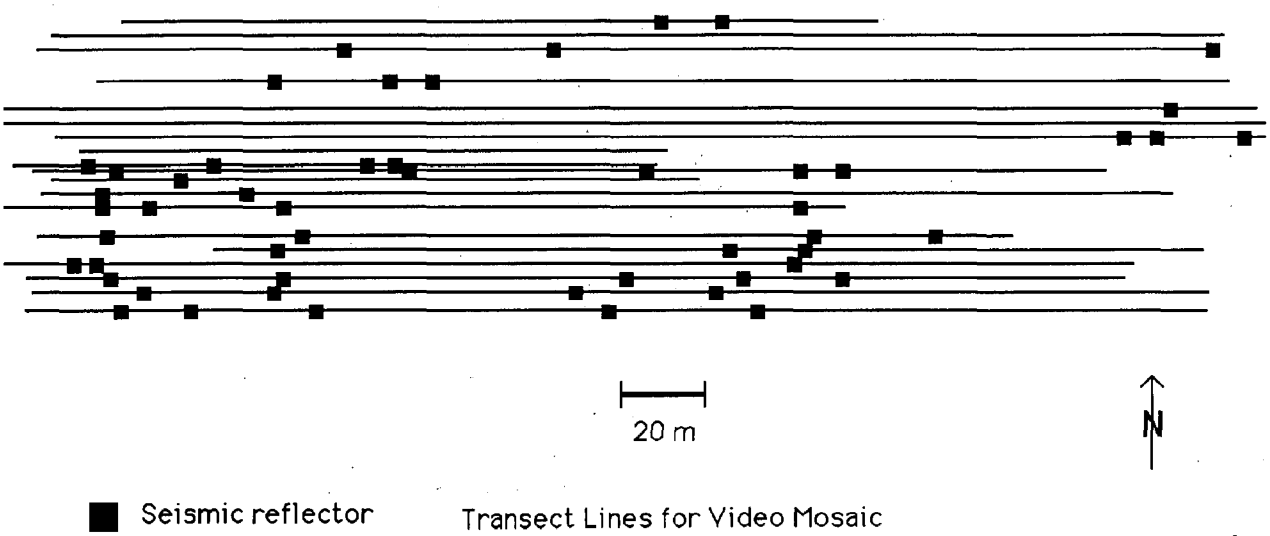

Figure 2. Location of transect lines used to obtain video mosaic images. Total study area is approximately 275 by 60 m. The study site was traversed by the submarine NR-1 along 19 transects spaced 3 m apart (the actual spacing was somewhat variable). The submarine recorded single-frame video images with a vertically mounted camera at 5 sec intervals during each transit. A total of 3940 images were taken. Solid squares show the position of seismic reflectors detected along the transects with a 3.5 kHz precision depth recorder.

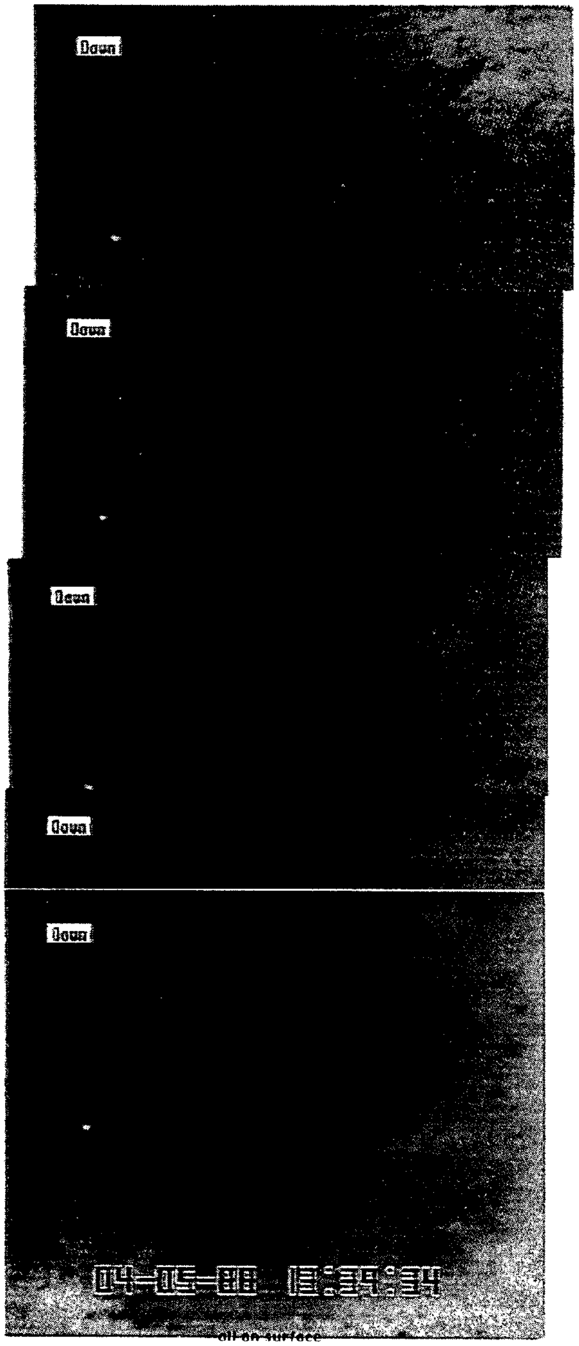

Figure 3. Absolute mosaic of photo-negative video images showing large beds of the seep mussel (*Bathymodiolus* -like) taken from the submarine NR-1. The images were digitized from video tape records by use of a video-capture board and printed with a laser printer. The actual area of the bottom shown in the images is approximately 5 by 13 m.

construction of absolute mosaics has been initially limited to piecing together frames taken along the same transect.

The linearity evident in the shape of the mussel beds shown in Figure 3 was a consistent attribute of the study site. In addition to mussel beds, other features showed this characteristic shape. These included patches of non-mussel bivalve shells on the sediment surface, mats of bacteria, and areas with apparent oil-stained sediment.

5. VIRTUAL MOSAICS

A second type of mosaic, which showed the distribution of seep mussels and shell materials at the study site, was produced by evaluating each of the video frames with respect to several qualitative measures (i.e., presence or absence of seep mussels, approximate shell densities, etc.). These values were then assigned to appropriate locations within a plot of the transects (Figs. 4 and 5). The methods used to produce these plots were the following.

The altitude of the camera above the bottom at the time each frame was available in the computer log of the submarine's altitude and position. From the acceptance angles of the lens of the video camera, it was calculated that a video frame taken from a camera altitude of 3.8 m (the mean altitude of the submarine) covered an area area of the bottom 4.3 by 5.3 m, or 22.8 m^2, in size. The diagonal dimension of such a frame would be 6.8 m. The location of the center of each frame in an X-Y coordinate system was determined from the submarine's latitude and longitude. Thus, the location and the scale of the video frame could be determined with great precision.

However, a simple calculation shows that at a mean camera altitude of 3.8 m, 3923 frames would comprise a total frame-area of approximately 89,500 m^2. Since the area of sea floor transected was only 16,500 m^2 in size, there was clearly considerable overlap between frames. It was therefore necessary to average the values of overlapping frames and assign these average values to a grid of mosaic elements.

Because the transects were intended to be spaced 3 m apart (Fig. 2 shows that this was not always achieved in practice.), an appropriate size for mosaic elements was 3 by 3 m. Other scales could be chosen as well. The algorithm used for the averaging process is known as a distance-weighted moving-average (Ripley, 1981) and has the following form:

$$\Sigma\, w\, (d_i/h)\, z_i \,/\, \Sigma\, w\, (d_i/h);$$

where, for each mosaic element, the intensity z_i is the weighted average of the $i = 1, 2, ..., n$ estimates of areal coverage; and d_i is the distance from the center of the video frame to the center of the mosaic element.

The band-width, h, can be obtained from the mean diagonal dimension of the video frames. It is

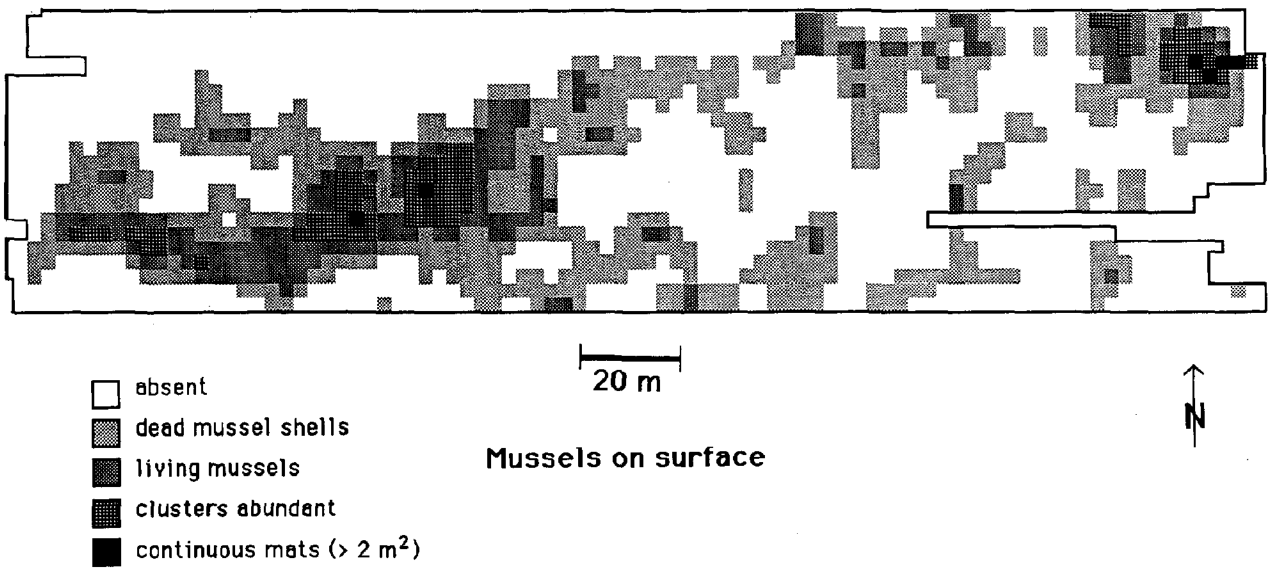

Figure 4. Virtual mosaic showing the distribution of living mussels and mussel shells within the study area. This plot was obtained by viewing the single-frame video images and coding each image according to the number of mussels present (see key for categories). Mussels and mussel shells were generally absent beyond the boundaries of the mosaic. Note the general linearity of the distribution of mussel within the site.

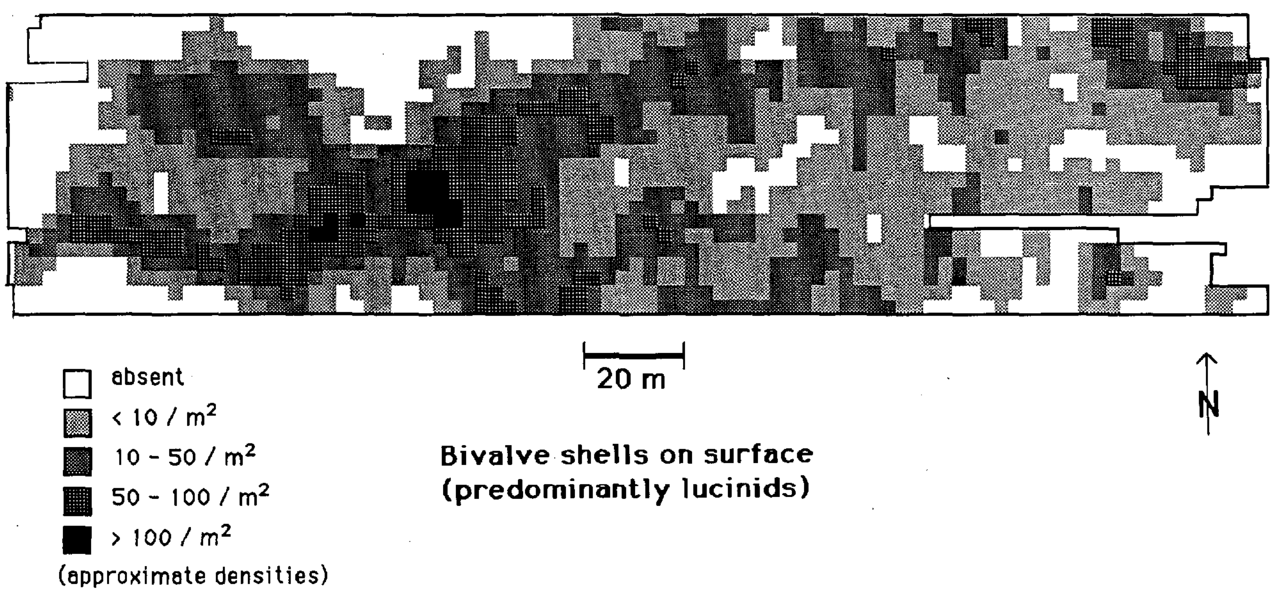

Figure 5. Virtual mosaic showing the distribution of dead bivalve shells on the surface within the study area obtained by coding single-frame video images. These shells included seep-mussel shells, those of lucinid and vesicomyid clams. The lucinid shells were numerically predominant. Areas of shell-covered bottom extended beyond the area of the mosaic; however, the mosaic area was characterized by particularly dense shell cover.

intuitively obvious that frames whose centers are farther apart than their diagonal dimension will not overlap. The weighting function, w, treated x, the distance divided by the band width:

$$w(x)=0.9375(1-x^2)^2$$

for $-1 < x < 1$.

The distribution of mussel beds shown in Figure 4 again shows a distinctly linear pattern, with several nodes of very high density. The lacunae at either end of the study area are the result of a combination of variation in transect lengths and reduced altitudes at the ends of transects. The linear pattern is repeated somewhat more diffusely in the distribution of lucinid shells (Fig. 5).

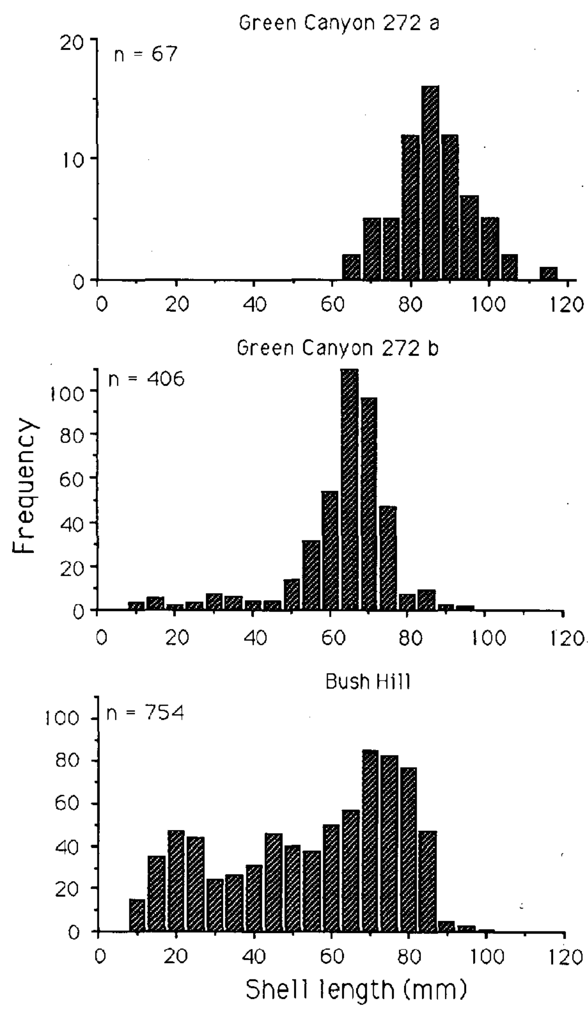

Figure 6. Length frequency histograms of three collections of the seep mussel (*Bathymodiolus* -like). Note the apparent size cohorts and the very different proportions of size frequencies in the three collections. Samples from Green Canyon 272 were collected from beds located approximately 200 m apart.

6. POPULATION CHARACTERISTICS OF SEEP MUSSELS

Three collections of seep mussels were measured to determine their length frequency distribution (Fig. 6). These collections were made from three distinct beds at two locations in the vicinity of the study site. (Unfortunately, no length frequency data were available for the mussels from the study site.) The distributions are similar in that all three show distinct size cohorts; however, the mean sizes and the size ranges of the collections were significantly different, even for collections made from virtually adjacent mussel beds (Fig. 6, Green Canyon 272 a and b).

The occurrence of size cohorts suggests that there is periodicity in the recruitment of juveniles to these mussel beds. Differences in the abundance of smaller individuals suggests that recruitment success was highest at the site of the Bush Hill collection, intermediate at the Green Canyon 272 b site, and that the Green Canyon 272 b site has not recruited any juveniles since the initial cohort was established.

Densities of individual mussels clusters were estimated by projecting 35-mm photographs of the clusters onto the platen of a digitizing planimeter. Because the photographs were taken with a vertically mounted camera, their scale could be calculated from the camera altitude as was done with the video images. Outlining the clusters and counting the number of mussels in a cluster provided a direct estimate of mussel density (Fig. 7). Densities were reasonably constant over the range of cluster areas studied. The mean density was 383.4 individuals per m^2 (standard deviation 145.32).

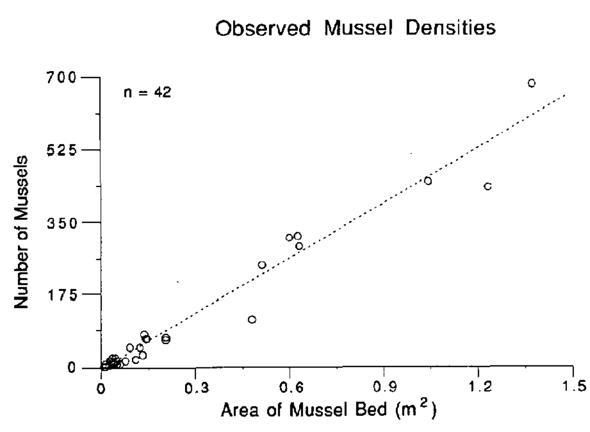

Figure 7. Plot showing the monotonic increase in number of mussels in beds of increasing area. Mean density was 383.4 per m^2 (standard deviation 145.32). Estimates of bed area were obtained by photographing mussel beds with a vertically mounted camera at a known altitude and tracing their outline on planimeter. The counts were of only mussels having both valves intact and held closed (i.e., living mussels).

7. DISCUSSION

The purpose of this study was to examine the analytical results that could be produced from video data and to consider how these results could be used to study the distribution patterns of seep organisms and to estimate their biomass. Our preliminary results show that large-area imaging techniques can be used to compile mosaics of substantial areas of the seafloor, but with sufficient detail to be useful for ecological investigations. The data are voluminous, but tractable to be manipulated with larger micro computers. The major advantage of digitized video data over normal photographs is that the scale of the images can be adjusted with relative ease. The trade-off is a distinct loss of resolution. One should consider, therefore, the type of mosaic that will be produced and how it will be used.

The absolute mosaic (Fig. 3) is a reproduction of the actual pictures at some constant scale and the assembly of these pieces into a single image of the total bottom area. As the scale of the final image is reduced so that it can be printed at some manageable size, one loses first the details that make it possible to distinguish between different types of feature, and second the capacity to distinguish the smaller features at all. To reproduce an image of a 275 m long mussel community at table-top size, it would probably be necessary to reduce the scale to the point where individual mussel beds could not be distinguished from rocky outcroppings or scatterings of lucinid shells.

Production of absolute mosaics is therefore best limited to selected portions of the overall study area. One salutary feature of producing hard copy with a laser printer is that paper copies could be turned out at a cost of just pennies per sheet. It was therefore possible to cut and paste the individual sheets with considerable freedom. Another possibility we are considering recognizes the fact that these video images are in many ways similar to unprocessed satellite images, which also must be assembled into a non-overlapping picture. It will probably be possible to adapt some of the satellite-image processing software developed by NASA to production of seafloor video mosaics.

Virtual mosaics avoid the difficulty of distinguishing between different features. Separate mosaics can be produced showing features that were distinguished in the full scale data (Figs. 4 and 5). Although the data we used were qualitative in nature, the technique is perfectly applicable to quantitative data. The recent proliferation of low-cost image-processing tools promises to speed the production of virtual mosaics from quantitative video data.

We noted that linear shapes were apparent both in the large-scale absolute mosaics (Fig. 3) and in the smaller scale virtual mosaics (Figs. 4 and 5). In light of the seep mussel's dependence on methane (Childress et al., 1986), this intriguing consistency suggests geochemical processes operating on two different scales. Verification of these patterns will require continued use of both absolute and virtual mosaics.

These preliminary results have convinced us that it is possible to obtain accurate estimates of the total area covered by seep mussels at a scale sufficient to define an entire seep community. In theory, a straight forward extrapolation of the mean density and mean size of seep mussels should provide a first order estimate of the biomass of the mussel population at the study site. However, the variability of mussel size and density among clusters within a community demonstrates the necessity for thorough ground-truthing. Plans for additional mussel collections and detailed photography of the study site are underway at the time of this writing.

Acknowlegments: We thank Lt. Commander Holloway and the crew of the USS NR-1, made available thru ONR Contract N00014-80-C-0113 to the Texas A&M Research Foundation. Use of the R/V Johnson-Sea-Link I was funded by NOAA NURP. Additional support was given by the Texas A&M University and Louisiana State University Sea Grant Programs.

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EMERGING ISSUES OF ENVIRONMENTAL IMPACT TO DEEP-SEA CHEMOSYNTHETIC PETROLEUM SEEP COMMUNITIES

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ABSTRACT

Continental slope chemosynthetic communities associated with hydrocarbon seeps off Louisiana and Texas are similar to communities associated with hydrothermal activity and polymetallic sulfide deposits. In each case potential environmental impact must be considered in conjunction with any plan to utilize the mineral resources. Unlike deep seafloor mining, which is still in the planning phase, progressively deeper petroleum production is now a reality. Therefore a higher priority should be assigned to determining the sensitivity of petroleum seep communities.

On the basis of current knowledge, two opposing sensitivity models can be proposed. According to the first (which has been implicitly adopted by MMS), seep communities are robust with respect to impacts due to changing exposure to hydrocarbons. As such, no impact is to be expected from exploration and production if reasonable care is used.to avoid mechanical disturbance. According to the second, seep model, communities are specialized to a narrow geochemical window. Drilling and pumping which alter the subsurface flow of hydrocarbons may have a very major impact upon the continued existence of this window. It is anticipated that future research will contrast and test these two hypothetical models.

INTRODUCTION

It is the purpose of this brief review to suggest a course of action which that will assure an appropriate level of environmental protection for the unique deep-sea chemosynthetic communities associated with petroleum seeps. Rather than considering these communities in isolation, it is important that they be treated as special cases in the larger problem of preventing unacceptable impact in the deep-sea. When this larger perspective is taken, we quickly find that assumptions borrowed from shallow water experiences are inappropriate. Fundamental questions about these deep systems, especially the reef-like chemosynthetic communities remain unanswered. Efforts to assess sensitivity of impact must be designed answer some very basic questions.

Concern over environmental impact at depths over 1000m is a relatively new facet of marine environmental protection which has gained a higher priority with deeper oil exploration and the discovery of polymetallic sulfides within the U.S. Economic Exclusion Zone (EEZ). Since an experienced and reasonably effective federal system is in place for the protection of shallower marine environments, it is understandable that designs for looking at deep systems might resemble designs appropriate for shallow systems. However, when we take a critical look at the real substance of impact work at shelf depths, the underlying assumptions are found to be inappropriate for the deep-sea.

In spite of an increasing emphasis upon understanding ecological processes in marine systems, the most important assumption which still underlies the vast majority of marine impact work is that species censusing is the best means of assessing both the potential for and the actual existance of impact. The persistance of this approach implies that the fundamental ecological processes of the systems are so well understood, that census data can be placed in a process oriented context without major investigations of those processes. An excellent example of this can be seen in Outer Continental Shelf (OCS) surveys and monitoring, where benthic sampling is done to the virtual exclusion of water colume studies. There is absolutely no effort made to describe the trophic structure of theses systems (see chapters in Boesch and Rabalais, 1987).

Of course, the continued emphasis on faunal census, is not based upon a profound ignorance of contemporary ecology. It is, rather, a cost effective compromise made when studing systems in which the fudamental processes are thought to be reasonably well known. Applied to the deep-sea, there are insidious consequences. We really know very little about the deep-sea. (See chapters in Rowe, 1985)

With respect to deep-sea trophic structure, we know only that biomass decreases markedly with depth. We still do not know the rates and routes which link carbon flux, sedimentary detritus, and the biota. The potential for impacting this system remains unknown. With respect to basic community composition, we know only that species diversity can be extraordinarily high. We can not explain what factors allow for such high diversity, and we known nothing of what would constitute a potential threat to these communities. Even with respect to simple species distribution, we do not know what causes the conspicuous bathvmetric

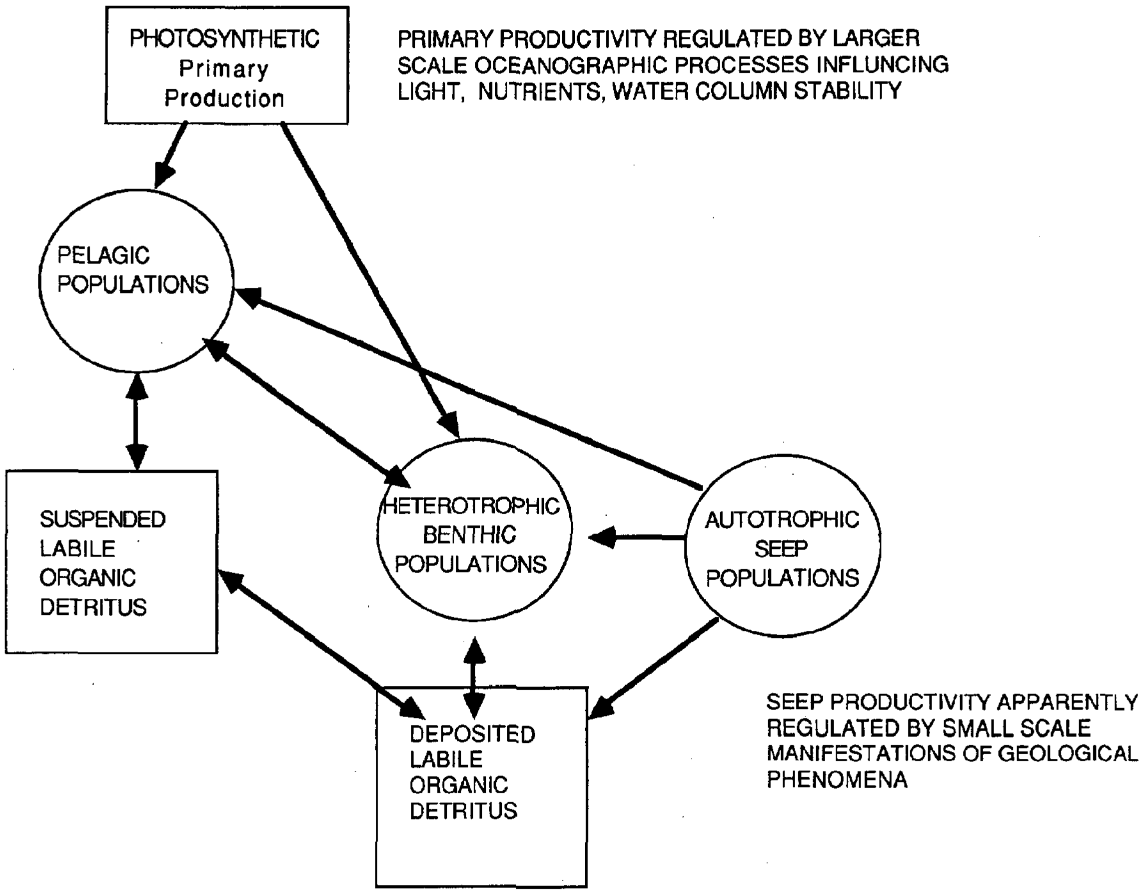

FIGURE 1. Deep-Sea chemosynthetic communities must be treated as spatially restricted subsystems of the larger deep-sea community. Since the actual routes and rates of energy flow through this ecosystem are not known. Designs to assess the potential for impact which stress faunal inventory over process oriented studies are not acceptable in this situation. Of primary concern is determining to what extent the ecology of chemosynthetic communities is controlled by geological processes which will be altered by exploitation.

changes in faunal composition. Therefore, it is a mistake to assume that deep-sea census data can be evaluated within an appropriate context of well understood ecological processes. Prudent investigation of the potential for impact in the deep-sea must be based upon first leaning about basic processes.

I hope that it has been established that in the planning stages of any deep-sea impact work, we must address a profound level of ignorance. When we encounter a deep-sea chemosynthetic community, an even greater level of complexity is acheived. Embedded in a detritus feeding ecosystem, we have a dense chemosysnthetic "reef"(Figure 1). The ecology of these communities is far less well understood than the biology of the key species.

HISTORY and SIGNIFICANCE of the PROBLEM

Recent discoveries in the northern Gulf of Mexico are dramatically altering our understanding of the geological, chemical and biological processes which control the overall ecology of the continental slope. In the geological area, high resolution profiling has increasingly shown that salt tectonism and related processes dominate mesoscale topography and produce islands of hard substrate in a predominantly mud environment (Roberts, et al. 1987). Active and widespread geochemical systems involving hydrocarbons at or near the deep-sea sediment-water interface were first confirmed by the discovery of oil stained cores and thermogenic hydrates by the Texas A&M Univ. Geochemical and Environmental Research Group (Brooks et al., 1984). Trawling in these areas later discovered that a fauna utilizing chemosynthetic symbionts were associated with these systems (

Kennicutt et al. 1985, papers here in) Clearly, as resource development of the EEZ progresses beyond the shelf break, concepts of Gulf of Mexico slope ecology developed prior to 1985 can not be used for management decisions.

The Louisiana continental slope chemosynthetic communities associated with hydrocarbon seeps are one of a series discoveries of functionally and taxonomically related assemblages in the deep-sea. All of these communities share the common feature of being associated with sources of methane or hydrogen sulfide in an oxygenated environment. The underlying geological processes supplying these reduced compounds vary from site to site. These communities are the focus of intense international research, and many of the questions to be asked in the Gulf of Mexico have already been identified and are being addressed.

1. What are the detailed geological, chemical, and ecological processes where by seeping hydrocarbons support distinct communities?

2. How do these communities persist, and to what degree do physical-chemical and biological factors interact on different spatial and temporal scales?

3. How do the component species reproduce, disperse, and then successfully recruit into new or existing communities?

In the Gulf of Mexico, these basic scientific questions assume an applied importance, since we are faced with the question of environmental impact upon a fauna that is uniquely associated exploitable hydrocarbon reserves. It is important that we understand how these communities persist in the natural environment, and the extent to which they will be resilient in the face of petroleum related activities.

Preconceptions about possible impacts (i.e. they have either a low or high probability), all depend upon how the chemosynthetic communities are envisioned, rather than specific findings. For example, if the authegenic carbonate hard substrates and the associated tubeworms, mussels, solitary corals, soft corals, etc. are considered to be a simple variation of a live bottom, then protection is a simple matter. As with any live bottom, sensitivity to petroleum activities would be determined, and appropriate limits placed on the proximity of activities.

Petroleum seep communities can not simply be treated as live bottoms. Rather, in addition to the usual live bottom concerns, it is important to determine what the unique links among geology, geochemistry, and biology are. Informed management decisions can only be made when the possible effects of petroleum activities on these critical (and possibly complex) linkages.

When the geological-geochemical-biological linkages are considered, the appropriate management goal should be to determine to what extent the Gulf of Mexico deep water petroleum seeps fit into two possible categories: a robust or fragile community

1. <u>A Robust Community</u>-Since these communities are associated with petroleum and degradation processes , then they may be uniquely immune from impact by hydrocarbons. They may, in effect, be "weeds" capable of rapidly locating and colonizing numerous sites which afford the correct geological-geochemical setting. In such a case, simple restrictions to prevent mechanical damage might be sufficient when combined with regulations which preserve some habitat areas.

2. <u>A Fragile Community</u>- Alternately, it can be argued that these communities occupy a relatively rare and narrow niche associated with different phases of petroleum degradation. Being so very highly specialize, the narrow range of environmental conditions which support these communities might be very easily altered by drilling and production activities. Indeed, production may result in a loss of the very energy source required by these communities.

Determination of the extent to which the hydrocarbon seep communities are robust or fragile entails coordinated geological, geochemical and ecological efforts that will develop an understanding of the spatial and temporal linkage pattern between hydrocarbon seepage and chemosynthetic community development on the seafloor. These investigations must determine how communities are established and persist within the particular geological and geochemical environments which support them (Sibuet et al. 1988). As stated above the key to understanding potential impacts lies in understanding how the processes of geology, geochemistry and biology interact.

PREVIOUS CONCERNS: The Gorda Ridge Hydrothermal Vent Communities

While resource exploitation beyond the continental shelf is relatively rare, there are a few ongoing programs within the U.S., which deal with the issue of potential damage to sensitive deep-sea communities. To a certain extent, these can serve as models for work on the chemosynthetic communities in the Gulf of Mexico and other OCS areas. Of particular relevance is the concern over environmental impact associated with deep-sea mining of polymetallic sulfides. These deposits have associated chemosynthetic fauna and fall under the authority of Minerals Management Services (MMS).

The Gorda Ridge is a deep-sea geological structure within the Economic Exclusion Zone (EEZ) off the coasts of Washington, Oregon, and California. It is an area in which seafloor hydrothermal activity results in the deposition of potentially valuable deposits of polymetallic sulfide minerals. The unique chemical environment associated with ore deposition also supports chemosynthetic communities very similar those on the Louisiana-Texas continental shelf. The draft environmental impact statement (DEIS) prepared by Minerals Management Service (MMS, 1983) established three very important points concerning resource development in regions where deep-sea chemosynthetic communities are found. First, these communities are of considerable scientific value and warrant efforts at preservation. Second, these communities may be more ecologically sensitive than the more typical, heterotrophic deep-sea fauna. Third, the most appropriate means of protection might be to prohibit mining in the vicinity of communities.

Due to a critical lack of information on the potentially impacted systems discussed in the Gorda Ridge DEIS, strongly negative public opinion lead to the formation of the Gorda Ridge Technical Task Force. This joint Federal-State research coordination effort, has grown into a major Department of Interior, National Oceanographic and Atmospheric Administration, U.S. Navy cooperative program (McMurray, 1986). The recommendations of a NOAA sponsored workshop chaired by Dr. Robert Hessler of Scripps Institution of Oceanography (Hessler, 1983) have played a central role in directing the research of the Task Force. It was recommended that population dynamics of communities be studied, and that long-term monitoring be initiated. Unlike the Gulf of Mexico situation where the location of some communities is very well known, a major exploratory effort has been initiated on the Gorda Ridge to locate systems for study (McMurray, 1985).

To a certain extent, the concerns and recommendations with respect to polymetallic sulfide mining were based upon earlier consideration of the potential impacts associated with deep-sea nodule mining. In order to protect the fauna associated with nodule rich environments, federal legislation mandates the establishment of stable reference areas (SRA) within which no mining activity would be allowed. A committee formed by the National Research Council of the National Academy of Sciences reviewed this approach, found it scientifically valid, and outlined a course of research (Natl. Research Council., 1984, R. Heath overall chairman, R.S. Carney chairman ecological workshop). The central theme of research is to determine the distance at which the bottom fauna receives no impact from mining. Once this distance is known, it will be possible to establish areas large enough to protect the fauna and small enough to avoid unneeded restrictions upon development.

AN EFFECTIVE APPROACH to PETROLEUM SEEP COMMUNITIES

The overall design of seep systems must be based upon a careful consideration of the state of knowledge of other deep-sea chemosynthetic communities, the concerns about impact to those systems within the U.S. EEZ, unique aspects of the Louisiana-Texas communities, and our own considerable experience in the Gulf and elsewhere. If the hydrocarbon seep communities are to receive appropriate protection, it will be necessary to determine those factors most important for the establishment and persistence of the communities. As will be detailed in the following sections, we feel that such information can be developed in a hierarchical fashion employing submersible survey, sampling, experimentation and monitoring.

First, what is the nature and distribution of geological structures with which such communities are associated?

Second, within the appropriate geological settling, what is the nature and distribution of the geochemical environment which can support chemosynthetic communities?

Third, within the appropriate geological and geochemical settings, what factors regulate the establishment, persistence and resilience of chemosynthetic communities?

Finally, with what confidence can faunal survey, geochemical survey, and/or topographic survey provide in a cost effective manner the information needed to locate and protect these communities?

In undertaking such an investigation, we are well aware of the slow rate of progress in some aspects of deep-sea community ecology. While our task are not trivial, they are obtainable because the Louisiana-Texas slope communities afford three special opportunities which we will exploit.

1. These sites are relatively shallow (less than 1000m). As a result, a wider variety of technologies can be employed than in deeper systems.
2. There is considerable information available on the geology and geological processes of the region.
3. There are obvious management needs will result in the appropriate priorities focusing upon the geological-geochemical-ecological link.

CONCLUSION

Deep-sea chemosynthetic communities pose a unique set of management problems. On the basis of current knowledge, it can be suggested that they depend upon the same geological resources which man seeks to exploit. If this is the case, then an effective protection plan must have at least two components. First, there must be conservation to assure an acceptable level of habitat preservation. Second, there must be assured protection from impact due to drilling/mining in areas open to exploitation. The research which leads to the adoption of a management program must provide a basis for both components. Therefore, it is critical that ecological processes be studied. The highest priority must go to the determination of the linkage between biology and the geological/geochemical phenomena which appear to be necessary for the communities to exist.

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PETROLEUM - DERIVED AUTHIGENIC CARBONATES OF THE LOUISIANA CONTINENTAL SLOPE

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ABSTRACT

Seismic and echo-sounder profiles across Louisiana's continental slope have historically suggested the presence of abundant hydrocarbons in shallow subsurface sediments and in the water column. Various mineralogical types of authigenic carbonates are common in hydrocarbon seep areas. Significance of a substantial carbonate component to the sedimentary architecture of the Mississippi delta complex has never been seriously evaluated.

Large topographic variations on the slope are related to salt tectonics. Close inspection of these features (geohazards data and cores) suggests that they are largely carbonate capped. These carbonates range from shell hashes through cemented clays and hardgrounds to massive mound-like buildups ten of meters in relief. Analysis of host sediments commonly reflect the presence of biogenic gas generated in situ and thermogenic gas and associated crude oil generated outside the realm of surface sediments. Numerous faults act as conduits for fluids and gases from the subsurface.

Isotopic values of the authigenic carbonate (δC-13 values to -48 o/oo PDB) reflect a link with hydrocarbons. Microbial oxidation of methane and heavier hydrocarbons provides a source of CO^2 in interstitial waters and triggers chemical precipitation of carbonates (primarily aragonite and Mg-calcite) characterized by extreme depletion of the C-13 isotope.

INTRODUCTION

Data taken in support of hydrocarbon exploration and production in slope-depth environments of the northern Gulf of Mexico have increasingly confirmed the abundance of authigenic carbonates. The bathymetrically, structurally, and sedimentologically complicated continental slope off Louisiana is an area where the occurrence of oil and gas seeps is convincingly associated with the production of enormous volumes of calcium carbonate, sediments and structures. Data that support these findings are largely high resolution seismic profiles, side-scan sonographs, bottom samples cores, and geochemical surveys run to assess potential drill sites and pipeline routes.

The slope is underlain by a massive salt unit (Louanne Salt, Jurassic), which largely controls major topographic and structural variations. The salt has been deformed into a variety of diapiric spines, domes, and ridges, some of which reach the surface or are close enough to influence modern seafloor topography and near-seafloor stratigraphy. Resulting seafloor complexity of the slope is expressed in highly irregular depth contours, (Figure 1). Processes of salt tectonics have produced numerous interslope basins and topographic highs. Bathymetric and structural maps of the slope lack the necessary detail to accurately portray the gradients and complexities of relief that actually exist (1).

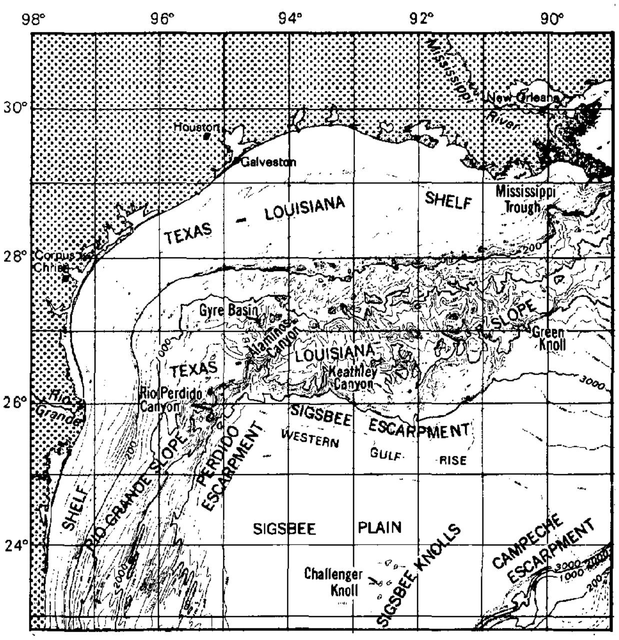

Figure 1. Bathymetry of the northern Gulf of Mexico continental slope topography associated with salt tectonics (modified from Martin and Bouma, 1978).

Recent data indicate that surface and near-surface sediments (2, 3) display a wide variety of depositional settings, including settings of slow hemipelagic deposition over more rapidly deposited low sea-level fluvial sediments, areas of seafloor failures and mass movement, and extensive regions of sediment stripping and erosion. In addition, these studies have shown that the slope is a zone of active faulting that provides avenues for fluid and gas movement from the deep subsurface to the modern seafloor. Oil and gas seeps are common (4). It is also clear, from studies of both sediment cores (3) and seismic profiling (2, 5, 6), that sedimentation on the slope is strongly modulated by sea-level fluctuations. Although the deposition of fine-grained hemipelagic sediments and various types of turbid flows/debris flows initiated by mass-movement processes are part of the rising to high sea-level suite, coarser sediments are typical of falling to low sea-level periods, when shelf-edge delta building takes place (5). However, many of the elevated salt domes were largely bypassed by fluvial deposition even during low sea-level periods and left to accumulate carbonates.

ABUNDANCE OF SLOPE HYDROCARBON SEEPS

Several researchers have shown that active gas and crude oil seepage is widely distributed across the upper continental slope of Louisiana (7, 8, 9, 10, 4). Seeps are common to diapir crests which are associated with complex faulting. Acoustic data from these areas commonly record gas in the water column and acoustic wipeout zones in the subsurface that are interpreted as shallow accumulations of biogenic and thermogenic gas and gas hydrates. Near shallow diapir crests, upturned and truncated bedding is common, as well as surface topography that is complicated by irregularities ranging from fist-sized carbonate nodules in the sediment to carbonate mounds that can attain vertical dimensions of tens of meters (Figure 2).

The biogenic gas is thought to be formed in place as the result of microbial activity on dominantly terrestrial organic matter transported to slope sediments. There is little doubt, however, that large volumes of thermogenic gas and crude oil are migrating to the slope surface at the present time. Among evidence for present migration of thermogenic gas to the present seafloor are unusual gas hydrates recovered from Green Canyon cores. These yellowish-orange nodules of thermogenic gas hydrates, found in association with biodegraded crude oil, included methane as well as ethane, propane, isobutane, and normal butane (8, 9). Additional analytical work on Green Canyon cores (11) also indicates the presence of carbon dioxide and hydrogen sulfide encased within the gas hydrate structure. Based on calculated thermal maturity models for the Louisiana slope, thermogenic gas and crude oil did not form at shallow depths, but instead migrated along faults from deeply buried Lower Tertiary or Mesozoic source rocks (12).

It has been noted (13, 14) that slope hydrocarbon seeps are frequently associated with chemosynthetic communities similar to hydrothermal vent fauna (tube worms, bivalves, gastropods, and other organisms) that utilize methane and hydrogen sulfide as nutrient sources. The origin of the methane utilized by these chemosynthetic organisms is complex. Both biogenic and thermogenic methane are available in seeps. Biogenic methane does not typically include higher hydrocarbons, whereas thermogenic gas can include higher hydrocarbons such as those noted in gas hydrates (8). Biodegradation of thermogenic hydrocarbons is known to result in preferential preservation of methane, as other higher hydrocarbon gases are preferentially oxidized by bacteria (15). This process results in methane-rich residual gas of thermogenic origin that could also be utilized by chemosynthetic organisms.

RELATION OF HYDROCARBON OXIDATION TO AUTHIGENIC CARBONATES

The relationship between microbial oxidation of hydrocarbons and the formation of carbonate minerals, including aragonite, Mg-calcite, and dolomite characterized by isotopically light carbonate carbon, has been documented (7, 8, 9, 16). Moreover, such processes occur at even greater water depths than the present paper encompasses. Isotopically light carbonate has been identified in association with crude oil and elemental sulfur in the shallow cap rock of Challenger Knoll, a salt dome in the Sigsbee deep abyssal plain at a water depth of 3600 m in the Gulf of Mexico (17).

Certain aspects of microbial oxidation of hydrocarbons and formation of carbonates with isotopically light carbon in the slope sediments are incompletely understood. The carbon isotopic compositions of authigenic carbonates on the Louisiana continental slope display wide variation, with values ranging from those typical of marine carbonates to values as light as -48 o/oo PDB (7, 9, 18). It could be assumed that the isotopic variability of the slope carbonates simply reflects a mixture of carbon derived from methane and marine carbonates, but research on the origin of Gulf Coast salt dome cap rocks suggests greater complexity.

Carbonate carbon isotopic values of salt dome cap rocks associated with crude oil seepage (-25 to -30 o/oo PDB) have been attributed to microbial oxidation of crude oil hydrocarbons with a similar carbon isotopic composition (19). Microbial oxidation is not necessarily limited to hydrocarbon gases as described (15), but can result in nearly complete oxidation of quantitatively more significant liquid saturated hydrocarbons of much higher molecular weight (20, 21). Crude oils from Green Canyon seeps are known to be biodegraded (7, 8, 22), suggesting that in some

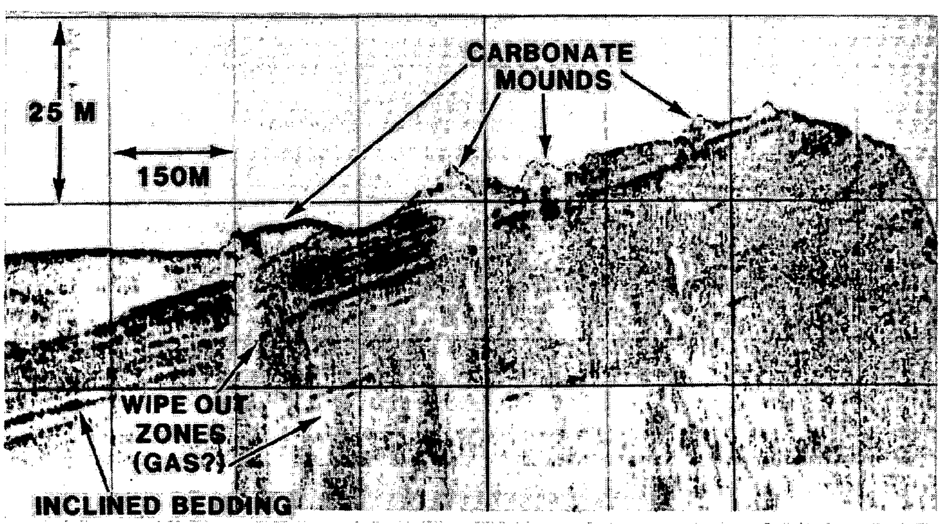

Figure 2. High resolution seismic profile near the crest of a shallow salt diapir. Note the upturned and truncated bedding, mounded surface topography, and acoustic "wipeout zones."

seeps hydrocarbons associated with crude oil could be a significant contributor to authigenic carbonates. Nevertheless, carbonate carbon isotopic values of some salt dome cap rocks not associated with oil seepage (-30 to -50 o/oo PDB) have been attributed to microbial oxidation of biogenic methane (23). Additional research needs to be done to elucidate the relative contributions of different hydrocarbon types to Louisiana slope carbonates with widely varying carbon isotopic compositions.

CARBONATE MOUNDS AND SEDIMENTS

Recently assembled and interpreted high resolution seismic data (24) clearly show carbonate buildups of various dimensions on the crests of many salt diapirs at varying water depths. They are found from the shelf edge, which was near sea level during the last low stand (~20,000 yrs BP), to depths that were far below the photic zone even when sea level was at its lowest. Acoustic data shown in Figures 2 and 3 indicate the seafloor irregularities common to slope areas affected by shallow salt diapirs. Note the surface mounds of Figure 2 and the associated acoustic wipeout zones. These areas of no acoustic return are usually interpreted as pockets of shallow subsurface gas, but a hard carbonate substrate, such as those shown in Figure 2, can reflect acoustic energy and create acoustic wipeouts beneath these features. The acoustic response seen in Figure 2 is commonly a combination of both effects in the salt diapir crest environment.

A side-scan sonograph showing the distribution of mounded areas near a shallow salt diapir crest is shown in Figure 3. Areas of smooth seafloor on the diapir flanks and in local areas of the diapir crests collect hemipelagic sediments. These sediments are characterized by lack of stratification, thorough burrowing, and abundant calcareous microfossil tests (up to 30%) (Figure 4). These thin (2-4 m thick) hemipelagic sediments, which represent rising to high sea-level deposits, drape nearly the entire slope (3). They are underlain by thicker and more stratified deposits from the last low sea-level period (5, 6). Surface sediments from mounded areas of seafloor are generally rich in sand-sized and coarser carbonate debris, including encrusting foraminifers, calcareous algal fragments, mollusc debris, carbonate cemented pellets, large carbonate clasts, and coral debris (both hermatypic and ahermatypic corals). The large cemented clasts of authigenic carbonate commonly found in these sediments are isotopically light (δC-13 values ranging from -20 to -46 o/oo).

It is thought that large carbonate mounds as shown on the seismic profile of Figure 2 are composed primarily of isotopically light calcium carbonate (mostly aragonite). A large piece of this material collected from the Green Canyon area off central Louisiana is shown in Figure 5A. It contains many voids, borings, and various types of epifauna, including solitary corals and brachiopods. Most of the matrix is cemented with isotopically light aragonite, and voids are filled with splays of acicular aragonite crystals (Figure 5B) or thick rims of botryoidal cements. Once a substrate is established by cementation catalyzed by the microbial oxidation of hydrocarbons, it becomes a habitat for hard substrate organisms. On the crests of shallow domes at the continental shelf edge it is not uncommon to find both living and dead ahermatypic and hermatypic (reef-building) corals (Figure 6). During low sea-level periods, many upper slope-distal shelf dome crests were in a favorable photic environment for reef growth. A few of these features, such as Flower Garden Banks off the Texas-Louisiana border, have survived as viable coral reefs. It is probable that many of these bioherms and true reefs began development on hard substrates provided by the process of authigenic carbonate production discussed previously. Carbonate mounds of the present continental slope that are located at depths beyond the photic zone even during periods of lowered sea level are likely to have a hydrocarbon seep origin. Research is currently underway to determine the origin of carbonate buildups at various depths in several slope areas.

CONCLUSIONS

Research on carbonate sediments and moundlike buildups on the continental slope off Louisiana have led to the following conclusions:

1. Acoustic data suggest the widespread occurrence of mounds and rough bottom areas

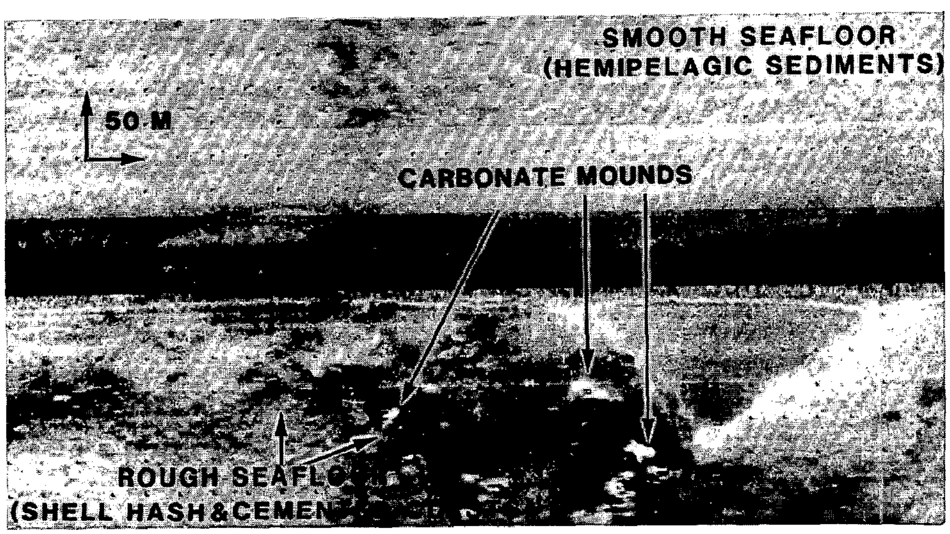

Figure 3. Side-scan sonograph from a slope diapir crest showing rough bottom topography associated with carbonate mounds. In the vicinity of the mounded areas the surface sediments are commonly composed of either shell hash or carbonate cemented clasts in a mud to shell hash matrix.

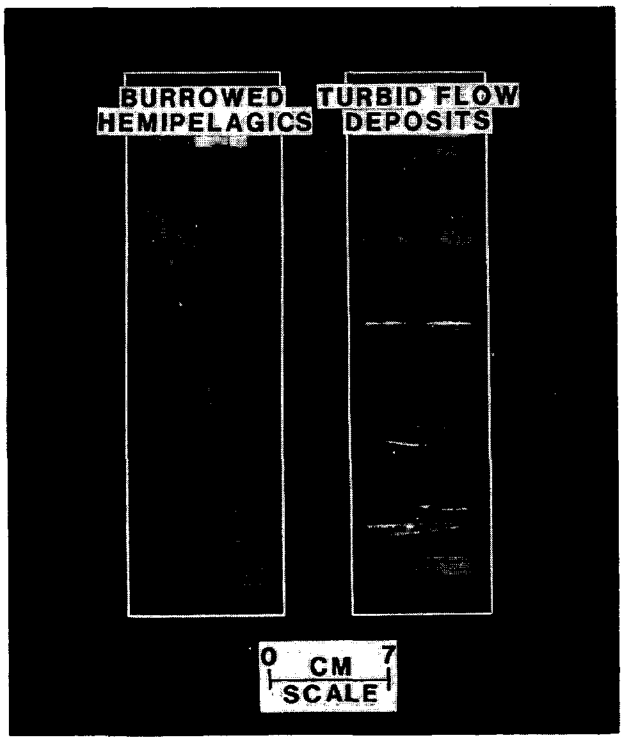

Figure 4. X-ray radiographs of cores from two common types of near-surface sedimentary facies, burrowed hemipelagics that drape much of the slope and turbid flow sequences commonly associated with sediments deposited during the last low sea level. Due to seafloor erosion, these low sea-level deposits are sometimes exposed on the modern seafloor. Prints are pictures of the radiograph negative. Light areas are dense to passage of X-radiation.

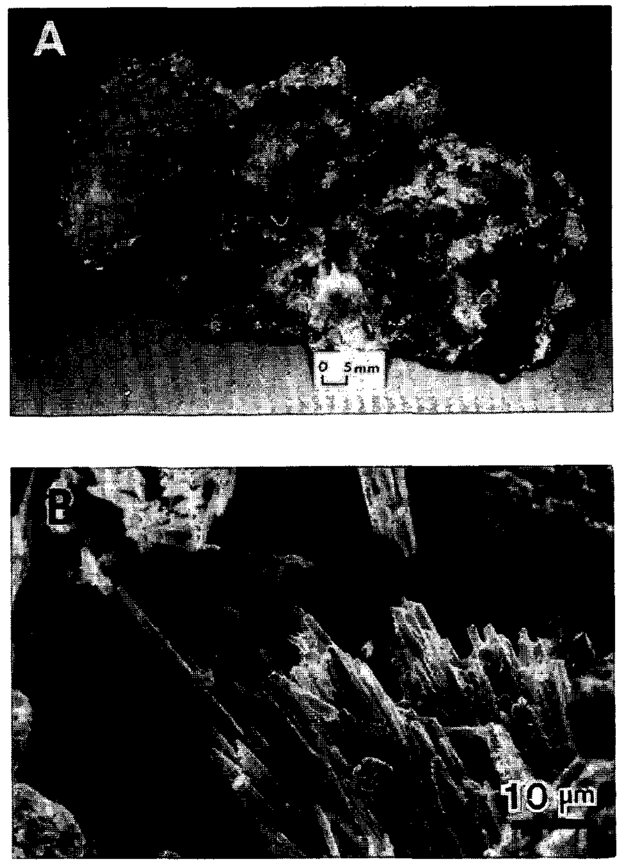

Figure 5. (A) A large block of isotopically light carbonate (mostly aragonite) collected from the Green Canyon area off central Louisiana. Dark areas around the voids are crude oil stains from a natural seafloor seep. (B) The small-scale voids in the larger rock shown above are filled with splays of aragonite crystals as shown on the scanning electron photomicrograph. Aragonite cements have δC-13 values as light as -48 o/oo PDB.

associated with salt diapir crests that, when sampled directly, are usually composed of various species of calcium carbonate minerals.

2. Cores and bottom samples from mounded areas are usually carbonate-rich and commonly contain crude oil. The presence of abundant gas in these areas is suggested by frequent acoustic wipeout zones in the shallow subsurface and reflection events from gas in the water column.
3. Geochemical analysis of hydrocarbons reflects multiple origins, from in situ biogenic methane to thermogenic gas and crude oil that has migrated to the surface from great subsurface depths, presumably by way of large growth fault systems.
4. Isotopic signatures of the carbonates (δC-13 values to -4 o/oo PDB) reflect a link with hydrocarbons in the carbonate-forming process. It appears that much of the isotopic variability of the carbonates is related to the varied pool of carbon made available by microbial degradation of a spectrum of hydrocarbons, from biogenic and thermogenic methane to crude oil hydrocarbons.
5. Hydrocarbon-derived carbonates provide a substrate for organisms requiring a hard substrate.

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Figure 6. Hermatypic corals collected by piston core from a carbonate mound on a shallow salt diapir crest east of the modern Mississippi River delta. This reef/bioherm probably started on a hard substrate of authigenic carbonate associated with a seep.

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SCIENTIFIC, TECHNOLOGICAL, AND SOCIAL IMPACT OF NOAA'S MOBILE UNDERSEA RESEARCH HABITAT

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ABSTRACT

The National Oceanic and Atmospheric Administration's (NOAA's) Undersea Research Center at Fairleigh Dickinson University (NURC-FDU) on St. Croix, U.S.V.I. presently operates (AQUARIUS), a recently commissioned scientific saturation diving habitat system. The unique undersea habitat is located in the apex of a submarine canyon on St. Croix's north shore at a depth of 50 ft. By utilizing saturation diving, teams of six aquanaut/scientists are able to spend up to four weeks living beneath the sea, studying the ocean floor and its inhabitants. Moreover, the AQUARIUS mobile system consists of the habitat, its anchoring baseplate, and a Launch, Recovery, and Transport (LRT) vessel that can be retrofitted to serve as a Mobile Support Base (MSB) and floating laboratory. This mobile capacity will allow NURC-FDU to serve the research needs of the entire Caribbean.

1. DETAILS ON THE HABITAT SYSTEM

The AQUARIUS habitat system was deployed in Salt River Canyon, St. Croix in September 1987. The habitat system is composed of four major elements; the habitat, the Life Support Buoy (LSB), the LRT/MSB, and the Baseplate. The habitat represents a major advancement in facilities for scientific saturation diving by providing enhanced scientific capabilities in a comfortable living environment. The habitat is an American Bureau of Shipping (ABS) classed double lock vessel capable of housing and supporting six persons in an environment closely approximating a typical field research laboratory. It is rated to an internal pressure of 103 psi (232 feet of sea water) and an external pressure of 54 psi (120 feet of sea water), allowing a maximum saturation depth of 120 feet. The pressure hull is 3.5 times larger than the original HYDROLAB (an undersea habitat operated in St. Croix by NURC-FDU between 1978 and 1985). It has rectangular hatches for easy entry and exit and several viewports up to 23 inches in diameter.

A non-pressure rated "wet-porch" is attached to one end of the habitat. This room will serve as the habitat entrance and provides a dressing room, shower for divers, and wet laboratory space, including a seawater table and aquaria. Wet laboratory space was not provided for in HYDROLAB, and is highly desirable. The wet porch also features a dumb-waiter system which will be used for the transfer of supplies in pressure-resistant containers to and from the habitat. During HYDROLAB missions, support divers carried bulky containers by hand.

Habitat life support systems include an Environmental Control System (ECS), two high pressure air sources, oxygen and oxygen/nitrogen gas supplies, primary and emergency power and communications systems, remote and direct monitoring of habitat atmosphere, and remote video monitoring. Remote environmental monitoring eliminates the need for a 24 hour radio watch, allowing scientists to have a normal sleep schedule during the mission. Remote sensing will relay all critical life support data continuously from the habitat to the support base via radio. *The decision was made in late 1986 to go with a radio system both for voice communications (on VHF channel 82A) and for transmitting sensor data from the life support systems (on channel 2A).*[1] The scientists can be alerted from shore if a problem is detected. A hard-wire communications umbilical has been installed as a back-up system. The addition of an onboard technician will free diving scientists from the daily maintenance and operation of the habitat and increase the time available for research.

Living conditions within the habitat will be markedly improved over HYDROLAB. The improvements include an indoor toilet, two sinks, a shower, a dining table, a large refrigerator, a microwave oven, bunks for all team members and several science work areas. The habitat will be supplied with hot and cold fresh water from a desalination unit and water heater on the LSB. Water will not be rationed. Provision for adequate bathing facilities should reduce the frequency of skin infections. An indoor toilet reduces exposure time and the need for extra showers.

Another technological advance in the system is that decompression in the habitat will be controlled by NURC-FDU staff on the surface. Controls are housed in the LSB. The advantages to remote control are that decompression will now be controlled by an experienced staff so that scientists will be freed to rest or pursue research.

2. LIFE SUPPORT BUOY (LSB)

The LSB was constructed from a 45 foot fisherman-type hull acquired from the U.S. Customs Service and delivered to NURC-FDU in late 1985. Design and conversion of this vessel was accomplished on St. Croix by the NURC-FDU staff and local contractors. The LSB will provide the primary life support for the habitat.

The LSB has been designed with a reverse osmosis desalinator for ample supplies of fresh water, two diesel engines and generators, two high pressure compressors, one low pressure compressor, the control unit for the ECS, and support for the habitat's VHF radio antennas. A continuous duty rotating video camera mounted on the LSB monitors sea conditions and boat traffic from the support base. An insulated, air-conditioned control room houses the controls for decompression, the atmosphere monitoring equipment, radios and video equipment. A small shop with tools and spare parts is housed below deck.

3. LAUNCH, RECOVERY AND TRANSPORT vessel/MOBILE SUPPORT BASE (LRT/MSB)

In 1987 the final design for the LRT/MSB and baseplate was completed with the contract to build these components being awarded to Brown & Root Marine. The LRT/MSB was completed during August 1987. This design features a new baseplate as well as a catamaran style vessel and a Mobile Support Base that can provide transportation for the entire system.

The LRT/MSB has three principal roles. The first is to launch, recover and transport the system around St. Croix and throughout the Caribbean. The second role is to house and transport a self-sufficient mobile support base that will allow offshore deployment in remote areas with few or no shore facilities. The third is to provide a "dry dock" facility able to lift the habitat and baseplate completely clear of the sea for periodic maintenance. This is the first time any habitat system has incorporated this important capability.

In its configuration as an MSB, the vessel will be equipped with all of the support equipment now located at the NURC-FDU operations base. Permanently installed apparatus includes main generators (2-100kw), high pressure air compressors (2-20cfm), a low pressure compressor (120cfm), a reverse osmosis desalination plant, and storage for fuel and breathing gases. In order to fully utilize the depth and personnel capabilities of the system, an 72-inch (large enough for six persons plus a tender) recompression chamber and a handling system for a Personnel Transfer Capsule (PTC) will be installed near the bow of the vessel. After the habitat is deployed, the LRT/MSB returns to the nearest convenient port with containerized freight handling equipment to pick up six trailer sized (40 feet x 12 feet) fiberglass modularized buildings which will span and cover the "moon pool" of the vessel. These buildings will contain the operations control room, field science laboratory, infirmary, shop, bunk rooms, galley, showers and marine toilets. Once these three buildings are loaded and "plugged-in" the vessel can be returned to an anchorage near the habitat and serve as the remote Mobile Support Base.

4. BASEPLATE

The baseplate is the foundation of the habitat and contains the ballast weight to hold the buoyant pressure hull on the bottom. The baseplate has adjustable legs which provide a means of levelling the habitat on an uneven sea floor. Hydraulic winches mounted on the baseplate are used to pull the buoyant habitat to the bottom in a controlled manner. The baseplate is a tubular framework measuring approximately 45 feet by 25 feet with four vertical tube legs and foot pads. Each of the vertical tube legs is ballasted with 21 tons of lead; it's length is adjustable by means of a hydraulically operated

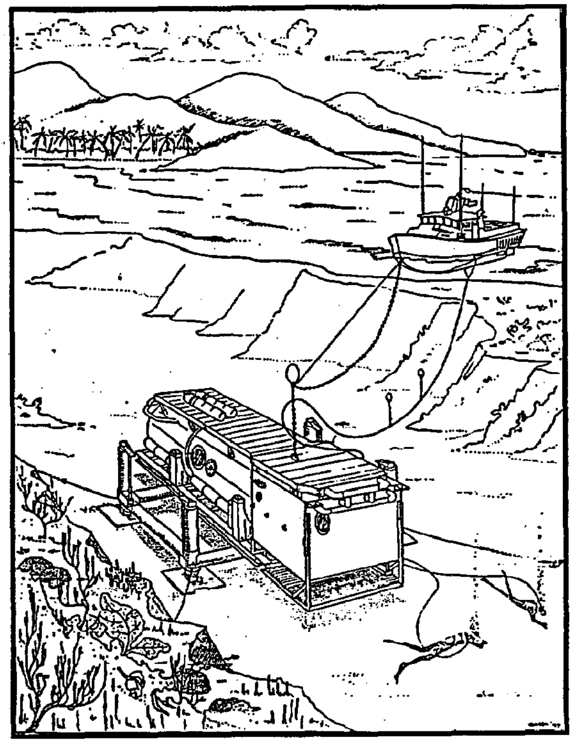

FIGURE 1. Habitat Operations in Salt River Canyon.

screw jack assembly. On the bottom the habitat is oriented perpendicular to the centerline of the baseplate and the lead filled legs act as "outriggers" to resist the overturning forces exerted by the sea on the large surface area of the side of the habitat. While on the LRT/MSB, the baseplate acts as the support platform for the habitat with the habitat parallel to the centerline of the baseplate.

5. OPERATIONS

Training and qualification of the habitat scientific team are conducted prior to the start of each research mission. Both in-water and classroom training sessions are held to familiarize the aquanauts with the operation of the habitat, modified diving equipment and safety procedures. Upon completion of required pre-dive checklists, the aquanauts SCUBA to the habitat. An onboard technician conducts the daily habitat checks, replenishes carbon dioxide absorbent, and performs any required maintenance. Life support parameters are monitored at the shore operations base with a data link and packet radio from the habitat and LSB.

The aquanauts routinely spend up to 9 hours a day working on their experiments on the seafloor. A video system allows monitoring of experiments and surface conditions. An onboard computer and data link are used to gather experimental data. After undersea experiments have been completed, decompression of the aquanauts must be conducted and is accomplished by slowly reducing the pressure inside the habitat to surface atmospheric pressure. When the aquanauts reach surface pressure, after approximately 20 hours of decompression, they exit the habitat and swim to the surface. The diving medical officer examines the aquanauts for signs of decompression sickness or other medical problems.[2]

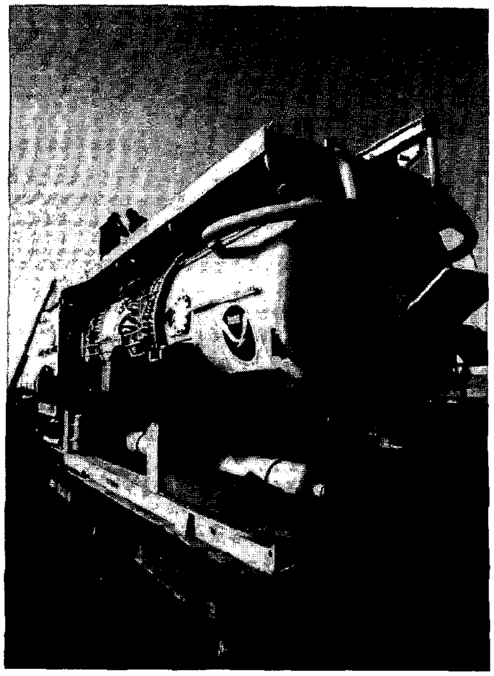

FIGURE 2. Modifications at St. Croix's Container Port.

FIGURE 3. Underwater Photo of AQUARIUS Habitat.

6. EQUIPMENT AND FACILITIES AVAILABLE THROUGH NURC-FDU

Other NURC-FDU equipment or facilities that may be used in conjunction with the AQUARIUS system are described below.

Remotely Operated Vehicles (ROV'S) - A Deep Sea Mini-Rover Mk. II is one ROV available for appropriate research projects. This vehicle has depth capabilities up to 1000 ft. (500 ft. nominal), a payload of 6-10 lbs., and is equipped with a low light level television camera with quartz halogen lights to provide real time observations to the user. Several packages of optimal capabilities such as articular arms, still cameras, etc. may be available to increase the flexibility of the Mini-Rover. A second tethered ROV available is the Deep Ocean Engineering Super Phantom. This vehicle is equipped with a one function manipulator, tube coring device, scoop and suction sampler. It has a color video with annotated depth, time and heading recorded on tape. There is a low light video, collimated light system for particulate/plankton assessment, and a 35 mm film camera. The program provides a trained technician for piloting the ROV. These vehicles may be used in conjunction with a saturation mission or may be used for a research project (in St. Croix or elsewhere in the Caribbean) that is independent of the saturation habitat.

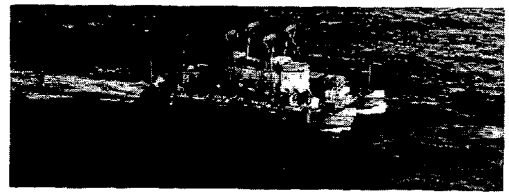

FIGURE 4. Habitat and Baseplate Aboard LRT Vessel.

Manned Submersibles - Several shallow and deepwater manned submersibles may be made available to support research projects requiring increased vertical flexibility. Studies requiring submersibles may be proposed for any location throughout the Caribbean; however support for submersible dives at a particular location will be more logistically feasible if several investigators propose to work collaboratively at particular locations. Such is indeed the case with the innovative, multi-investigator Beebe Project which will be based on St. Croix in 1989.

NURC-FDU Support Facilities - The shore support base is located on a peninsula in the middle of the Salt River Estuary, approximately 1,000 meters from the habitat site. The base has a bunk room and kitchen facilities for the nine research team personnel. During the saturation period, habitat operations personnel are also housed at the shore base.

Two recompression chambers capable of treating four and six divers respectively (as well as an attendant), a SCUBA charging station with associated high pressure air bank, and a small boat dock are located adjacent to the main base facility.

Medical facilities include an emergency room/clinic on-site. It is equipped for advanced cardiac life support and is prepared to meet treatment needs for diving and occupational emergencies.

A small laboratory, suitable for basic sample treatment and analysis is available at the Salt River shore support base. A NURC-FDU laboratory facility is also located at the West Indies Laboratory (WIL), where more sophisticated instrumentation can support complex sample analyses. The NURC-FDU science facility at WIL will also support pre- and post- mission research activities of funded investigators. This has become an increasingly important aspect of the research projects funded by NURC-FDU, as it allows time to refine techniques prior to a mission and/or extend the studies into shallow water habitats. This represents another aspect of the flexibility in approaches that are provided and supported by NURC-FDU.

7. RESEARCH

During 1987, a Caribbean-wide marine research program was designed that is being implemented in 1988 and beyond, to drive research supported by NURC-FDU. This program will provide modern oceanographic tools and support facilities to scientists conducting research within the areas of research concentration of the NURC-FDU program. The program will foster integrated, multidisciplinary studies on scientific questions of particular regional significance. It consists of a Core Research Program that provides a framework for the science conducted using the AQUARIUS mobile habitat system, remotely operated vehicles, submersibles, other research tools and efforts to develop instrumentation and techniques that will aid in the conduct of research supported by the program.

The major function of this program is to provide a scientific framework that focuses research projects supported by NURC-FDU in a multidisciplinary way on topics of particular interest. The topics that are the foci for research at NURC-FDU and which address NOAA's undersea mission objectives in the Caribbean Basin are.

Biological Productivity and Living Resources - larval recruitment processes and reproductive biology of coral reef fishes and invertebrates; identification of new fisheries species/stocks; primary and secondary production; food web studies; benthic/pelagic coupling.

Coastal, Oceanic, and Estuarine Processes - production and transport of carbonate sands; biological stabilization and disruption of the seafloor; benthic nutrient regeneration and its contribution to primary productivity; history of sea level changes and sea surface temperatures; role of groundwater and terrestrial runoff in tropical coastal environments.

Pathways and Fate of Materials in the Ocean- effects of pollutants, sediment loading, hurricanes, dredging, blasting, and eutrophication on coral reef ecosystems; processes of recovery.

Ocean Services - oxygen toxicity effects; biofouling and corrosion; assessment of biomedicinals in Caribbean biota;

physiological and psychological effects of hyperbaric conditions.

1988 saturation missions in the habitat have lasted as long as 14 days. Studies have included:

Primary Productivity and Nutrient Fluxes of the Benthic Microflora of Coral Reef Sediments,

Oxygen Dynamics and Anaerobic Metabolism in Sediments of Salt River Canyon,

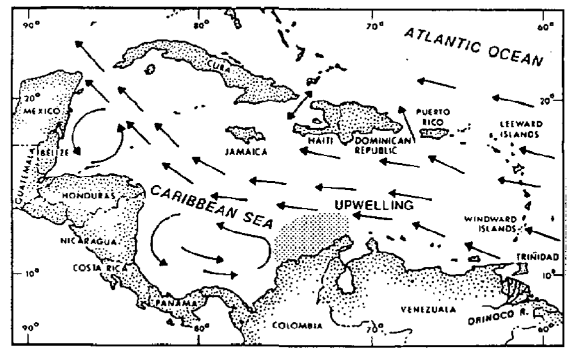

FIGURE 5. Map of Caribbean Region

The Energetics of Sediment Removal and Zooplankton Feeding in Caribbean Reef-Building Corals,

Patterns and Processes Structuring Tropical Algal Communities Along a Depth Gradient: The Dynamic Roles of Productivity and Herbivory Revisited,

Zooplankton Capture by Corals: The Effects of Water Movement Under Field Conditions,

and Field Measurement of Diffusional Boundary Layer and Turbulent Enhancement in Scleractinian Reef Corals.

Special Projects

Another aspect of the Core Research Program is a group of proposed research projects that may lie outside the designated areas of research concentration but that show promise in that they explore new directions in marine science and technology.

Studies supported in 1988 within this category are development of a reef/coral coring apparatus that could operate in a remote mode in order to retrieve reef or coral cores from depths beyond safe saturation diving limits. Earlier studies suggest that data obtained from a Caribbean-wide coring program could provide a more complete record of sea-level changes and reef growth (from reef cores) throughout the Holocene and with recently developed techniques, may even provide a detailed record of climatic changes for the past 100-200 years (from fluorescent banding patterns in coral cores). The initial portion of this project being conducted in 1988 will involve the development of the coring apparatus and determining the feasibility of applying the fluorescent techniques to detect freshwater run-off events that were developed in Australia, to Caribbean reef corals.

Another area of special interest is the effects of hyperbaric conditions on human physiology. Data gathered in conjunction with ongoing saturation missions will increase the understanding and limits of saturation diving.

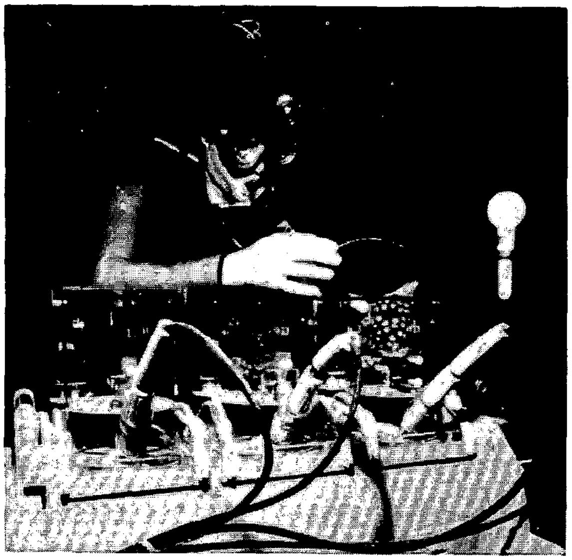

FIGURE 6. Aquanaut Testing Coral with Respirometer.

The optical properties of marine waters are very important in acquiring data obtained from photographic techniques whether they are in situ or remote (satellite). Exploring techniques by which images can be enhanced using optical technology or allow data to be retrieved from poor quality photographs which were compromised by conditions beyond the control of the scientist (e.g., low light, turbidity).

NURC-FDU Staff Research Projects

The third component of the Core Research Program consists of the research projects conducted by members of the NURC-FDU scientific staff or other related organizations. Currently this includes a project looking at the effects of herbivores on algal primary productivity and a preliminary project investigating gradients in marine productivity across the Caribbean.

Environmental Monitoring Program

NURC-FDU will expand the environmental monitoring program that was instituted in 1987 to provide supported investigators with an array of environmental information that relates to their research projects, and to build an archive of data that will be of use to future investigators designing new experiments. Presently, data is being collected routinely within Salt River Canyon on water temperature, photosynthetically active radiation at the surface, and at 10m and 20m depths, water current speed and direction, wave height, and conductivity. These data are relayed to the habitat for real-time use by investigators and are also relayed back to a shore base computer and stored on floppy disks. NURC-FDU is expanding the monitoring effort to include wind speed and direction, tide height, turbidity, concentrations of major nutrients (ammonium, nitrate + nitrite, and phosphate), and a description of the physical oceanography of Salt River Canyon and other nearshore areas around St. Croix.

Instrumentation and Technique Development

The technical expertise of NURC-FDU has often furthered the research projects of supported investigators. The development of a series of remote data acquisition systems to accompany the new habitat will not only monitor life support parameters within the habitat but is also designed to accept data from a variety of sensors to obtain routine oceanographic data or data from experiments setup by scientists. These systems will allow rapid data analysis, either in the habitat or at the shore base, and allow modifications in the experimental design where necessary.

Future Developments

The sites of future undersea research supported by NURC-FDU using the AQUARIUS system will be determined primarily by the nature of the scientific problems to be investigated, subject to safety and operational constraints. The portability of some oceanographic tools (e.g., ROV's, submersibles, and oceanographic vessels) will ensure that important scientific questions can be addressed in a wide variety of Caribbean environments. The mobility of the AQUARIUS system will also allow the in-depth study of processes over a wide geographic range in the Caribbean.

Use of the available oceanographic systems provides NURC-FDU-supported scientists with horizontal mobility and flexibility. In addition, the combination of surface-supplied diving, saturation diving, and the use of ROV's and submersibles to be offered by the program in the future will also provide vertical mobility. These tools will give scientists the capability to address unique aspects of different habitat types over both geographical and depth ranges, but more importantly to address the coupling between systems and processes from shallow water habitats to the deep sea.

8. RELOCATION

The decision to move to any site will be driven by scientific research needs and opportunities . Operational and support needs can be adapted accordingly within the framework of safety which is paramount from both a scientific and an operational viewpoint. Evaluations of the recent deployment suggest that six months is the minimum amount of time required to safely make a transition from missions at one site to missions at another. Because of this anticipated down time and the needs of scientists for follow up studies, the cost of relocating, the potential for damage to equipment, and other factors, it is not cost or safety effective to move on an annual basis. NURC-FDU will interact extensively with local scientists and engineers and contribute to the local island economies while operating at future remote sites. NURC-FDU will emphasize safety and scientific needs as the overriding factors governing the future locations of the AQUARIUS system and the timing of relocation.

9. COMMUNITY INTERACTION

Operations associated with the AQUARIUS Mobile Saturation System and the proliferation of NOAA sponsored scientific and technical research have focused considerable

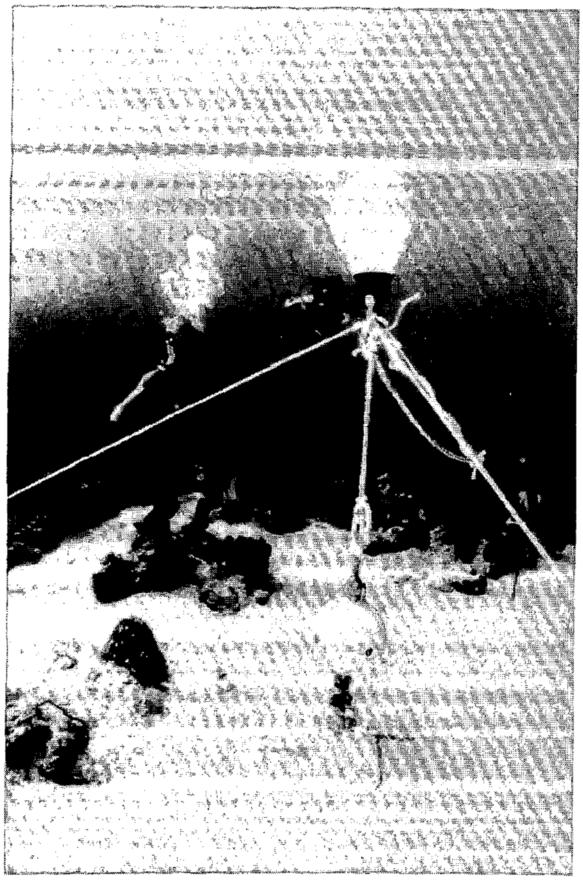

FIGURE 7. Researchers Inspecting Current Meter.

attention on Fairleigh Dickinson University and St. Croix. Visitors to the operations base have ranged from elementary school classes to government officials. The habitat has become a popular stop for sport divers, and tourists often write or call for literature and pictures. In its six months of operation the AQUARIUS System has generated extensive media coverage. Stories about the habitat and associated undersea research have appeared in print media and on television locally, nationally, and internationally. NOAA's Undersea Research Center in St. Croix has been featured on the Cable News Network's weekly Science and Technology report as well as ABC's *Good Morning America*. Film crews have come to St. Croix from as far away as Japan and Australia.

Community outreach has extended far beyond public relations. Education has been a primary focus. Local students have had tours, lectures, and multi-media presentations. Several student interns have worked in NURC-FDU's Operations and Administrative divisions. Graduate students are actively involved in research in cooperation with mission principal investigators and special project researchers. Funding is to be made available for independent student research projects in 1989. NURC-FDU staff have been actively engaged in career counseling, particularly in the areas of marine science, ocean engineering, and diving.

NURC-FDU has been a major proponent of the fusion of science and technology. The design and operation of the habitat and its components as well as the development of research techniques and tools has necessitated and will continually demand close cooperation among scientists, engineers, technicians, and administrators at every level. Now that the system has proven functional and reliable, NURC-FDU will aggressively pursue multidisciplinary and multi- investigator studies in situ and in the laboratory. FDU has fostered cooperative projects with other universities and institutions such as a current human factors study being conducted in St. Croix by the National Aeronautics and Space Administration (NASA). Diving physiology can be studied uniquely in the rare field environment of the habitat.

10. SUMMARY

The Caribbean region is of vital importance to America economically, socially, and militarily. It is a region which supports rich ecosystems with unique flora, fauna, and natural phenomena. The island nations of the Caribbean are depleting resources available to them from the ocean. Moreover, they often lack the financial resources and scientific expertise necessary to support in situ research. By providing a mobile saturation habitat system and other research tools NOAA can insure that its research objectives are met while contributing to the well-being of the region. In short, state-of-the-art tools, outstanding researchers, and a commitment to safety and excellence have made NOAA's representative, Fairleigh Dickinson University, an ambassador of science, technology, and goodwill in the Caribbean region.

11. REFERENCES

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MANNED SUBMERSIBLES SUPPORT A WIDE RANGE OF UNDERWATER RESEARCH IN NEW ENGLAND AND THE GREAT LAKES

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ABSTRACT

NOAA's National Undersea Research Center at the University of Connecticut at Avery Point (NURC-UCAP) has experienced a meteoric rate of growth since its inception in 1984. Chartered submersibles (manned) support the majority of the underwater research conducted by NURC-UCAP scientists in the Gulf of Maine, southern New England, and in the U.S. Great Lakes. The investigations addressed a wide range of applied and basic research topics. For example, assessments were made of: the impact of "ghost gill nets" on ground fish populations, studies of deep sea scallops, the phenomenon of bioerosion on the ocean and lake floors, the nature and role of the "fluff" and "nepheloid" layers in recycling nutrients and pollutants, water column ecology, the environmental factors governing benthic productivity, and calibration and groundtruthing of conventional surface-oriented sampling gear. Much of the research conducted with manned submersibles has evolved to quantitative, replicated,and site specific experiments. Sophisticated sampling, sensing, photographic and manipulative techniques have been developed to address a wide range of scientific requirements. The "ideal" shallow water (0 - 1000 meter) manned submersibles for the 1990's and beyond and their associated scientific capabilities are defined, based on 18 years of submersible experience (approximately 1150 dives in the northeast and Great Lakes) and an assessment of scientific requirements for the northeast and "Large Lakes of the World".

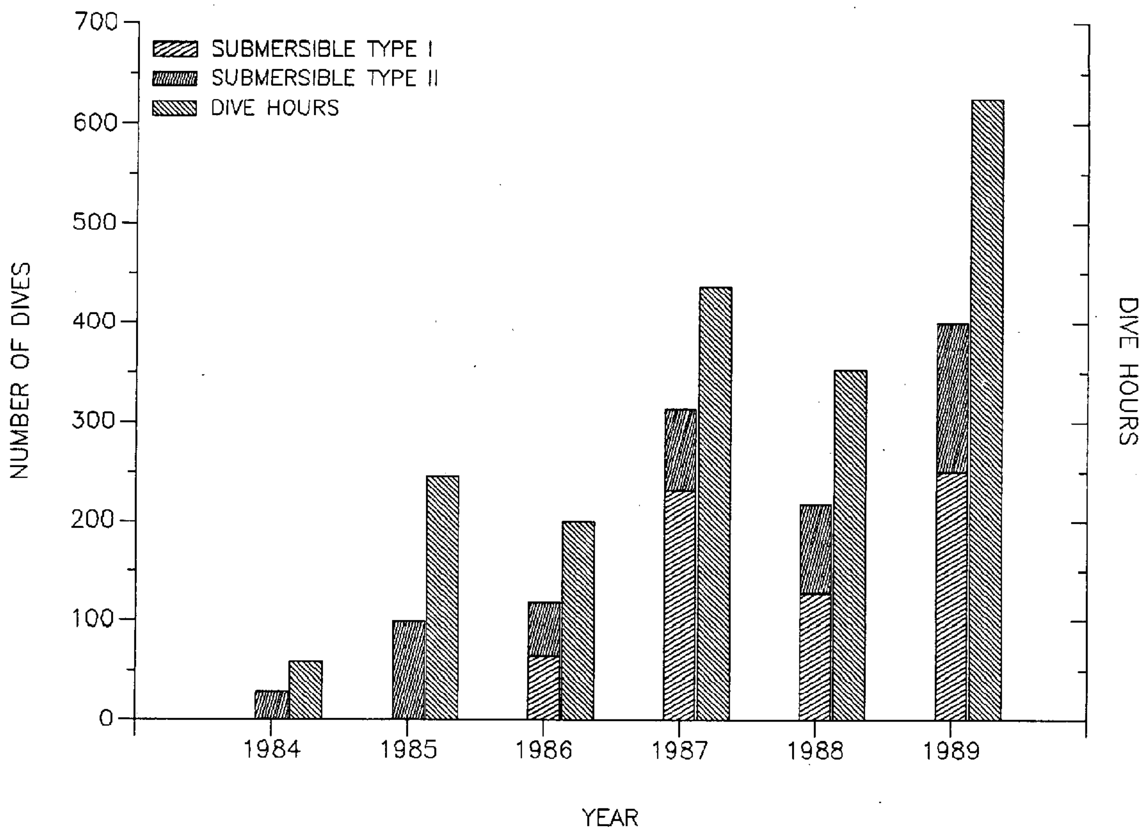
INTRODUCTION

The National Oceanic and Atmospheric Administration (NOAA) supports underwater research through several National Undersea Research Centers (NURCs) that conduct manned and unmanned research missions. The NURC at the University of Connecticut at Avery Point (NURC-UCAP) fulfills this mandate by leasing manned systems, and operating/leasing remotely operated vehicles (ROVs). By leasing submersibles, NURC-UCAP retains maximum flexibility in terms of matching the research support capabilities of various dive systems to the specific requirements of the scientist.

The science program at the NURC-UCAP has experienced a meteoric growth rate since its inception in 1984. The number of submersible dives, participants, and affiliations associated with NURC-UCAP has witnessed a ten-fold increase in just 4 years (Figure 1). Typically, NURC-UCAP leases two classes of submersible: 1) Type I - a two-person, low payload, highly maneuverable, moderate sampling capacity reconnaissance sub (e.g. Marfab Inc.'s Delta), and 2) Type II - a three to four-person, high payload, highly sophisticated sampling capacity sub (e.g. Harbor Branch Oceanographic Institution's Johnson Sea Link I and II and International Underwater Contractor's Mermaid). The first class of sub usually dives for about one hour and averages 6-7 dives per day, while the latter remains submerged for 2-3 hours for two dives a day. Therefore, the absolute number of dives can be misleading, unless one compares the actual bottom time of a submersible dive (Figure 1). Beginning in 1986 the focus of research was divided every other year between the Great Lakes and the New England area, which reduces the number of dives during the Great Lakes years for two reasons, 1) the amount of transit time required, and 2) the type sub used was the type II exclusively. Both classes have direct application to NURC-UCAP depending upon scientific need, and these along with ROVs and scuba comprise the diving methodologies utilized to conduct fine scale, in situ

FIGURE 1.

NURC-UCAP SUPPORTED MANNED SUBMERSIBLE DIVES, 1984-1989*



* - 1989 figures are projections based on geographic area of focus and type of research to be supported.

sampling and manipulative experiments that are the hallmark of the entire National Undersea Research Program. Occasionally an ROV is teamed with a manned sub for maximum efficiency of the dive systems in use.

Not only has the quantity of dives increased dramatically over the past five years, but the quality of dives in terms of scientific productivity has been enhanced significantly as well. This rise in productivity is the result of three major factors: 1) trial and error based on 18 years of submersible experience, 2) increased investigator familiarity with the sensing, sampling, and manipulative capabilities of submersibles, and 3) a concomittant enhancement in the design of sampling devices as NURC-UCAP personnel, submersible contractors and ocean engineers respond to the increasing demands of the submersible scientist. This greater sophistication in sampling capabilities has allowed for the establishment of site-specific, long-term experiments that address process-oriented questions. Submersible-based research has made the leap from pure observation of natural history and biota-habitat pattern definition (although this initial phase of the scientific method is still an important component of NURC-supported research) to an experimental, manipulative, process-oriented level of investigation. In situ investigation using deep diving techniques has become a credible, multidisciplinary aspect of oceanography and limnology.

SUPERSITES

As more researchers realize the capabilities of manned submersibles to conduct in situ investigations they have unified their research efforts. This coordinated effort is more efficient scientifically and operationally. Given the high cost to lease manned submersibles, and the multidisciplinary nature of many investigations, a single research cruise that can collect information useful in testing several hypotheses by "piggybacking" investigations is economically sound and scientifically more productive.

Furthermore, many physiographic areas lend themselves to this unified and cooperative approach and groups of investigators are presently identifying these areas as "supersites" that can be revisited seasonally and annually by teams of investigators. This concept allows for quantification of environmental parameters (water temperature, salinity, transmissivity, current, etc), species population dynamics (abundance, distribution, recruitment), sediment dynamics (deposition rates, particle sizes, resuspension) and other time-series processes (predator/prey interactions, bioerosion, benthic productivity, benthic-pelagic coupling). By collecting biological, chemical, and physical data a supersite can be a natural laboratory to quantify environmental change caused by pollution. The location of supersites in ecologically sensitive habitats therefore becomes an important component of this concept.

RESEARCH THEMES

The National Undersea Research Program has outlined six principle research themes that meet NOAA's mandate for underwater research. These include: 1) biological productivity and marine resources, 2) coastal oceanic, estuarine, and lacustrine processes, 3) pathways, fates, and effects of materials in the oceans and Great Lakes, 4) ocean lithosphere and mineral resources, 5) global oceanic processes, and 6) ocean services.

Within these themes, NURC-UCAP has identified specific, regionally defined research needs including: 1) biological, geological, and technical research to improve living resource assessment for fisheries conservation and management, 2) studies to understand population, ecosystem response to stress, natural and man-made, 3) research to understand the factors responsible for high benthic productivity in the Gulf of Maine, 4) studies of the geological and sedimentary features on the ocean floor and Great Lakes bottom and processes that shape these environments, and 5) to provide ocean services assistance to state, federal and academic teaching and research institutions. Within this latter category, NURC-UCAP includes its recently initiated "High School Aquanaut" program - an activity to introduce the underwater world and the field of aquatic sciences to young adults as potential diver scientists and/or future decision-makers regarding environmental or resource issues.

A "Large Lakes of The World" initiative began in 1987 in cooperation with seven African nations and Israel. This study is directed towards comparing bio-geochemical systems of the ancient "Rift Valley" Lakes with the infant U.S. Great Lakes. Manned submersibles will play a major role in this activity in the immediate future.

MANNED SUBMERSIBLE RESEARCH MILESTONES

There are several research projects that have been particularly successful in fulfilling these research needs and taking advantage of manned submersibles as either their primary research tool, or as a complement to other methodologies. Among these are research on benthic-pelagic coupling, in the Gulf of Maine and Great Lakes, sediment dynamics in the Gulf of Maine, and benthic productivity on hard substrates in the Gulf of Maine, and benthic productivity on hard substrates in the Gulf of Maine.

<u>Benthic/Pelagic Coupling</u>

The mid-water environment makes up more than 98% of the habitable volume of the earth. Little is known of the composition and habits of the fauna, the fine-scale processes that occur there, or the nature of the interactions between pelagic and benthic zones. Many NURC-UCAP investigators have adopted an ecosystem-based research approach that has allowed them to begin to map the energetics of these interactions. The flow of energy within these ecosystems approximates the following pathway.

o - Organic carbon enters the food web via primary production by phytoplantkon. A large portion settles directly to the benthos as phytodetritus.

o - Another large portion of this production is consumed by herbivorous zooplankton, and later settles as fecal material.

o - Some quantity of the primary production is broken down by bacteria to reenter the water column in a reusable nutrient form.

o - The organic matter is transformed and aggregates in various hydrographically defined compartments, e.g. subsurface particle maximum layers or the benthic nephloid layer (BNL).

o - In temporate zone waters, a major fraction of organic matter input to the sediments occurs through the BNL as a result of settling of the spring bloom (due to inadequate zooplankton grazing) before warming and subsequent stratification takes place. The BNL is often tens of meters thick, with a thinner (up to several cm thick), flocculant portion, called the "fluff" layer often visible at the sediment-water interface.

o - Due to this flocculant consistency and biochemically labile nature of the material, it has never been properly sampled using surface based methodologies. For the past three years, NURC-UCAP research has focused on developing the technology for precisely sampling the fluff and nepheloid layers of the seabed and lake floor from a submersible. The approach has been 1) to deploy a flume which would resuspend and filter the material and 2) to pump large volumes of water from a precisely positioned suction device through filters on the submersible. Both techniques have proven to be highly successful.

o - In addition to the obvious role this material plays in energy transfer, it also is the medium for transporting and sequestering organic pollutants, inorganic heavy metals, and nutrients. The dispersal potential of this material makes it an extremely important target for understanding its potential in pollutant mobilization in the environment. The fluff and nepheloid layers in the Great Lakes are hypothesized to function as a cleansing zone for these contaminants.

o - Megabenthic fauna play a major role in the resuspension and horizontal distribution of particulates within the fluff layer through bioerosion. Considerable research is being directed toward this phenomenon as it relates to benthic-pelagic coupling.

o - Future proposals will address the the role of mobile fishing gear in resuspension and transport of nutrients and pollutants in the marine environment.

Sediment Dynamics in the Gulf of Maine

NURC-UCAP has sponsored several geological investigations that have utilized submersibles for in situ video recording, mapping, fine scale sampling and precise placement of instruments (e.g. sediment traps, sediment profile cameras, current meters) to "ground truth" and verify recently generated synoptic data (e.g. seismic, side-scan and high frequency reflections charts). Major geological environments (rocky ledge, sand nearshore ramp and deposition basins) have been described from direct observation and the patterns of transition zones determined. Site specific inspection has provided detailed reconnaissance of; rock outcrops, seabed feature orientation, sand-wave field crests, ripple and scour zones, basin furrows, and pock marks. Sedimentary stratigraphy has also been addressed from the sediment water/interface to depths of 20-30 cm and related to biogenic effects on sediment fabric and heterogeneity of surficial sediment features.

As part of the overall ecosystem of the Gulf of Maine, sediment dynamics is a critical area of study. Surficial sediments are an important part of the benthic habitat, controlling distribution and abundance of organisms to a large degree, and are intimately involved in the food web through transport pathways, substrates for microorganisms, and through storage and recycling of nutrients within the bottom. Besides nutrients, sedimentary particles also transport, store and recycle pollutants, affecting the benthos in less beneficial ways.

A prime area of current research is the source, transport pathways, and sinks of sedimentary particles. Part of that study is the present distribution of sediment types and the geologic record of past distributions. The redistribution of sediments by slumps, tidal currents, and wave aciton occurs at least seasonally, and probably at a more frequent rate on most ridges and shoals. The rate at which this material is carried to deeper basins has important consequences to benthic communities. On hard bottoms, being swept clear of sediments has a distinct advantage. On muddy bottoms, input of new sediments is advantageous up to a certain rate, since new food is made available. When sediment smothers the bottom to a critical depth, however, macroinvertebrates will be killed, and nutrients will be buried too deeply for excavation. The rate of sediment accumulation and the episodicity of processes thus requires quantification.

o - Three major nearshore

environments have been identified in the Gulf of Maine: rocky ledge, sandy nearshore ramp, and basin. Rocky ledges are swept clear of sediments, but often have a talus pile of angular rocks at their base. Next to the talus pile are carbonate shell hash-rich gravel aprons, grading into basinal muds or sand. Sandy ramps are reworked paleodeltas or beach shoreface deposits. Sand waves and oscillation megaripples provide evidence for current and wave activity on these surfaces. Basins are usually the sites of former estuaries, produced at the early Holocene low sea stand, and are muddy and abundantly bioturbated

o - Not all the sediment found within the system is mineral particles; a fecal pellets composed of plankton which have passed through the gut of larger organisms, or films and coatings of mucus and bacteria. The composition and methods of breakdown and utilization of this material at the base of the food web are critical issues for the overall productivity of the Gulf of Maine. Buried organic-rich sediment has produced natural gas accumulations visible in seismic reflection profiles and possibly as seeps in pockmarks on the seafloor. These phenomena are important clues to location and nature of past nearshore and estuarine environments.

<u>Benthic Productivity on Hard Substrates - Gulf of Maine</u>

Hard substrates comprise a major portion of benthic habitats in the Gulf of Maine. Understanding the environmental conditions that govern productivity in this habitat type is critical to wise management of the environment and its living resources. NURC-UCAP is sponsoring several investigations dealing with benthic productivity at a submerged bedrock pinnacle (Ammen Rock) in the central Gulf of Maine. Ammen Rock is a "Supersite" study location.

o - The benthic algal community on Ammen Rock is one of the deepest reported in the north Atlantic. It exists without any macro-herbivores and the shallower zone is dominated by a previously undescribed kelp species.

o - Recruitment and competition of sessile invertebrates with macrobenthic algae contributes to their (algae) depth distribution. Recruitment at the spore, gametophyte and early sporophyte stage is being examined.

o - The question, does the lower limit of an algae (the extinction depth) correspond to the lowest depth at which net photosynthesis can be achieved, or are other factors, such as recruitment or competition with sessile invertebrates important, is being investigated through time series, site-specific, manipulative experiments.

o - Mechanisms contributing to the lack of herbivores on Ammen Rock were examined. These experiments indicate that the offshore megabenthic communities are heavily influenced by fish predators which remove most of the mobile benthic invertebrates, normally the top predators in coastal regions.

o - The composition, structure and dynamics of benthic invertebrate communities from inshore, coastal, and offshore rock pinnacles are being compared, producing quantitative definitions of community structure.

o - Estimates of growth rates, recruitment, mortality, and abundance of sessile benthos to depths of 60 m have been made yielding estimates of secondary production. Various processes affecting invertebrate abundance and distribution have been identified, i.e. - sponge mortality and nudibranch predation on anemones are the major processes opening up space for settlement of other organisms in the highly space-limited hard substrate community. Recolonization experiments are an integral part of this research.

o - Time lapse photography has demonstrated that fish predation has a much greater impact on the invertebrate population offshore than inshore. Also fish predation rates on invertebrate prey are several times greater at shallower depths.

o - These above experiments are yielding information for the definition of a benthic food web.

MANNED SUBMERSIBLE SAMPLING TOOLS

In-situ research requires the design and development of special samppling devices that can function from or be deployed by submersible or ROV. A major objective of NURC-UCAP is to conceive, engineer, test and evaluate unique tools, requested via scientific proposals, and make them available within our inventory (or on lease) to the marine research community. Several modifications to conventional gear have been made in collaboration with contractors and principal investigators, as NURC-funded innovative prototype projects. The following is a list of tools currently being utilized by NURC-supported researchers with the organization responsible for its development in parentheses.

Parallel laser scaler - for image calibration and size measurement (Harbor Branch Oceanogrpahic Institution (HBOI), NURC-UCAP).

Suction sampling - for collection of soft-bodied organisms and plankton. (HBOI).

Nepheloid fluff layer sampling system - for collection of the fluff layer (HBOI, NURC-UCAP).

Fluff layer flume nozzel - for high resolution sampling fluff layer (University of Maine).

Independent nepheloid fluff sampler - for smaller submersible and diver deployment (University of Maine).

Plankton & epibenthic net - for depth specific manipulator controlled quantitative zooplankton samples (HBOI, NURC-UCAP).

Cores and quivers - for box and punch core collection and retrieval (HBOI, NURC-UCAP).

Bioturbation rates - measured by glass bead spreaders, rare earth element blocks (NURC-UCAP).

Video Sediment Profile Camera - for real time data on vertical profile of sediment/water interface (30 cm) - for strategic core sampling and gradient detection (University of Wisconsin).

FOVAR camera - for event recording via light beam actuated bathypelagic 35 mm camera and strobe (HBOI, NURC-UCAP).

Electroshocker/Suction Sampler - manipulator mounted, variable voltage-pulse rate anode-cathod bar or probe for selective sampling of lamprey & sculpin in fresh water (HBOI, NURC-UCAP).

Interstitial water sampler -manipulator control of micro pipette for descrete habitat water quality determinations (lake trout spawning sites) (NURC-UCAP).

Transmissometer mounts - for near bottom gradient changes in suspended particulate load (HBOI).

Cameras lights and mounts - for special applications (HBOI, NURC-UCAP).

Hasselblad camera frame - for in situ photographs of fouling panel and algal colonization plates (HBOI).

OPTIMAL RESEARCH SUBMERSIBLE

Due to the variety of tasks defined by the various scientific disciplines, no one manned submersible dive system will effectively serve the needs of all diver scientists in NURC-UCAP's program. These needs and the range of operating conditions dictate two distinct dive systems, 1) Type I -a relatively small, light weight reconnaissance vehicle that can operate from a number of support vessels and be trucked/flown readily from coast to coast or country to country and, 2) the Type II - a relatively large vehicle that can carry an array of sensing and sampling systems and store a large number of samples per dive. Specifically, the following features characterize these optimal research submersibles:

Light Weight Reconnaissance Sub

1. Weight not to exceed 3-4 tons.
2. Depth capability to 500 meters, highly maneuverable.
3. Two/three person capacity.
4. Viewing distance from observer to ocean/lake bottom not to exceed 1 meter.
5. Capable of averaging 6 dives per 12 hr. work day to depths of 200 meters, average "bottom time" of 1.0 to 1.5 hrs.
6. Capable of independent movement in 1.0 knot water currents for minimum of 2 hrs.
7. "Robotic" arm with 5/6 degrees freedom.
8. Sample payload of 100 pounds.
9. Sample receptacle capacity to hold three punch cores or two box cores and three distinct animal containers.
10. Sample suction and retainer capability for sampling water column or bottom animals/sediments.
11. Ports/hemisphere positioned for effective 3/4", 1/2", or 8 mm video (hand held) documentation, as well as 35 mm photographs.
12. Submersible format conducive to externally mount a 35 mm camera and strobe and/or video for sharp down angle documentation.
13. Launch and recovery in seas up to 2 m wave height (short period), launch and recovery amidships most effective.
14. Total system (submersible and support vessel cost not to exceed $7-8,000 per day.

Medium Sized Sampling Sub

1. Weight not to exceed 10-12 tons.
2. Depth capability to 1000 meters, good maneuverability.
3. Minimum three person capacity (one pilot, two observers).
4. Viewing distance from observer to ocean/lake bottom not to exceed 1.5 meters.
5. Capable of averaging 2 dives per 12 hr. work day to depths of 1000 meters, average "bottom time" of 2.0 to 3.0 hrs.
6. Capable of independent movement in 1.0 knot currents for minimum of 2 hrs and the ability to "hover" in midwater for extended periods of time.
7. Robotic arm with 6/7 degrees freedom.
8. Sample payload of 300 pounds.
9. Sample receptacle capacity to hold 12 punch cores, 3 box cores, a lazy susan or 12 bin receptacle for storing separate samples (scallops, rocks, etc). Submersible can also be rigged for extensive water column sampling using externally mounted still and video cameras and suction sampling into separate receptacles (12 or more).
10. Submersible must have sufficient external framing/work bars/work platform as to mount very specialized equipment such as an electroshocker suction sampler for collecting mobile fauna.
11. Ports/hemisphere positioned for effective observation of benthos and water column.
12. Submersible format conducive to mount externally forward portion of sub two 3/4', 1/2", or 8 mm video cameras and required lighting and two 35 mm cameras and strobes.
13. Launch and recovery in seas up to 2 m wave height (short period), standard operating procedure. Launch and recovery restricted to stern of support vessel.
14. Submersible should have adequate through-hull connectors and should carry environmental parameter data loggers (minimum transmissometer and CTD) to augment sampling capability.
15. Total system (submersible and support vessel) cost not to exceed $10-11,000 per day.

Of upmost importance, observer viewing, comfort, and manipulative (external robotic arm) capabilities must be maximized. Eye-mind manipulation/sampling coordination is critical to the effective support of underwater research.

CONCLUSIONS

The development of manned submersible support for science has rapidly evolved in the past 5 years, not only in New England and the Great Lakes, but in other regions of the country that are supported by the National Undersea Research Program. The quantity and quality of dives will continue to increase, particularly as sampling equipment and submersible design simultaneously become more sophisticated. The demands of the research community will continue to drive the development of the ideal research submersibles.

FIELD RESEARCH PROGRAMS AT THE CARIBBEAN MARINE RESEARCH CENTER NATIONAL UNDERSEA RESEARCH PROGRAM

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ABSTRACT

Marine science programs of the Caribbean Marine Research Center (CMRC) include studies on recruitment, ecology and population dynamics of Queen conch, spawning and recruitment of grouper and other important resource species, surveys of deepwater fish stocks and marine geological processes.

All of these programs utilize to some degree undersea techniques requiring the use of various subsea platforms and vehicles. Research facilities operated by the Center and headquartered at Lee Stocking Island, Exuma Cays, Bahamas, include the research vessels J.W. Powell and Undersea Hunter (85 ft and 156 feet, respectively), the PC-1401 submersible, a shallow-water habitat and a remote operating vehicle.

Several remote and environmentally controlled experimental laboratories are operated by CMRC in both the Bahamas and Florida.

1. INTRODUCTION

The Caribbean Marine Research Center (CMRC), funded by the National Undersea Research Program of NOAA and the Perry Foundation Inc., conducts research aimed at problems of natural resources and marine food production for Caribbean regions including the Bahamas, southeast United States and the Gulf of Mexico.

The general goals of the Center are (1) to provide facilities and support for scientific research on the marine environment, (2) to develop technology for low-cost aquatic food production in the Caribbean and similiar locations around the world, (3) to study physical and ecological relationships on deep, shallow-reef and other benthic environments of the Caribbean, (4) to develop the scientific bases for rational habitat utilization through conservation and enhancement, (5) to define ecological requirements of important species residing in the coastal areas of Florida, the Bahamas and other Caribbean nations, and (6) to provide a field laboratory for educational programs in all of the marine sciences geared toward graduate and undergraduate curricula, and technical training in aquatic food production.

Much of the research is carried out close to the Center's field laboratory at Lee Stocking Island, Exuma Cays, Bahamas, located on the eastern rim of the Exuma chain 110 miles south of Nassau. This location provides easy access to pristine marine environments, including shallow reefs, ooid shoals, mangrove swamps, grass beds, deep water and other habitats.

Lee Stocking Island has a variety of facilities to support the research effort, including housing for permanent scientific and support staff, accomodations for small groups of visiting scientists and students, an experimental hatchery for rearing selected aquaculture species, lab space/computers, experimental and production tanks, boats, 3000-ft airstrip, dock, dive equipment, decompression chamber, workshops, dining hall and an unlimited supply of uncontaminated seawater required for research projects. Additional experimental facilities have been recently extended to the Florida State University Marine Laboratory on the Gulf of Mexico, sixty miles from Tallahassee, FLorida.

Vessels with high seas capabilities include the Undersea Hunter, an 85-foot dive and submersible support ship, and the J.W. Powell, a 156-foot ship acquired from the U.S. Geological Survey as part of a cooperative program between the USGS and CMRC. The latter ship, originally a seismic vessel, has been refitted to perform various fisheries and oceanographic projects and as a platform for research submersible support. The J.W. Powell works with other NURP centers, particularly the University of Connecticut and the University of North Carolina-Wilmington under a cost-covering lease basis. CMRC also operates the PC-1401, a submersible with a 1000-ft depth capability, the Shark Hunter wet submersible, a small self-contained habitat and a Phantom-300 ROV.

Major field research programs of the Center fall under three major categories: 1) benthic resource ecology, 2) fish resource ecology and 3) marine geology. All of these research activities incorporate scuba diving and/or deep submersible systems to varying degrees. Over 700 dives employing SCUBA were logged in 1987, with the anticipated 1988 total exceeding 1500 dives. Approximately 150 submersible dives ranging from 100 to 2300 feet in the Delta and Deep Rover submersibles have also been logged over the past three years.

2. RESEARCH PROGRAMS

Benthic Resource Ecology

Benthic research at CMRC is presently focusing on the Queen conch, *Strombus gigas*, one of the most important food species of the Caribbean region. This species has been heavily fished throughout the Caribbean and is commercially threatened in some areas.

The general goal of this research is to study mechanisms of Queen conch distribution, reproduction and abundance through experimental field studies that can be ultimately applied to sound management practices. Particular emphasis is being placed on mechanisms and processes ranging from larval ecology to reproductive biology and biogeography.

A large population of reproductively active adult *S. gigas* were found by divers on the eastern side of Lee Stocking Island in Exuma Sound. This population is beyond the depth of traditional commercial exploitation techniques (15-25m). Utilizing SCUBA and, on occasion, a wet submersible (Shark Hunter) and a tow scooter for surveys, investigations in 1987 showed that virtually all individuals were adults with densities as high as 3.0/100m2. While initial tagging efforts showed that the population was mobile, they were, nevertheless, resident to the area. In July 1988 over 20 percent of this population were seen to be reproductively active. The abundance and distribution of individuals and egg masses are in the process of being quantified, with special emphasis being placed on potential relationships between animal density and egg production. Concurrently, larval ecology studies, including plankton tows and laboratory rearing of conch veligers through metamorphosis, have been conducted to determine larval dispersal, nutrition, recruitment and settlement of which there is presently little information. Egg masses are collected by divers in the field directly from spawning females. Productivity of the spawners and larval recruitment are compared to determine survivability in the field.

Recently, the successful rearing of juvenile conch to metamorphosis has provided clues to the length of the pelagic stages of the larvae and settlement in response to environmental stimuli. Additionally, the effect of food supply, both from natural seawater and from artificial feeding, is being examined in the laboratory.

During the spring of 1987, diver-scientists discovered a massive aggregation of juvenile conch in shallow water exceeding 250 individuals per square meter. This aggregation, totalling approximately 130,000 conch, was the result of a synchronous emergence from the sediment and has provided valuable clues to the distribution of the 0+ yearclass for which little information exists.

Distribution of conch populations and habitat are now being studied using images taken from the Landsat 4 and 5 satellites. Their ability to penetrate the clear waters of the Bahamas makes the imagery potentially suitable for benthic habitat identification with proper groundtruthing techniques. Seagrass species density and biomass will be matched to conch distribution.

Fish Resource Ecology

This program is concentrating on the Nassau grouper, *Epinephelus striatus*, among the most important fish in the Caribbean. Fishing pressure has significantly depleted this species in most countries, particularly the island nations of the Caribbean. Despite its popularity as a foodfish, the biology of the Nassau and other groupers is not well understood and has, therefore, impeded progress toward their rational stock management.

One important aspect of this research is to examine ontogenetic changes that occur in habitat requirements of *E. striatus*. Young fish first appear in a habitat characterized by shallow (<2m) _Thallassia_ seagrass beds and vacant conch shells, as well as debris such as old tires, buckets and the like, during March of each year. The smallest juvenile grouper found during this time of year average under 25mm. By the fall these fish have grown to 75 and 100mm and have changed their habitat requirements, moving toward the Island characterized by coral, small holes and adjacent seagrass beds. Coral heads or small caves in the bottom are also used as this second juvenile grouper habitat and a monitoring study of these fish show them to remain at least one year.

The study of reproductive aggregations of the Nassau grouper is the key to understanding the complicated life history of the species. During January 1988 diver-scientists discovered a spawning aggregation of Nassau grouper off the southern tip of Long Island, Bahamas. Thousands of adult grouper gathered in a small area at a depth of between 60 and 100 feet allowing the researchers to study population numbers and individual sizes, social behavior, sex ratio and reproductive state of the fish. The discovery and initial study of this aggregation, which appears to occur each year, will be the focus of a major fisheries-oceanographic project during the fall and winter of 1988-89. Eggs and larvae of Nassau grouper will be followed by the R/Vs _J.W. Powell_ and _Undersea Hunter_ using current drogues tracked by satellite from their point source to their settling habitat concurrently with ichthyoplankton collections. Early development of larval _E. striatus_ will also be studied in the laboratory to determine growth, feeding, survivability and identification soon after spawning.

Marine Geology

The unique marine geological features of the lower Exuma Cays have provided a rich opportunity for a marine geology program at CMRC.

In 1984 large fields of giant lithofied subtidal columnar stromatolites were discovered off Lee Stocking Island. These stromatolites grow in 5 to 8 meters of water in a current-swept tidal channel that is flushed with both open-ocean water and bank-top water each six-hour tidal period. Current velocities during peak flow periods reach 100 cm/sec and set the entire sediment bottom (sand-sized ooid-dominated) in suspension. This environment is not typical of what has been previously thought to promote stromatolite development.

The Bahamian subtidal stromatolites provide a new set of environmental parameters for interpreting spatial distribution, orientation, water depth, salinity constraints on growth forms and the timing of cementation and mineralization of ancient stromatolites. Unusual carbonate mud beds are also found in the inter-island channels of the Exuma Cays associated with large submarine sand dunes migrating across flood tidal deltas and bars. The strong currents that sweep in and out of the four-to-eight-meter deep channels three hours out of every six are not usually associated with mud deposition. These will be the subject of major study during the next year.

3. ADDITIONAL STUDIES

Deepwater Surveys

Several deepwater surveys which have incorporated the submersibles _Delta_, _Deep Rover_ and _PC-1401_ are being conducted by CMRC. Large deposits of sediment in the Exuma Sound were discovered in depths of 900 to 2300 feet. Origins of the sediment are unknown although high production and low accumulation of sediments on the bank suggest that the deepwater deposits are carried off the shallow bank by offshore tidal currents.

Other projects include the collection of rocks to study boring organisms in deep water and population surveys of deepsea fish, particularly the Queen snapper.

Coral Reef Bleaching

During the late summer and fall of 1987 unprecedented levels of zooxanthellae loss resulted in bleaching and some mortalities in stony corals and other reef cnidaria and sponges throughout the Caribbean, Bahamas and southern Florida waters. Zooxanthellae, an endosymbiotic algae, is lost when the coral host organism is stressed. Scientists examining bleaching in the Exumas using SCUBA and the submersible _Delta_ discovered a high proportion of bleaching at 10-55 m, but none deeper. Warmer-than-usual water, which was prevalent in the region during the summer, is thought to be responsible for this occurrence, but further study is required to ascertain the causative agent.

Caribbean Temperature Studies

Efforts to assign a cause to the coral bleaching phenomenon and the possible role of temperature in this and other biological processes were impeded by the fact that there are virtually no longterm data sets on temperature available for the Caribbean and adjacent regions. In response to this lack of information, CMRC has initiated a Caribbean-wide temperature study. Subsurface recording thermographs have been placed in 20-m depth in five locations around the Bahamas, south Florida and the Caribbean, including the Turks and Caicos, Puerto Rico, St. John (V.I.), Barbados, Martinique, Belize, Tobago, Jamaica and Columbia. Temperatures will be measured every two hours over the next five years. The aim of this research will be to analyze the possible longterm effects of temperature changes on coral reef ecosystems, including important resource species, and trends in the Caribbean that may be indicators of global temperature changes.

Artificial Reef Surveys

Studies to determine the effectiveness of artificial reefs in shallow and deep water off southern Florida were conducted in September of 1987 from the J.W. Powell and submersible Delta. The reefs were constructed mainly of old ship hulls ranging in depths from 30-120 m. Temperature ranged from 30 C at 43 m to 10.6 C at 120 m. Surveys showed that the most effective reefs were limited to depths less than 45 m . In general, those below 45 m were devoid of most tropical reef species. The deeper wrecks were all below the thermocline, indicating that temperature is the limiting parameter to reef success in this area.

Aquaculture

While aquaculture research is one of the major programs at CMRC, it falls outside the scope of the conference, and therefore will be only briefly mentioned here.

Since July 1984 CMRC has undertaken a program to identify potential candidate species for mariculture development. Presently, research is aimed at developing technology for marine culture of tilapia (a euryhaline, freshwater finfish group) as an inexpensive source of animal protein for Caribbean islands and similar regions where freshwater resources are limited. Although not indigenous to the Caribbean, tilapia were identified as a finfish group encompassing most of the important criteria established by CMRC, including seawater adaptability and tolerance, acceptance as food fish, ease of breeding and rearing, ability to utilize a variety of inexpensive feeds of both plant and animal origin, and adaptability of culture methods to less developed regions.

The Florida red tilapia hybrid Oreochromis ureolepis hornorum (female) X O. mossambicus (male) was selected from initial studies suggesting that it was suitable for marine culture. Subsequent studies focused on seawater tolerance and growth of this hybrid. Suitability for high density culture in seawater cages has become an important part of the program which is aimed at farming in coastal waters of the Caribbean.

4. SUMMARY

The Caribbean Marine Research Center will continue to develop new and innovative research programs to meet the problems of marine ecology, resource management and food production throughout the Caribbean and southern U.S. tropical and subtropical environments. Future projects will emphasize field research using undersea techniques, including saturation diving from a habitat, increased submersible use and new ROV systems.

OIL AND GAS INDUSTRY CONFLICTS ON THE OUTER CONTINENTAL SHELF

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ABSTRACT

Conflicts between the fisheries industry and oil and gas exploration and production activities have occurred in all regions of the OCS. The primary, and most persistent, suggestions of conflict have been claims of fixed fishing gear damage resulting from geological and geophysical exploration activities and mobile fishing gear damage from bottom debris in oil and gas exploration and production areas. Other potential conflicts are ascribed to competition for docking space and spatial exclusion of fisheries from fishing grounds. Additional conflicts result from the perceived risk to fishing livelihoods, which many fishermen attribute to the potential that an oil spill may occur during oil and gas industry activities. Since 1973, MMS has provided funding for over $111 million of biological research studies, many of which are directly applicable for identifying, assessing, and mitigating potential conflicts between the oil and gas and fishing industries. The MMS continues to strive to minimize OCS conflicts between oil and gas industry activities and fisheries by using the information obtained from environmental studies to develop deferral alternatives, stipulations on leases, and Information to Lessees and Notices to Lessees communications.

Hello and welcome to the Oceans '88 sessions on potential multiple-use conflicts on the Outer Continental Shelf. My name is Bob Middleton and I represent the Offshore Environmental Assessment Division of Minerals Management Service (MMS). Dr. Mark Holliday and I will be cochairing these two sessions.

The primary focus of this topic is to review and evaluate the potential for conflicts between the two primary industries on the OCS; fisheries and oil and gas.

We have, as our speakers, four representatives from each of the agencies -- the National Marine Fisheries Service and the Minerals Management Service. These agencies are responsible for the overall management of the natural resources of these two industries. We are going to assume a geographic format for presenting the information on potential multiple-use conflicts on the U.S. OCS, starting in the Northeast portion of the country and proceeding to the southeast, Gulf of Mexico, Pacific, and Alaska.

The speakers from the National Marine Fisheries Service will provide an overview of the various fishery activities and methods used around the Nation and present areas of potential conflict with other OCS activities. The Minerals Management Service speakers will follow and identify oil and gas industry activities that may conflict with fisheries industry activities and specifically address environmental studies that have been initiated to assess potential effects resulting from multiple interests in resources of the OCS. After these presentations, Ms. Alana Knaster of the Mediation Institute will speak on conflict resolution efforts to minimize or mitigate potential multiple-use disputes between the fisheries and oil and gas industries.

At this time, I will present a general overview of the potential concerns that have been raised concerning the coexistence of the two industries. Basically, the potential conflicts between oil and gas and fisheries industry activities can be roughly divided into three major categories. These are: (1) space-use conflicts, (2) gear-damage conflicts, and (3) resource-damage conflicts.

Space-use conflicts may occur onshore as well as offshore. In areas of high oil and gas industry exploration and/or development activities, competition for dockage space, repair facilities, and general maintenance facilities may occur in onshore areas. Even if space at these facilities is available, the increased competition may result in a concomitant increase in cost for their use. Although this has a net positive effect on the facilities, it has a negative effect on the fisheries industry. Space competition onshore, however, is typically minor in most regions and hard to distinguish. By far, the primary space-use concern of the fisheries industry is the potential exclusion of fishermen from specific fishery areas, which the fishery industry contends separates them from their product. The placement of offshore structures by the oil and gas industry may exclude fishermen from the immediate vicinity of the structure. Typically, it is calculated that a bottom-founded structure will require approximately 0.8 square miles and that a floating structure such as a semisubmersible will require about 1.8 square miles because of the anchoring system that extends out from the rig (Centaur, 1981). These areal estimates represent the space that an oil and gas structure may physically occupy. However, with particular mobile fishery techniques such as trawling, the area precluded by a structure may be greater. This is a result of the necessary buffer zone that the fisherman must allow for either setting or retrieving the fishing gear. But, it should be pointed out that semisubmersibles are mostly used in water depths of over 200 meters and are not usually in direct conflict with the majority of trawl fisheries.

Additional concerns have been raised over other types of mobile fisheries, which include surface longlines and drift gillnets. In both of these fisheries, the fisherman will set the gear and have no direct control of the movement of the gear until it is recovered, which may be 8 to 12 hours or more. If we assume that the current is moving at a modest 0.5 kts, a 12-hour drift will move the gear approximately 6 nautical miles. The gill nets are typically of lengths of about 1600 m (1 mile) or more. However, with the advent of strong, single-strand monofilament, some of the surface longlines on the shelf break of the East Coast have lengths as long as 64,000 m (40 miles). These surface longlines are used to fish for swordfish and tuna off the northeast coast of the United States. Because of the extent of these free-moving types of fishing gear, fishing efforts may be excluded from larger areas up-current of OCS structures.

Spatial competition, however, is not restricted to just occurring between industries. Recently, because of the very high prices received for prime tuna, there has been an increase in interest in the longline fishery for tuna off the northeastern coast of the United States. Consequently, It has been reported that there are severe spatial conflicts among the fishermen for setting their longline gear in the northeast tuna fishery areas because of diverse techniques for setting the longlines and, presumably, from the length of line that is set (National Fisherman, 1988).

By far, the most easily identifiable conflict between the fisheries and oil and gas industries is gear damage. Typically, gear damage can be separated into two categories. The first occurs when a fisherman towing mobile gear, such as a trawl, hangs the gear on bottom obstructions such as anchors, pipelines, structures, or debris. The second category is damage to fixed gear such as crab or lobster pots, or to free moving gear, such as drift gill nets or longlines. The second category of damage is typically attributed to seismic survey vessels or supply vessel traffic. The seismic vessels are towing sound-producing and sound-recording equipment behind the vessel for analyzing the geologic formations under the sea bed. If this equipment is towed through a fishing gear set, it could snag and move or damage the fishing equipment. Although all seismic survey locations and dates are required to be announced in advance in the Notice to Mariners and/or other information sources available to fishermen, some damage occurs or may be attributed to seismic surveys, occasionally. To offset any confirmed damage, amendments to the Outer Continental Shelf Lands Act establishing a Fishermen's Contingency Fund were passed. This fund may contain up to $1,000,000 for reasonable compensation to fishermen who suffer gear damage and economic loss.

Resource-damage concerns are the most difficult to assess. It is assumed that some damage to local populations of sessile or minimally motile species may occur in proximity to a well site. This would include mortality resulting from setting a platform on the bottom or anchoring a semisubmersible and from smothering benthic organisms by discharging drill muds and cuttings, which settle to the bottom. However, these mortalities are extremely localized and not estimated to cause any long-term damage to species abundance and distribution. The National Academy of Science (NAS, 1983) completed a thorough review of the available literature on the effects of drilling muds and cuttings discharge into the marine environment. They concluded that there was no evidence that these discharges would cause either acute or chronic long-term effects.

Until now, I have been discussing the potential effects on the fishery industry that may result from various actions. However, the most difficult aspect of determining the conflicts between oil and gas and fisheries industries involves the potential effects that may be caused by the occurrence of an oil spill. Oil spills, of course, are events that everyone is attempting to prevent. Therefore, oil spills which may occur are accidental in nature and the potential risk assessment is estimated using probability theory. However, if an oil spill does occur in an offshore area, we can anticipate two events: (1) surface fishing gear such as marker buoys, longlines, and gillnets and any fishing vessels that move into the area are likely to be fouled, and (2) fishing vessels will be excluded from the area in which the oil spill occurs. Additional concerns have been raised over other potential effects that may be manifested by an oil spill. The first is tainting of the flesh of fish harvested near areas in which an oil spill occurred. Uptake of petroleum hydrocarbons by harvested species could give the flesh of the organism a "kerosene" flavor, which would eliminate or minimize the marketability of the product. In some cases it may be possible to affect the perception of the "freshness" of the fish even if actual tainting does not occur. This would, of course, affect the economic viability of the specific fishery. It has been demonstrated by various researchers that most organisms metabolize or purge hydrocarbons in a short time (NAS, 1985). However, the stigma of tainted products may remain for an appreciably longer period of time.

The second concern is the potential effect on fishery population levels from egg and larval mortality resulting from oil spills. Many of the commercially important species have eggs and larvae that spend part, if not all, of their life history stage in the upper water column areas. Prediction of the potential effects of offshore oil spills is strictly subjective. The magnitude of impact on the resource would be determined by the exact combination of biological, physical, and chemical factors at the time at which the spill occurs. However, the high variability of year class recruitment to the fish populations adds further complications to the evaluation of potential effects of oil spills on fish resources. Although it is widely accepted that the earlier life stages of fish species are most susceptible to the toxic effects of petroleum hydrocarbons, it is difficult -- if not impossible -- to determine what effect on the total population the loss of a specified number of eggs and larvae would have for a given species. It is anticipated that any effects that may be manifested, assuming an equal toxicity response, would be qualified by a number of factors including: (1) correspondence of the spill with spawning season and area, (2) percentage of the spawning area affected by the spill, (3) duration of contact of the spill with the early-life stages of the species, and (4) any ecological factors that affect the survivability of the other early-life-history-stage individuals. Although it may be possible to calculate estimates of the potential effects of the first three factors based upon fundamental assumptions and probability equations, incorporation of the fourth factor adds an indeterminate component to the analysis. Considering that over 99.9 percent of all eggs and larvae do not survive to become recruited into the population, it is questionable that the loss of some early-life-stage individuals to an acute environmental event such as an oil spill could be determined to have an effect on population level.

In this paper, I have provided an overview of the potential conflicts between the fisheries and oil and gas industries. The authors that follow will specifically discuss the fisheries of each of the regions and Minerals Management Service's role in assessing and mitigating conflicts between the two industries. Since 1973, the Minerals Management Service has provided approximately $111 million for various scientific research studies to evaluate the potential effects of oil and gas industry activities on fisheries. This represents a substantial effort on the part of MMS to accurately and competently evaluate the potential conflicts between the two industries and to identify reasonable mitigation techniques when they are needed. Although some conflicts are inevitable when two or more affiliations are competing for use of a finite resource -- in this case the OCS -- it is also possible to minimize any disputes by factual evaluation of the events causing the conflicts and exchanging information among the concerned parties. Hopefully, this session will augment ongoing efforts to mitigate fishery and oil and gas industry controversies.

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OUTER CONTINENTAL SHELF FISHERY RESOURCES OF THE SOUTH ATLANTIC

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ABSTRACT

Natural limestone outcroppings and artificial reefs provide much of the productive fishery habitat of the South Atlantic Outer Continental Shelf (OCS). Only 19 percent of the total South Atlantic commercial landings in 1987 came from the OCS, but they accounted for 37 percent, or $55.3 million, of the value. The six major commercial fisheries in the South Atlantic OCS are shrimp, offshore reef fishes, coastal pelagics, oceanic pelagics, calico scallops and the North Carolina winter trawl fishery. The recreational catch of finfish from the South Atlantic OCS in 1987 was 8.0 million fish, or 13 percent of the South Atlantic total. Bottom fishing and trolling are the preferred OCS recreational fishing methods. OCS activities have the potential for major impacts on South Atlantic fishery resources.

INTRODUCTION

This paper provides descriptive information on the fishery habitat, commercial fisheries and recreational fisheries of the Outer Continental Shelf (OCS) of the South Atlantic. It is intended to serve as background for further discussion of potential impacts of OCS oil and gas activities.

The fishery statistics presented in this paper cover the Exclusive Economic Zone (EEZ), the area of ocean between 3 and 200 nautical miles from shore. Although these statistics include fisheries inshore of the OCS, they are the best available data. Commercial fishery data were collected through the Southeast State/Federal Cooperative Statistics Program and recreational data were collected through the Marine Recreational Fishery Statistics Survey (MRFSS). All data presented are preliminary from the Fisheries Statistics Division of the National Marine Fisheries Service (NMFS), Washington, DC. Final fishery statistics are published in Fisheries Statistics of the United States[1] and other NMFS Current Fishery Statistics publications[2].

FISHERY HABITAT

The coasts of North Carolina, South Carolina, Georgia and east Florida form a large bight of the Atlantic Ocean called the South Atlantic Bight. The outer boundary of the Continental Shelf in the South Atlantic Bight, as demarked by the 100-fathom depth contour, is approximately 80 miles from shore throughout much of the region from southern North Carolina to northeast Florida. The shelf break moves inshore in the northern and southern portions of the bight to within 25 miles from shore off Cape Hatteras, North Carolina to within five miles from shore off Palm Beach, Florida[3]. The Gulf Stream generally tracks the shelf break and is very important in the distribution of eggs and larvae of OCS finfish and shellfish.

The ocean bottom in the South Atlantic Bight is primarily sand with little relief. However, natural "live bottom" areas of limestone outcroppings are scattered throughout the OCS area at varying distances from shore. These outcroppings provide substrates for attachment by soft and hard corals, sponges, and other invertebrates. An example of a live bottom area is Gray's Reef National Marine Sanctuary, a 17 square mile area 16 nautical miles offshore of Sapelo Island, Georgia. The National Oceanic and Atmospheric Administration (NOAA) is responsible for managing the sanctuary, including the issuing of fishery regulations to protect its unique fishery resources.

All four South Atlantic coastal states have been very active in artificial reef development and maintenance programs over the last 15 years. Artificial reefs provide opportunities for productive fishing not otherwise available along much of the coast. For example, South Carolina currently maintains 20 offshore artificial reefs. MRFSS intercept data from the last six months of 1987 show that 35 percent of the charter boat and private boat ocean fishing trips in South Carolina were associated with artificial reefs[4].

Many South Atlantic artificial reefs have recently been designated as Special Management Zones through the provisions of the Snapper/Grouper Fishery Management Plan (FMP) of the South Atlantic Fishery Management Council (SAFMC). This designation allows the placement of special restrictions on fishing activities on the reefs. On a broader scale, the Council is responsible for managing all South Atlantic fishery resources between 3 and 200 miles from shore through the FMP process.

COMMERCIAL FISHERY RESOURCES

Commercial landings of finfish and shellfish in the South Atlantic region in 1987 represented 3 percent of the nation's total. In 1987, 235.1 million pounds of finfish and shellfish were landed in the four South Atlantic states, compared to almost 7 billion pounds nationwide[5]. The value of the 1987 South Atlantic catch was $150.4 million. Although only 19 percent of the total 1987 South Atlantic commercial landings came from the EEZ, they accounted for 37 percent, or $55.3 million, of the value. Over 50 percent of east Florida commercial landings were from the EEZ.

South Atlantic EEZ commercial fisheries can be grouped into six major types. Fisheries that occur throughout the entire region are shrimp trawling, handlining for offshore reef fishes, gillnetting and trolling for coastal pelagics, and surface longlining for oceanic pelagics. Two other more localized fisheries are a calico scallop fishery off the east Florida coast and a winter trawl fishery for coastal ground fish off northeast North Carolina.

Shrimp

The shrimp fishery is the bread and butter fishery of the South Atlantic region, accounting for the greatest value of all fisheries. In 1987 the harvest of shrimp in the South Atlantic region was 22.9 million pounds valued at $46.4 million. The South Atlantic shrimp fleet in 1985 was comprised of approximately 1,500 vessels and 1,500 boats and employed 6,000 full and part-time fishermen.

Most of the South Atlantic shrimp harvest is from state territorial waters inside three miles from shore, eg., 72 percent in 1987. However, the EEZ landings of 6.3 million pounds valued at $11.1 million in 1987 represented 14 percent of the volume and 20 percent of the value of the total South Atlantic EEZ catch. East Florida and Georgia combined to produce 97 percent of the South Atlantic EEZ shrimp catch.

The EEZ shrimp fishery is a trawl fishery targetting primarily on shrimp of the Penaeidae family. Species represented in commercial quantities are white shrimp, _Penaeus setiferus_, brown shrimp, _P. aztecus_, and pink shrimp, _P. duorarum_. These species utilize estuaries as nursery areas, so they migrate inshore-offshore as well as along the South Atlantic coast. White and brown shrimp overwinter in deeper EEZ waters off northeast Florida.

Rock shrimp, _Sicyonia_ spp., and royal red shrimp, _Hymenopenaeus robustus_, are also targetted during certain times of the year. These are deepwater species also caught by trawling. There are no federal regulations on shrimping in the South Atlantic EEZ except for the requirement for nets to have trawling efficiency devices (TED's) to reduce bycatch of threatened and endangered sea turtles.

Offshore Reef Fishes

South Atlantic offshore reef fishes targetted commercially include groupers, _Epinephelus_ spp. and _Mycteroperca_ spp.; snappers, Lutjanidae family; porgies, Sparidae family; tilefish, _Lopholatilus chamaeleonticeps_; and black sea bass, _Centropristis striatus_. Important grouper species are gag, _Mycteroperca microlepis_, scamp, _M. phenax_, red grouper, _Epinephelus morio_, and snowy grouper, _E. niveatus_. Red snapper, _Lutjanus campechanus_, and vermilion snapper, _Rhomboplites aurorubens_ are the most common snapper species. Important porgy species are whitebone porgy, _Calamus leucosteus_, and red porgy, _Pagrus pagrus_,

Commercial landings of offshore reef fishes in the South Atlantic EEZ in 1987 were 4.5 million pounds valued at $7.2 million. North Carolina and South Carolina combined landings represented 74 percent of this harvest. Natural live bottom areas and artificial underwater obstructions produce the greatest catches.

The majority of the offshore reef fish catch is taken by snapper reels. These are electric or manual reels mounted on the boat's transom that contain line and baited hooks. Bottom longlines are used to fish for deepwater species at the shelf break like tilefish and snowy grouper. In southeastern North Carolina, black sea bass are caught in fish pots. Roller-rigged trawls are used to catch vermilion snapper, black sea bass and other smaller reef fishes, but the SAFMC is currently amending the Snapper/Grouper FMP to prohibit the use of trawls in this fishery between Cape Hatteras and Cape Canaveral.

Coastal Pelagics

Major coastal pelagic species targetted by South Atlantic commercial fishermen include bluefish, Pomatomus saltatrix, king mackerel, Scomberomorus cavalla, and spanish mackerel, S. maculatus. South Atlantic EEZ landings of these three species in 1987 totalled 6.1 million pounds valued at $4.2 million. North Carolina and east Florida accounted for 97 percent of the landings. Bluefish and king mackerel were important species in North Carolina, while king and spanish mackerel were important species in east Florida. Seventy-eight percent of the nation's king mackerel landings were from the South Atlantic.

Several gear types are employed in South Atlantic EEZ coastal pelagics fisheries. Gill nets set around schools of fish near the water surface account for a large portion of the catch. Trolling is also an important method of catching coastal pelagics species.

Coastal pelagics species are migratory so their availability to the commercial fishery is quite seasonal. Markets for bluefish are often flooded by high volumes of landings within a short period of time. A bluefish FMP is currently under development. The Coastal Migratory Pelagics FMP includes commercial and recreational quotas for king and spanish mackerels that have triggered closures of these fisheries in the South Atlantic in recent years.

Oceanic Pelagics

A diverse group of oceanic pelagic fishes is caught by commercial fishermen in the South Atlantic region. Swordfish, Xiphias gladius, is probably the most sought species since it commands such a high price. The South Atlantic fishery for yellowfin tuna, Thunnus albacares, has expanded in the last five years, with 1987 landings up over 500 percent since 1983. Other important tunas include blackfin, T. atlanticus, bigeye, T. obesus, and bluefin T. thynnus. Sharks like shortfin mako, Isurus oxyrinchus, and spinner shark, Carcharhinus brevipinna, are also caught in this fishery.

South Atlantic oceanic pelagics landings were 4.0 million pounds valued at $8.0 million in 1987. East Florida accounted for 72 percent of the total landings and over 80 percent of the landings of swordfish and sharks in the South Atlantic region.

The principal gear used in the oceanic pelagics commercial fishery is the surface longline. This gear has a mainline on the surface from which baited hooks are suspended at varying depths to several hundred feet. Mainlines may have over 1000 hooks and stretch over 50 miles.

A swordfish FMP exists and a shark FMP is under consideration. Tunas are considered highly migratory species that are not managed through the Councils but through the International Commission for the Conservation of Atlantic Tunas (ICCAT).

Calico Scallops

The principal fishing grounds for the calico scallop, Argopecten gibbus, are in the EEZ off Cape Canaveral, Florida. Landings of calico scallops in Florida in 1987 were 8.2 million pounds valued at $8.9 million. These landings represent the total U.S. production for this species. No federal regulations exist for this fishery.

Calico scallop fishermen use heavy trawls fished at bottom depths from 10 to 75 meters. Many vessels in the calico scallop fishery were originally built for shrimp trawling. The ease of conversion between fisheries is important since scallop abundance varies considerably from year to year. South Atlantic calico scallop landings have varied from 1.6 to 39.1 million pounds in the last five years. A North Carolina calico scallop fishery important in the early 1970's is no longer in exixtence.

North Carolina Winter Trawl Fishery

From November to March, there is commercial trawling directed toward coastal ground fishes in the inshore portions of the EEZ off North Carolina. Targetted species include weakfish, Cynoscion regalis, summer flounder, Paralichthys dentatus, and Atlantic croaker, Micropogonias undulatus. The EEZ landings of these three species in 1987 were 9.3 million pounds valued at $6.5 million. This important fishery accounts for 75 percent of the U.S. EEZ landings of weakfish and 66 percent of the U.S. EEZ landings of Atlantic croaker. A summer flounder FMP for EEZ waters is currently under development.

RECREATIONAL FISHERY RESOURCES

Marine recreational fishermen caught an estimated 61.0 million finfish in the South Atlantic region in 1987. This represented 16 percent of the nation's total estimated marine recreational catch of 383.1 million fish in 1987. Since forty percent of the

South Atlantic catch was released alive, the remaining 36.7 million fish represented fish removed from the system. They weighed an estimated 49.3 million pounds.

Over 4.0 million marine recreational fishermen were estimated in the South Atlantic region in 1987. These anglers made an estimated 20.9 million trips, or 28 percent of the nation's total marine recreational fishing trips. Retail sales associated with marine recreational fishing in the South Atlantic was estimated at $2.0 billion in 1985[6]. The number of participants and retail sales in South Atlantic OCS recreational fisheries is not known, but the estimated number of fishing trips was 2.5 million in 1987. This represents 28 percent of the South Atlantic boat fishing trips.

The recreational catch of finfish from the South Atlantic EEZ in 1987 was estimated at 8.0 million fish, or 13 percent of the South Atlantic total catch. Disregarding fish released alive, an estimated 4.9 million fish weighing 21.9 million pounds were removed from the South Atlantic EEZ by recreational anglers in 1987. EEZ harvest by weight was 44 percent of the total 1987 South Atlantic harvest. Recreational harvest of shellfish in the South Atlantic EEZ is insignificant.

Modes of fishing in the South Atlantic EEZ are party boats, charter boats and private boats. Party boats, or head boats, provide fishing space and privileges to individuals for a fee. These are large boats that can carry from 10 to over 100 anglers. In the South Atlantic they do bottom fishing exclusively. Charter boats are hired by a pre-formed group of individuals for a fishing trip. They usually carry six or fewer passengers and go trolling, but may bottom fish on occasion. Private boats belong to individuals and may go bottom fishing or trolling.

Most recreational fisheries in the South Atlantic EEZ can be characterized by the two major fishing methods - bottom fishing and trolling. Bottom fishing with natural baits while either anchored or drifting is the typical method of fishing for offshore reef fishes and inshore bottom fish. Trolling with artificial lures or natural baits is the preferred method of fishing for coastal and offshore pelagic fishes. Other methods that are used occasionally include casting artificial lures and fishing natural baits near the water surface.

Bottom Fishing

An estimated catch of 1.8 million black sea bass dominated the South Atlantic EEZ bottom fish recreational harvest in 1987. Other major offshore reef fishes and their estimated 1987 South Atlantic EEZ recreational catches in number were: grunts, Haemulidae family, 918 thousand; snappers, 886 thousand; groupers 378 thousand; and porgies, 124 thousand. The majority of these catches were associated with natural live bottom areas or artificial underwater obstructions.

Inshore EEZ bottom fish recreational catches were dominated by members of the drum, Sciaenidae, family including Atlantic croaker, spot, *Leiostomus xanthurus*, and spotted seatrout, *Cynoscion nebulosus*.

Trolling

The 1987 South Atlantic EEZ recreational troll fishery was dominated by an estimated catch of 955 thousand dolphin, *Coryphaena hippurus*. Other common pelagic fishes and their estimated numbers caught by recreational trolling in 1987 were: king mackerel, 388 thousand; little tunny, *Euthynnus alletteratus*, 310 thousand; spanish mackerel, 297 thousand; bluefish, 258 thousand; great barracuda, *Sphyraena barracuda*, 185 thousand; blue runner, *Caranx crysos*, 103 thousand; and greater amberjack, *Seriola dummerili*, 77 thousand.

Billfishes are highly prized by offshore recreational anglers fishing the blue waters outside the shelf break. Species targetted are sailfish, *Istiophorus platypterus*, blue marlin, *Makaira nigricans*, white marlin, *Tetrapturus albidus*, and longbill spearfish, *T. pfluegeri*. A billfish FMP is currently under development. Blue water anglers also catch wahoo, *Acanthocybium solanderi*, and tunas including skipjack, *Euthynnus pelamis*, albacore, *Thunnus alalunga*, yellowfin, blackfin and bluefin.

Fishing tournaments are popular in South Atlantic OCS waters. King mackerel is the favorite target species, but there are also numerous tournaments targetting billfishes, sharks, and other offshore species. The top prizes in tournaments are typically several thousand dollars or new boats, so the competition is keen. Recreational fishermen may bring their boats long distances to participate in tournaments in neighboring states.

Other Surface Fishing

Recreational fishing for sharks in the South Atlantic EEZ typically involves chumming to attract fish to an anchored boat. Lines with baited hooks are set out at varying depths near the boat. The estimated 1987 South Atlantic EEZ catch of sharks was 91 thousand fish. Blacktip shark, Carcharhinus limbatus, was the most commonly caught species.

There are other surface fishing methods used in certain circumstances for certain species. Bluefish, spanish mackerel and other species are sometimes caught by casting lures while the fish are actively feeding at the surface. Fishermen sight cast to species like cobia, Rachycentron canadum, that are attracted to buoys and dolphin that are found along weedlines. King mackerel can be caught on live baits fished near the water surface.

POTENTIAL IMPACTS OF OCS ACTIVITIES

Certainly one of the events associated with South Atlantic OCS activities with the greatest potential to impact fishery resources would be a major oil spill. The magnitude of its impact would depend heavily upon its location and time of year. For example, a major oil spill off the northeast Florida coast in early spring could potentially affect the entire South Atlantic population of white and brown shrimp. This is when newly hatched larvae occur high in the water column and begin their inshore recruitment to estuarine nursery areas further north.

A major oil spill in the vicinity of a productive area of natural live bottom or an artificial reef would certainly curtail commercial and recreational fishing activities in the short term and may damage the long term health of fish populations associated with the reef.

Evidence from the Gulf of Mexico suggests that the installation of oil and gas platforms would create new fishing opportunities, particularly for recreational fisheries. MRFSS data from the Louisiana OCS show that up to 70 percent of all recreational fishing trips took place within 200 yards of a structure. However, there may be negative impacts with commercial fisheries such as displacement from traditional fishing grounds and gear loss due to oil and gas related structures and debris.

There is the potential that increased marine traffic due to OCS activity will cause difficulties in fishing operations or loss of fixed gear like gillnets and longlines. Another potential impact is the destruction of live bottom areas or scallop beds through activities associated with mining or laying pipeline.

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The Outer Continental Shelf Fishery Resources Of The Pacific Coast

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Abstract

The fish and shellfish resources of the Pacific coast are very diverse. The major commercial fisheries are for groundfish, salmon, scombrids, crabs, and shrimp. Recreational fishing with 47.5 million fish caught also constitutes a substantial harvest. In addition to fisheries, marine sanctuaries and marine mammal interaction must be taken into account when discussing the impact of Outer Continental Shelf (OCS) development.

Introduction

The fish and shellfish resources in the ocean waters adjacent to the Pacific coast states of Alaska, Washington, Oregon, and California are very diverse. The numerous fisheries associated with this diversity range from the two-person crew of a salmon troller to the large catcher-processor vessels employing over 100 crewmen to land and process-at-sea the abundant Alaska pollock stock. An attempt to delineate the fisheries of inshore waters versus outer continental shelf fisheries would be misleading. The migratory patterns of the fish and shellfish stocks as well as the species interaction recognize no boundaries.

With approximately 59 thousand fishermen utilizing 25 thousand vessels employing gears such as gillnets, longlines, pots and traps, trawls, and purse seines, landings for 1987 along the Pacific coast states amounted to 2.5 billion pounds worth an exvessel value of 1.4 billion dollars. When compared to total U.S. landings of 6.9 billion pounds valued at 3.1 billion dollars, the Pacific states represent 36 percent of the volume and 45 percent of the value. In addition to direct landings, two other forms of commercial activity must be recognized. Joint venture fishing in which U.S. vessels catch the fish and then transfer to a foreign vessel accounted for an additional 3.5 billion pounds worth 212 million dollars. Although on the decline, direct fishing by vessels from China, Poland, South Korea, and Japan contributed a catch of 263 million pounds valued at 60 million dollars. Thus the commercial fisheries of the Pacific coast in it's entirety is approximately 6.3 billion pounds valued at 1.7 billion dollars.

Needless to say that with most natural resources comes regulations, either federal, state or in the case of fisheries international. We now know that fish and shellfish stocks are not limitless as once perceived. To enhance or preserve the optimal sustainable yield of specific fisheries, managers employ a number of methods. Some of these are: size restrictions on the fish or shellfish, gear restrictions, quotas, seasons, and limited entry to a fishery. On the federal side is the Magnuson Fishery Conservation and Management Act that provides for the conservation and management of all fishery resources within the U.S. Exclusive Economic Zone (EEZ) except highly migratory tuna. The EEZ extends from three nautical miles to 200 nautical miles from shore. The Act also provides for fishery management authority over continental shelf resources and anadromous species beyond the EEZ, except when they are found within a foreign nations recognized territorial sea or fishery conservation zone. At the close of 1987, seven Fishery Management Plans (FMP) were in place: Northern Anchovy, Alaskan King Crab, Commercial and Recreational Salmon, High Seas Salmon, Pacific Groundfish, Gulf of Alaska Groundfish, and Bering Sea and Aleutian Islands Groundfish. Additionally, two Preliminary Management Plans (PMP), Bering Sea Herring and Bering Sea Snails, were in place for Pacific Fisheries. The Tanner Crab FMP which was implemented in 1978, was repealed by the Secretary of Commerce in 1987. The United States is also a signatory to four commissions that manage those fisheries that have international cross boundary stocks: International Pacific Halibut Commission, International North Pacific Fisheries Commission, Pacific Salmon Commission, and the Inter-American Tropical Tuna Commission.

The Pacific states also have specific regulations that they apply to inshore fisheries. Some of the fisheries that are managed directly by the states are salmon, crab, shrimp, herring, spiny lobster, squid, and mackerel.

In an attempt to simplify the commercial landings data compiled by the National Marine Fisheries Service (NMFS), I have grouped the numerous species into six categories: Groundfish, Salmon, Scombrids, Crabs, Shrimp and other fish and shellfish. Groundfish includes the numerous species of rockfish and flatfish, Pacific cod, Pacific hake, Alaska pollock, lingcod and sablefish. The salmon group is made up of chinook, chum, pink, red, and coho. The scombrids would include the tunas, bonito and Pacific mackerel. Although not a true scombrid, jack mackerel is also included in this group. Crabs are principally dungeness, king, and snow along with minor landings of spider and rock crab.

Alaska

Alaska is first in the nation with direct landings valued at 942 million dollars and second only to Louisiana with landings of 1.7 billion pounds. At the national level Alaska accounts for 25 percent of the landings and 29 percent of the value. Regionally, Alaska makes up 68 percent of the landings and 69 percent of the value. The Alaskan groundfish harvest of 930 million pounds represents 53 percent of the state's landings but only 22 percent of the exvessel value at 207 million dollars. The highly prized salmon with landings of 489 million pounds accounts for 29 percent of the state landings but with an exvessel value of 473 million dollars accounts for 50 percent of the value. The crab fishery principally snow and king accounts for 152 million pounds valued at 208 million dollars. Respectively these landings account for only nine percent of the landings but 22 percent of the state's values. The shrimp fishery accounts for 2.7 million pounds and 2.3 million dollars which is less than one percent of the volume or value of the state's fishery. The other fish and shellfish, principally the inshore herring fishery, category accounts for 123 million pounds valued at 52 million dollars or seven percent of the volume and five percent of the value.

Washington, Oregon, California

The three coastal states of Washington, Oregon, and California had landings of 795 million pounds valued at 419 million dollars. The groundfish combination accounted for 32 percent of the landings with 261 million pounds worth 93 million dollars or 22 percent of the total value. Salmon landings of 73 million pounds was only nine percent of the total volume but 29 percent of the value at 123 million dollars. The bulk of the scombrid group is landed from Monterey, California southward. At 204 million pounds, scombrids accounted for 26 percent of the landings but only 12 percent of value at approximately 50 million dollars. The crab fishery, principally for dungeness, landed 22 million pounds valued at 30 million dollars. The fishery for the *Pandalus* shrimp has increased in recent years. Landings of 69 million pounds represent 9 percent of the landings and at an exvessel value of 48 million dollars, 11 percent of the area's value. The last category of other fish and shellfish accounted for 21 percent of the volume at 166 million pounds at 75 million dollars representing 19 percent. This very diverse group includes fisheries for anchovy, sea bass, sharks, swordfish, spiny lobster, clams, squid, and sea urchin as well as many other.

Joint Venture and Foreign Fishing

As previously mentioned, there are two other forms of commercial fishing activity off the Pacific states. Vessels of foreign nations which have negotiated a Governing International Fishery Agreement (GIFA) with the United States may fish in the EEZ for species managed under the Magnuson Act after receiving an allocation of that species and a valid fishing permit. After a GIFA is in force, a foreign nation must submit a permit application to the U.S. Department of State for each vessel to fish in the EEZ. Permit applications must also be made for foreign vessels to receive U.S. joint venture harvested fish. The Department of State provides copies of the applications to Congress, Coast Guard, Regional Fishery Management Councils and the National Marine Fisheries Service. The Assistant Administrator of NMFS after review and in consultation with Department of State and the Coast Guard may approve an application in whole or in part. Any conditions and restrictions on the approval of an application are sent to the foreign nation through the Department of State, and must be accepted by the nation before a permit is issued.

Direct foreign fishing within the Pacific region in 1987, was restricted to the eastern Bering Sea and Aleution Island's, 57 percent of the volume, and to waters off of Washington, Oregon, and northern California. The foreign catch in 1987, contributed 263 million pounds, 97 percent of which was groundfish, valued at approximately 57 million dollars or 96 percent of the foreign catch. Pacific cod and Pacific hake accounted for 229 million pounds of the 254 million pounds groundfish category.

Joint venture fisheries which began in 1979 contributed 3.5 billion pounds valued at 212 million dollars to the Pacific coast fisheries in 1987. As with direct foreign fishing the groundfish catch makes up the majority of the catch with 3.4 billion pounds worth 207 million dollars. Alaska pollock which is processed into fillets and surimi accounts for 67 percent of the catch at 2.3 billion pounds. It is expected that in the foreseeable future with the development of shore side facilities and U.S. at-sea-processing much of the joint venture catch will shift to U.S. commercial landings if not entirely eliminated.

Recreational Fisheries

Recreational fishing must be discussed when examining the impact of OCS development. Besides generating income for the states, recreational fisherman harvest a substantial number of fish. Utilizing preliminary data which excludes Alaska and the west coast salmon fishery, NMFS reports that approximately 47.5 million fish were caught by fisherman in California, Oregon, and Washington. This represents 12 percent of the national estimated total of 384.4 million fish.

The catch in number of Pacific mackerel was the highest of any species on the Pacific coast in 1987. Top-ranked species groups in each subregion were Pacific mackerel in Southern California, rockfishes in Northern California, black rockfish in Oregon, and spiny dogfish in Washington. Southern California accounted for 67 percent of the Pacific coast in number catch.

The ocean 3 miles or less from shore had the highest catch in numbers (59 percent) in 1987. The portion of the catch in the area more than 3 miles from shore (20 percent) was similar to the 16 percent for the Atlantic and Gulf coast EEZ. Percentage catches in number of fish were 59 percent for private/rental boats, 23 percent for shore, and 19 percent for party/charter boats.

National Marine Sanctuaries

The Marine Sanctuaries Act established by Congress in 1972, provides for the protection and preservation of ocean areas and resources. Under this law the Secretary of Commerce may designate ocean and coastal waters, and areas of the Great Lakes as National Marine Sanctuaries. The Marine Sanctuaries Act provides the only opportunity to designate and manage discrete areas as ecosystems, as opposed to managing individual resources, such as mammals or fish, under several different laws.

Two National Marine Sanctuaries have been established off the coast of California. The Channel Islands sanctuary designated in September 1980, is located offshore from Santa Barbara. This 1,252 square mile area protects the habitat for marine mammals and sea birds. The Gulf of the Farallones sanctuary was designated in January 1981. The 948 square mile habitat located northwest of San Francisco also protects marine mammals and seabirds.

In addition to the established sanctuaries, one additional area is under proposal and five areas are undergoing site evaluation. Originally considered in 1977, the proposed Monterey Bay sanctuary was withdrawn by NOAA in 1984. Following protest from conservationist and local officials, Representative Leon Panette (D-CA) introduced HR-734 in January, 1987, which directs NOAA to reverse its decision and to move the sanctuary through the designation process. If approved Panette's bill will be the first successful congressional effort to designate a major ocean area as a national marine sanctuary. Undergoing site evaluation at this time are areas off Washington, Oregon, and California. The Washington State Nearshore encompassing approximately 275 square miles is located around the San Juan Islands within Puget Sound, Washington. Western Washington Outer Coast containing 230 square miles is located along 90 miles of coastal northwestern Washington. The Hecata-Stonewall Banks are submerged banks off Oregon lying along the 100 fathom depth contour and would encompass 400 square miles. The Morro Bay site located south of Morro Bay, California contains an area of three square miles. The offshore Tanner-Cortes Banks west of San Diego would be approximately ten square miles in area.

Marine Mammals

When discussing outer continental shelf development the potential impact on marine mammals must be considered. Numerous species of porpoise, whales, seals, and sea lions haul out, migrate, or reside in waters bordering the Pacific coast states. The NMFS by authority of the Marine Mammal Protection Act (MMPA) administers long-term management and research programs to conserve and protect these animals. Some marine mammals are protected by the Endangered Species Act as well as the MMPA.

Most marine mammals are wide-ranging migratory animals, and international laws, treaties, and conventions are necessary for their protection. The U.S. is a participant of the International whaling commission, Inter-American Tropical Tuna Commission, International North Pacific Fisheries Commission, Fur Seal Act, and the U.S. - U.S.S.R. Marine Mammal Project.

Potential Impacts of OCS Activity

Platform blowouts, pipelines, well heads, seismic exploration, mining, and additional marine traffic have the potential to adversely impact fishing activities and marine ecosystems. Depending on the time of the year and location a platform blowout or tanker spillage could impact marine mammal rookery sites, whale migration routes, or marine sanctuaries. Displacement of fishing activity by seismic surveys and seabed mining is also a possibility.

The impact of the 1969, Union oil, platform blowout off of Santa Barbara, California and the resulting damage is still fresh in the minds of west coast citizens. More recently the explosion and partial sinking of the "Puerto Rican" in 1984 off the Gulf of the Farallones sanctuary and the collision and sinking of the "Pac Baroness" in 1987 off the Channel Islands sanctuary reawakened concern for the protection of the marine environment.

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COEXISTENCE OF FISHING AND OIL AND GAS INDUSTRIES IN THE GULF OF MEXICO

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ABSTRACT

Fishing and oil production coexist in the Northern Gulf of Mexico (GOM). Oil and gas activities on its Outer Continental Shelf (OCS) have increased from 890,000 acres under lease, less than 100 platforms and 6.7 million barrels of oil produced in 1955 -- to 21 million acres under lease, 3,350 platforms and 340 million barrels of oil produced in 1986. In the same period, commercial fish landings rose from 850 million pounds to 2,400 million pounds. The majority of the 2.2 million sport fishermen who fish the GOM visit oil platforms, taking advantage of the artificial reefs they create.

At least four oil spills have contacted the shoreline of Louisiana or Texas. The effects of these spills were never investigated. Modern oil spill prevention programs and technologies make such accidents unlikely in the future. Accidental oil spills throughout the OCS from 1971 through 1987 totaled about 69,000 barrels while the tanker "Alvenus" lost 45,000 barrels over a two or three day period after it ran aground off Galveston in 1984. Drilling fluids used in the GOM have low acute and chronic toxicities in light of the fluids expected to be used and rapid dilution and dispersal after discharge. Space competition, even cumulatively, is not a significant issue. OCS operations are responsible for less than 5 percent of all the direct wetland losses that occurred between 1955 and 1978.

Finally, laws and regulations play a major role in reducing adverse impacts on fisheries and in compensating fishermen for loss or damaged gear, as well as for consequent loss catches due to OCS oil and gas activities.

1. INTRODUCTION

The fishery resources of the northern Gulf of Mexico (GOM) constitute one of the largest fishery biomasses in the world. The 1986 commercial harvest for the five Gulf States totaled approximately 2.4 billion pounds valued at $781 million (USDC, NMFS, 1987a). The northern GOM is the site of the greatest concentration of coastal and offshore oil industry activity in the world with well over 4,000 oil and gas structures in State and Federal waters. These structures represent over 99 percent of our nation's offshore oil and gas structures. Most of them (3,600) are located off the Louisiana coast and about 3,200 are in Federal waters (Reggio, 1987). In Federal waters in the northern GOM, there are currently over 21 million acres under lease, over 7,600 producing wells, and over 33,500 offshore petroleum-related workers. Petroleum production in the coastal marshes and offshore waters of Louisiana alone exceeds 400 million barrels of oil and 6 trillion cubic feet of gas per year (Perrett and Roussel, 1984). Although the mutual existence of fishing and oil and gas industries has not been without problems, these industries have successfully coexisted in the northern GOM for over 50 years.

2. FISHERIES RESOURCES

Characteristic fishes are associated with the various Gulf environments. The low salinity estuaries are generally dominated by finfishes such as croakers, spot, sand trout, anchovies, mullet and menhaden, and shellfishes such as oysters and crabs. The shallow Gulf (surf zone) characteristically contains such fishes as the Gulf whiting and Atlantic threadfin. The bottom becomes muddier outside the surf zone, and fishes found here include the croaker, spot, star drum, silver trout, and longspine porgy. Farther offshore toward the middle shelf, the number of Sciaenids (croaker family) is drastically reduced, and the fish community is dominated by small flounders and sea robins. The offshore reefs support such fishes as snappers and sea basses, while oceanic fishes such as the bluefin tuna and broadbill swordfish inhabit the offshore open ocean waters (USDC, NMFS, 1979).

3. COMMERCIAL FISHERIES

Nearly all species significantly contributing to the Gulf's commercial catches are estuarine dependent. With the exception of such species as the oyster and spotted seatrout, most leave the estuaries as juveniles or subadults and spawn at sea after becoming reproductive adults. The eggs of the majority of these species hatch in the waters of the open Gulf. The developing larvae become part of the offshore planktonic community. Under the influence of tides, currents, and winds, the young eventually arrive at the estuarine nursery grounds where they feed, grow, and mature prior to migrating out to sea to repeat the spawning process.

Approximately 50 species of food finfish are harvested in the Gulf. Some of the more important species include croaker, snappers, groupers, black mullet, red and black drum, spotted and silver seatrout, Spanish mackerel, spot, pompano, flounders, crevalle, Gulf kingfish, sheepshead, and king mackerel. The majority of food finfish are caught in coastal waters with the exception of such fishes as the snappers, groupers, mackerels, tunas, and billfish.

Nine species of Penaeids contribute to the northern GOM fishery. Brown, white, and pink shrimp are the three most important commercial species. Brown shrimp are centered in the northwestern Gulf while white shrimp are centered on the mud and sand bottoms off the coast of Louisiana. Pink shrimp have an almost continuous distribution throughout the Gulf, but consistent commercial pink shrimp catches are made on the shell, coral sand, and coral silt bottoms off southern Florida. Other important invertebrates landed in the Gulf include oyster and blue crab. Spiny lobster are landed in the eastern Gulf.

Gulf menhaden occur in the shallow waters of the northcentral Gulf from eastern Florida to eastern Texas with about 93 percent of this fishing effort occurring within 10 miles of shore. Also, the industrial bottomfish trawl fishery exists in the nearshore waters of the northcentral Gulf. Generally, the following fishes contribute 95-98 percent of the trawl fishery catch: croaker, spot, sand seatrout, silver seatrout, silver eel, catfish, and longspine porgy. Croaker, the largest component of the catch, prefer a mud bottom and are generally not found at depths exceeding 60 fathoms.

4. RECREATIONAL FISHERIES

Recreational fishing is big business in the Gulf States with an estimated 2.2 million United States residents participating annually. In 1980, marine recreational fishing in the northern GOM resulted in an estimated $1.3 billion in retail sales (the highest of any region in the nation). This represented approximately 33 percent of total marine United States recreational fishing related sales (Sport Fishing Institute, 1983).

Spotted seatrout and red drum were the most sought after species in 1986. Forty-one percent of the total marine recreational catch in the Gulf consisted of various members of the Sciaenid family. Spotted seatrout was the most commonly caught species and contributed 16 percent of the total catch. Other commonly caught species were sand seatrout, Spanish mackerel, Atlantic croaker, saltwater catfishes, and pinfish (USDC, NMFS, 1987b).

5. IMPACTS ON COMMERCIAL FISHERIES

Possible adverse impacts on commercial fisheries from oil and gas activities include oil spills, discharge of drilling fluids, space competition, gear damage or loss and loss of catch on underwater obstructions, loss of wetlands, and removal of oil and gas structures by explosives.

Oil interferes with vital functions of many aquatic organisms. Free oil and emulsions can cover epithelial surfaces of aquatic animals and interfere with respiration. Sublethal effects of petroleum are largely unquantified. However, many aquatic organisms are known to display adverse responses to petroleum components at levels 100-1,000 times lower than acutely toxic concentrations. Even very low oil concentrations can taint fish flesh (Penkal and Phillips, 1984). Fish and bivalves are moderately sensitive (10-100 ppm); however, lethal concentrations may be lower (0.1-1 ppm) for the more sensitive larval and juvenile forms (USDI, MMS, 1985). Studies cited by Evans and Rice (1974) show that certain fish eggs are extremely sensitive to the influence of oil products.

A large oil spill is one of the major impact-producing factors that could affect commercial fishery resources in the northern GOM. Oil spills that contact the coastal marshes, bays, estuaries, and open Gulf areas with high concentrations of floating eggs and larvae have the greatest potential for damage to commercial fishery resources (USDI, MMS, 1987). Little is known about the levels of hydrocarbons in coastal and ocean pelagic fishes, reef fishes, coastal herrings, and groundfish. Data are also scarce on the long-term effects on fisheries from oil and gas activities in the northern GOM.

Commercial fishery resources could be adversely affected by the discharge of drilling fluids. The National Academy of Sciences (1983) stated that most water-based drilling fluids used in Outer Continental Shelf (OCS) drilling programs have low acute and chronic toxicities to marine organisms, considering the fluids expected to be used and discharge dilution and dispersal. Effects of drilling fluids and cuttings are restricted primarily to the ocean floor in the immediate vicinity and for a short distance downcurrent from the discharge. The bioaccumulation of metals from drilling fluids appears to be restricted to barium and chromium and is observed as a low value in the field. This impact-producing factor is considered minor.

Installation of oil and gas production structures removes 3-5 acres of trawling space for each structure. USDI, MMS (1987) estimated that the cumulative loss of trawling area through installation of offshore structures results in at most a very low impact on commercial fishing in the northern GOM. The presence of underwater obstructions (many of which are not oil and gas related) causes gear conflicts and results in losses of trawls, shrimp catch, business downtime, and vessel damage. Financial losses to fishermen as a result of unknown OCS obstructions may be compensated by the Fishermen's Contingency Fund.

Loss of wetlands has a detrimental effect on fisheries production (Turner, 1984). However, most of the data on this relationship is correlative. Wetlands serve as food-rich refuges from predators during the critical growth stages of the young. In comparison to the open water, the wetland edge is rich in organics and the interior has a high density of benthic prey. The impact of the present coastal wetland losses is not yet evident in the commercial landing statistics because of the wide annual landing variations that mask long-term effects. OCS operations are responsible for less than 5 percent of all the direct wetland loss that occurred between 1955 and 1978 (Turner and Cahoon, 1987).

The removal of obsolete oil- and gas-related structures with explosives has the potential to cause mortalities of commercially important fish such as snappers and groupers. However, 80-90 percent of the fish killed are usually of no commercial value. The magnitude and significance of this impact-producing factor has not been assessed.

A benefit to commercial fishing from Gulf of Mexico OCS oil and gas activities is the apparent creation of productive shrimp trawling areas adjacent to pipelines. Tate (1982) stated that older pipelines have a continuing positive impact because uncovered pipe has a "log in water" effect on attracting fish and shellfish. Also, anomalies along the pipe tend to trap current-driven material such as rope, plastic, and netting and serve as small artificial reefs to congregate fish and shellfish. These benefits persist long after the pipeline is laid. New pipeline activity seems to have the most profound effect because fish congregate and forage through the disturbed bottom. Fishing greatly improves in the area until the bottom settles and exposed foods are eaten. The fish then scatter and remain in certain areas such as near exposed pipe or wherever the bottom was left uneven. Fishermen willing to add mud-dragging gear to the nets may be rewarded by catching shrimp that congregate on both sides of the freshly installed pipelines.

Another benefit to commercial fishing is the provision of productive hook and line fishing areas by oil and gas structures. Gallaway (1984) stated that oil platforms constitute a major portion of the red snapper habitat and fishing ground in the northwestern Gulf. Perrett and Roussel (1984) mentioned that many fish species may be more exploitable because they congregate under and around offshore structures. Dimitroff (1982) stated that the snapper/grouper fishermen from Niceville and Pensacola, Florida, almost exclusively fish the oil and gas structures in the Central Gulf. Ditton and Auyong (1984), in a study conducted offshore Louisiana from April 1980 - March 1981, found that of the 11,911 fishing boats in the vicinity of 164 major structures, 1,030 were commercial fishing boats. There is still some question as to whether artificial reefs enhance fish production or merely concentrate fish. Whatever the case, the offshore fishing industry has benefited by the presence of offshore structures.

6. IMPACTS ON RECREATIONAL FISHERIES

Oil and gas activities may adversely impact recreational fisheries in the same way as commercial fisheries. However, installation of the more than 4,000 petroleum structures in the northern GOM has been a real benefit to recreational fishing. Ditton and Auyong (1984) noted that out of 11,911 boats observed fishing near major offshore structures off the Louisiana coast from April 1980 - March 1981, that 10,881 were recreational boats. This included 8,983 private fishing boats, 1,624 charter/party fishing boats, and 274 scuba boats. Hardison (a charter boat operator in the northern GOM for over 30 years) (1982) stated that he annually takes over 10,000 people deepsea fishing. All of his fishing is conducted while tied up to oil and gas structures. Scogin (1982) found that approximately one-quarter of all the offshore ocean fishing originating in Texas, Louisiana, and Mississippi was directly associated with oil and gas structures. Ditton and Graefe (1978) found that oil and gas structures off the Texas coast attracted 87 percent of the boats and 50 percent of all offshore recreational fishing. Witzig (1985) found that approximately 60 percent of the fish caught near structures within three miles of the shore were kept compared to less than 10 percent caught at nonstructure sites. The proportion of the catch kept on fishing trips greater than three miles from shore was over 70 percent for trips to structure sites and approximately 35 percent to nonstructure sites.

Scogin (1982) stated that structures constitute a major change in the ecology of the northern GOM since the offshore seafloor consists largely of a flat, soft-bottomed, gradually sloping plain. Shinn (1974) estimated that a typical major platform in water depths of 30 meters provides 8,173 square meters of steel substrate; the average major platforms in the northwestern GOM provide over 2,471 acres of submerged steel substrate. Structures are subject to biofouling organisms, a basic food source of many recreational fishes. Gallaway and Lewbel (1982) determined that structures constitute approximately 28 percent of the known hard-bottom habitat off the Louisiana and Texas coasts.

7. MEANS THAT LESSEN NEGATIVE IMPACTS

The Fishermen's Contingency Fund, administered by the National Marine Fisheries Service (NMFS), was authorized in 1978 under Title IV of the OCS Lands Act Amendments. Claims for compensation through this fund must demonstrate that the obstruction is related to OCS oil and gas exploration, development, or production and lies within a 3-mile radius of such activities. The damage or loss must not be caused by fishermen negligence, must have occurred after September 18, 1978, and must not be covered by insurance. There is no ceiling on a single claim, although the damage or loss must not exceed the replacement value of the fishing gear. Claims must be filed within 60 days of the incident. Funds are obtained by assessing levies on each exploration permit, lease, easement, or right-of-way that has been issued or maintained under the OCS Lands Act since its authorization in 1978 (Louisiana Geological Survey, 1985). During 1985, 157 GOM claims were approved for a total of $561,199. The average claim processing time has been reduced from as much as 7 months to about 40 days after the claim is received by NMFS (USDI, MMS, 1987).

Title III of the OCS Lands Act, as amended (43 USC 1801-1866), provides for the Offshore Oil Spill Pollution Fund, whereby a fishing vessel or equipment damaged by contact with spilled oil may receive compensation.

Several OCS Orders and Notices are designed to minimize conflicts with fishermen. OCS Order No. 9 states that all pipelines shall be installed and maintained to be compatible with trawling operations and other uses. Section 22 of the current lease form (MMS 2005, March 1986) states that within one year after termination of the lease the lessee shall remove all devices, works, and structures. OCS Order No. 3, paragraph 2.9, requires that, upon abandonment, the well locations be cleared of all obstructions to a depth of 16 feet (5 meters) below the ocean floor. NTL 81-5 establishes the minimum requirement for verification of site clearance with at least one of the following requirements: a trawl dragged in two directions across the location, a chain or cable dragged between two boats in two directions across the location, a diver search around the well bore for a minimum radius of 100 feet, or a side-scan sonar survey across the location. The Louisiana Concerned Shrimpers Association recently brought to the attention of MMS its concern over debris remaining on the site after structures are removed. In order to minimize this impact on commercial fishing MMS is currently forming a task force with the shrimpers and the Offshore Operators Committee to further identify acceptable techniques and develop rules to accomplish the requirements of OCS Order No. 3. Further, Department of Transportation Regulations Parts 192.319(c) and 195.246(b) require that all offshore pipe in water at least 12 feet deep but not more than 200 feet deep, as measured from the mean low tide, must be installed so the top of the pipe is below the natural bottom unless it is supported by stanchions, held in place by anchors or heavy concrete coating, or protected by an equivalent means.

Although not specifically designed to do so, several Gulf of Mexico OCS stipulations lessen impacts on commercial and recreational fishes by providing protection to topographic features and their biota in the central and western GOM, to pinnacles and their biota in the central GOM, and to live bottoms in the eastern GOM.

Topographic Features Stipulation

The topographic features stipulation was first developed in the early '70s and has recently been modified by a DOI workshop of MMS and FWS biologists. Comments were solicited from Federal and State agencies, industry, academia, and interested environmental groups. The stipulation wording is based on years of scientific information collected since the inception of the stipulation. This information includes various Bureau of Land Management/MMS-funded studies on the topographic highs in the Central Gulf, numerous stipulation-imposed, industry-funded monitoring reports, and a National Academy of Science (NAS) report (1983). The stipulation was formulated based on consultation with various Federal agencies and comments solicited from State, industry, environmental organizations, and academic representatives.

The banks that would cause this stipulation to be applied to blocks of the Central Gulf are the following:

Bank Name	Isobath (meters)
McGrail Bank	85
Bouma Bank	85
Rezak Bank	85
Sidner Bank	85
Sonnier Bank	55
Sackett Bank[2]	85
Ewing Bank	85
Diaphus Bank[2]	85
Alderdice Bank	80
Parker Bank	85
Fishnet Bank[2]	76
Jakkula Bank	85
Sweet Bank[1]	85
Rankin Bank	85
29 Fathom Bank	64
Bright Bank	85
Geyer Bank[3]	85
MacNeil Bank[3]	82

[1]Only paragraph (a) of the stipulation applies. (See page 6.)
[2]Only paragraphs (a) and (b) apply.
[3]Western Gulf of Mexico bank with a portion of its "3 Mile Zone" in Central Gulf of Mexico.

The banks that would cause this stipulation to be applied to blocks of the Western Gulf are:

Bank Name	Isobath (meters)
Shelf Edge Banks	
West Flower Garden Bank[1]	100 (defined by 1/4 1/4 1/4 system)
East Flower Garden Bank[1]	100 (defined by 1/4 1/4 1/4 system)
MacNeil Bank	82
29 Fathom Bank	64
Rankin Bank	85
Geyer Bank	85
Elvers Bank	85
Bright Bank[5]	85
McGrail Bank[5]	85
Rezak Bank[5]	85
Sidner Bank[5]	85
Parker Bank[5]	85
Stetson Bank	6
Applebaum Bank	85
Low Relief Banks[2]	
Mysterious Bank	7 (see leasing map)
Blackfish Ridge	70
Big Dunn Bar	65
Small Dunn Bar	65
32 Fathom Bank	52
Coffee Lump	Various (see leasing map)
Claypile Bank[3]	50
South Texas Banks[4]	
Dream Bank	78, 82
Southern Bank	80
Hospital Bank	70
North Hospital Bank	68
Aransas Bank	70
South Baker Bank	70
Baker Bank	70

[1]Flower Garden Banks - In paragraph (c), a "4 Mile Zone" rather than a "1 Mile Zone" applies.
[2]Low Relief Banks - Only paragraph (a) applies.
[3]Claypile Bank - Paragraphs (a) and (b) apply. In paragraph (b) monitoring of the effluent to determine the effect on the biota of Claypile Bank shall be required rather than shunting.
[4]South Texas Banks - Only paragraphs (a) and (b) apply.
[5]Central Gulf of Mexico bank with a portion of its "1 Mile Zone" and/or "3 Mile Zone" in the Western Gulf of Mexico.

The stipulation reads as follows:

(a) No activity including structures, drilling rigs, pipelines, or anchoring will be allowed within the listed isobath ("No Activity Zone") of the banks as listed above.

(b) Operations within the area shown as "1,000 Meter Zone" shall be restricted by shunting all drill cuttings and drilling fluids to the bottom through a downpipe that terminates an appropriate distance, but no more than ten meters, from the bottom.

(c) Operations within the area shown as "1 Mile Zone" shall be restricted by shunting all drill cuttings and drilling fluids to the bottom through a downpipe that terminates an appropriate distance, but no more than ten meters, from the bottom. (Where there is a "1 Mile Zone" designated, the 1,000 Meter Zone in paragraph (b) is not designated.)

(d) Operations within the area shown as "3 Mile Zone" shall be restricted by shunting all drill cuttings and drilling fluids from development operations to the bottom through a downpipe that terminates an appropriate distance, but no more than ten meters, from the bottom.

Live Bottom (Pinnacle Trend) Stipulation
(Central GOM)

(To be included only on leases in the following blocks: Main Pass Area, South and East Addition Blocks 219-226, 244-266, 276-288; Viosca Knoll Blocks 521, 522, 564, 565, 566, 609, 610, 654, 692-698.)

For the purpose of this stipulation, "live bottom areas" are defined as seagrass communities; or those areas which contain biological assemblages consisting of such sessile invertebrates as sea fans, sea whips, hydroids, anemones, ascidians, sponges, bryozoans, or corals living upon and attached to naturally occurring hard or rocky formations with rough, broken, or smooth topography; or areas whose lithotope favors the accumulation of turtles, fishes, and other fauna.

Prior to any drilling activities or the construction or placement of any structure for exploration or development on this lease, including, but not limited to, well drilling and pipeline and platform placement, the lessee will submit to the Regional Director (RD) a live bottom survey report containing a bathymetry map prepared utilizing remote sensing techniques. The bathymetry map shall be prepared for the purpose of determining the presence or absence of live bottoms which could be impacted by the proposed activity. This map shall encompass such an area of the seafloor where surface disturbing activities, including anchoring, may occur.

If it is determined that the live bottoms might be adversely impacted by the proposed activity, the RD will require the lessee to undertake any measure deemed economically, environmentally, and technically feasible to protect the pinnacle area. These measures may include, but are not limited to, the following:

(a) the relocation of operations; and

(b) the monitoring to assess the impact of the activity on the live bottoms.

Live Bottom (Low Relief) Stipulation
(Eastern GOM)

(To be included on leases on blocks in water depths of 100 m or less.)

A description of live bottom areas for this stipulation is the same as that for the Pinnacle Trend Stipulation. Prior to any drilling activities or the construction or placement of any structure for exploration or development on this lease, including, but not limited to, well drilling and pipeline and platform placement, the lessee will submit to the Regional Director (RD) a live bottom survey report containing a bathymetry map prepared utilizing remote sensing technique and an interpretation of live bottom areas prepared from a photodocumentation survey. The live bottom survey report, including the attendant surveys, will encompass an area within a minimum 1,000 m distance of a proposed activity site.

If it is determined that live bottom areas might be adversely impacted by the proposed activity, then the RD will require the lessee to undertake any measure deemed economically, environmentally, and technically feasible to protect live bottom areas. These measures may include, but are not limited to, the following:

(a) the relocation of operations to avoid live bottom areas;

(b) the shunting of all drilling fluids and cuttings in such a manner as to avoid live bottom areas;

(c) the transportation of drilling fluids and cuttings to approved disposal sites; and

(d) the monitoring of live bottom areas to assess the adequacy of any mitigating measures taken and the impact of lease initiated activities.

In addition, the MMS worked with the Gulf of Mexico Fishery Management Council and National Oceanic and Atmospheric Administration (NOAA) to protect coral and algal communities (which serve as fish habitat) from explosives and anchoring at the Flower Gardens in the western GOM. As a result, language was provided on nautical charts requesting mariners to avoid anchoring at those areas.

Rigs-to-Reefs[1]

The Rigs-to-Reefs Program provides for converting obsolete, nonproductive offshore oil and gas structures to designated artificial reefs. The Secretary of the Interior joined with the president of the National Ocean Industries Association in 1983 to form the Recreational and Environmental Enhancement for Fishing in the Seas (REEFS) task force. The task force, composed of marine fishery representatives from coastal states and public and private officials, set out to develop a strategy that would lead to the creation of a national artificial-reef policy, plan, and program in the United States. On November 8, 1984, that objective was advanced when President Reagan signed into law the National Fishing Enhancement Act (NFEA) of 1984 (Title II of P.L. 98-623). In the NFEA, Congress recognized the social and economic value in developing artificial-reefs, established national standards for artificial-reef developments, called for creation of a National Artificial Reef Plan under the leadership of the Department of Commerce, and established a reef permitting system

[1]Extracted from Reggio, V.C., Jr, 1987.

under the U.S. Army Corps of Engineers that limits the liability of participants in the program. Congress intended that artificial-reef support and development be accomplished through existing Federal programs in conjunction with public and private cooperation leading to the use of materials of opportunity. The law calls for an evaluation of incentives likely to encourage private sector support for artificial-reef development. The National Artificial Reef Plan lists specific materials and design standards that include oil and gas structures among recommended materials of opportunity.

The oldest and most highly recognized fishing structures are those within 25 miles of the GOM shore and in water depths less than 200 feet. National Research Council information indicates that by the year 2000, twelve years from now, two-thirds of the existing offshore structures will have become nonproductive and removed for onshore disposal. Estimates are that over 100 structures will be scheduled for removal in the GOM each year for the next 20 years. The size, shape, design, and profile of major structures result in their being desired for productive artificial fishing reefs. The oil and gas industry is anxious to cooperate with reef developers and will probably devote a major portion of disposal savings to artificial-reef projects since it is seldom feasible to reuse obsolete structures for oil and gas operations, and the scrap value barely pays for shore-based dismantling and disposal. Overall, there have been over 125 artificial-reef projects permitted throughout the northern GOM. Nine Rigs-to-Reefs projects have been permitted to date.

Krahl (1986) stated that MMS has adopted a policy aimed at encouraging the use of obsolete petroleum structures for fishery development. The MMS is evaluating and updating its regulations and procedures and will cooperate with intradepartmental initiatives to allow sanctioned reef builders the maximum possible flexibility to capture the fisheries enhancement value for oil and gas structures.

8. CONCLUSION

Fishery resources of the northern GOM constitute one of the largest fishery biomasses in the world. In 1986, the total commercial harvest amounted to 2.4 billion pounds, valued at $781 million. Over 2.2 million United States residents participate annually in northern GOM marine recreational fishing, with retail sales exceeding $1.3 billion. In this Region, over the last 50 years, extensive oil and gas activities have been conducted. Currently, there are over 21 million acres under lease, over 7,600 producing wells, and over 33,500 petroleum-related employees.

Fisheries could be negatively impacted by several impact-producing factors. Oil spills that contact the coastal marshes, bays, estuaries, and open northern GOM having high concentrations of floating eggs and larvae have the greatest potential for damage to fishery resources. Most drilling fluids used in the northern GOM have low acute and chronic toxicities to marine organisms considering the fluids used and dilution and dispersal after discharge. Installation of oil and gas structures is estimated to remove from 3-5 acres of trawling space for each structure. Even in a cumulative sense, this is expected to result in no significant impacts. Gear damage or loss and loss of catch on underwater OCS obstructions may be compensated for through the Fishermen's Contingency Fund. However, many of these claims may result from non-OCS obstructions. Loss of wetlands and explosive structure removal operations may negatively impact fishery resources. However, this has not been quantified.

As a benefit, newly installed pipelines provide productive areas for fishing and shrimping. Of particular importance are the more than 4,000 oil and gas structures in the northern GOM that provide substantial and popular commercial and recreational fishing areas.

Several means other than the Fishermen's Contingency Fund lessen negative impacts on fisheries in the northern GOM. These include Title III of the OCS Lands Act; OCS Order No. 9; OCS Order No. 3; NTL 81-5; Section 22 of MMS Lease Form 2005, March 1986; topographic features stipulation in the central and western GOM; pinnacle trend stipulation in the central GOM; live bottom stipulation in the eastern GOM; and the Rigs-to-Reefs program. Further, MMS has worked with the Gulf of Mexico Fishery Management Council and NOAA to protect fish habitats at the Flower Gardens.

Fishing and oil and gas industries have coexisted in the northern Gulf of Mexico for over 50 years. The general trend in both commercial fisheries landings and oil, condensate, and gas production has been on the increase since before 1968, indicating that oil and gas activities have not devastated fishery resources.

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POTENTIAL CONFLICTS BETWEEN OIL AND GAS INDUSTRY ACTIVITIES AND COMMERCIAL FISHING

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ABSTRACT

Offshore oil and gas activities occur worldwide in areas that have important commercial fishing industries. Examples include the North Sea, Alaska, southern California, the Gulf of Mexico, and the Atlantic Outer Continental Shelf. Fishing methods and gear may vary, but the potential for conflict between oil and gas activities and commercial fishing exists in all these regions.

This paper looks at how the two industries have interacted in the portion of the North Atlantic known as Georges Bank. It also examines the measures employed by the Department of the Interior to ensure that the seemingly conflicting interests of oil and gas exploration and commercial fishing could both be served without significant problems.

INTRODUCTION

The commercial fishing industry associated with Georges Bank in the North Atlantic is one of the world's most productive and lucrative. Following years of negotiations, litigation, environmental research, and analysis of potential environmental impacts, the Department of the Interior in 1979 received total high bonus bids exceeding $816 million for 63 oil and gas leases between 110 and 170 miles offshore Cape Cod, Massachusetts. These leases were located along the southern flank of Georges Bank, an area with fishing efforts directed toward cod, haddock, pollock, scallops, lobster, and yellowtail flounder.

FISH VERSUS OIL

Of immediate concern to fishermen was the potential for oil and gas activities interfering with fishing gear such as trawls, seines, longlines, traps and pots, dredges, and gill nets. Fishing vessels, gear, and methods vary depending on fish species sought and the distance of the fishing grounds from shore. How could drilling rig, service vessel, and geophysical survey vessel personnel possibly understand fishing patterns in the North Atlantic?

A basic knowledge of commercial fishing operations on Georges Bank was considered vital to minimizing interference by exploratory operations. As such, Lease Stipulation No. 6 and Notice to Lessees (NTL) NA-80-10 required that all personnel involved with operations on Sale 42 leases complete a Fisheries Training Program (FTP). This program was designed to give shore-based supervisors, service vessel crews, and all drilling rig personnel information on the "value of the commercial fishing industry and the methods of offshore fishing operations, and the potential hazards, conflicts, and impacts resulting from offshore oil and gas exploration activities."[1]

The FTP was prepared by the oil industry under the auspices of the Offshore Operators Committee and in response to the requirements of the Department of the Interior. The draft program was reviewed by representatives of several State and Federal Agencies, as well as by officers of New England fishermen's cooperatives. Recommended changes were adopted prior to implementation of the FTP. To date, more than 1,000 people have completed this training.

The FTP stresses that exploratory operations could conflict with commercial fishing activities in several ways. Included in these potential conflicts are physical preemption of fishing grounds, direct interference with gear by service and geophysical vessels, dumping of debris, and acute/chronic effects on the biota from discharged drilling muds, cuttings, and oil spills. The FTP summarizes various protective measures that have been instituted to minimize the potential effects.

The FTP and resultant coordination of oil/gas and fishing activities minimized the number of gear conflicts during exploratory operations in the North Atlantic Planning Area. Following the drilling of eight exploratory wells on Georges Bank, there were two claims of damages allegedly resulting from oil industry anchor buoys that had broken loose from their moorings. The first incident involved a fisherman who abandoned his gear while attempting to recover an anchor buoy. When he returned to his gear, he found it had been destroyed by sharks. After making a formal complaint to the owner of the anchor buoy, the fisherman was reimbursed for replacement of his gear, lost catch, costs incurred while retrieving the buoy, and a "finders fee."

The second incident involved the loss of gear because of an anchor buoy and attached cable floating through a lobstering area. Repeated requests by the Minerals Management Service (MMS) to have the gear's owner submit a detailed listing of losses were unproductive; therefore, no reimbursement was completed.

Both of these claims involved oil company equipment that was clearly marked, so ownership was never in question. Accidentally discharged materials could be traced back to the appropriate operator because of the marking of equipment requirements outlined in NTL NA-82-11. Marking of equipment is a quick and easy way to expedite fishermen's claims for reimbursement.

Five allegations of gear interference resulted from the presence of seismic vessels in the area. Geophysical survey vessels traverse an area being studied prior to the onset of drilling operations. Equipment used during these surveys includes towed arrays, which stream behind the seismic vessel. The array may be more than a mile behind the boat and can become entangled in fishing gear. Of the five incidents, one resulted in no damages, two were resolved through reimbursement for damages, and two could not be settled because the fishermen failed to file accurate claims.

Even though the number of gear conflict occurrences has been small, the MMS has decided that expansion of the coverage of the FTP would further mitigate this problem. As a result, prelease geological and geophysical (G&G) surveys located between Maine and North Carolina were brought under the FTP requirements in 1984. In conjunction with this change, G&G permit holders are required to complete the FTP and give fishermen 2 weeks advance notice of impending operations. Additionally, permit holders are urged to coordinate their activities with representatives of major fishermen's cooperatives. Both the fishermen and the survey companies have seen this as being beneficial in minimizing gear conflict.

As discussed above, the FTP and marking of equipment requirements have been effective in minimizing gear conflict. An absolute prohibition on jettisoning debris and the requirement that items accidentally lost overboard be recovered have resulted in the Sale 42 drilling area being virtually free of oil industry material that could snag gear. Following abandonment of drilling sites by oil companies, operators had to conduct sidescan sonar surveys to ensure the area did not contain any debris that could be potentially hazardous to fishing. Time and catch are lost whenever fishing gear hangs up on obstructions, and expensive fishing gear can be lost or damaged. Serious injuries and deaths may occur if towing warps snap as a result of snagging heavy debris.

Any large material identified on the sidescan sonar records had to be retrieved by the operator. This retrieval system uses grappling hooks, divers, and in some cases, small submersible crafts. To date, no problems concerning the snagging of oil industry debris on the sea floor in this area have been raised by commercial fishermen.

The discharge of oil, drilling muds, and cuttings has also been of major concern to commercial fishermen. In efforts to minimize any potential negative effects from these discharges, stringent discharge requirements were adopted for the Sale 42 drilling.

In most areas of the world where offshore drilling has occurred, drilling muds and cuttings have been routinely discharged into the surrounding ocean. Numerous studies have shown that these discharges are rapidly diluted upon entering the receiving water and have little measurable effect on the biota more than a few hundred meters from the drilling rig.[2,3,4] A clockwise system of currents known as the Georges Bank gyre effectively maintains water masses on the Bank for longer times than would be expected without the gyre.[5] This circulation is believed to be important to the fishery since larvae are sometimes kept in the nutrient-rich waters of Georges Bank for extended periods when the gyre is firmly established. This same gyre could cause drilling discharges or spills to be circulated around the Bank and thus increase the amount of exposure received by various organisms. To minimize any potential effects of such discharges, the Environmental Protection Agency's (EPA's) National Pollutant Discharge Elimination System (NPDES) permits for Sale 42 leases contained some of the strongest restrictions ever attached to offshore operations.[6] These restrictions included the following requirements:

1. Muds and cuttings be shunted to at least 10 meters (33 feet) below the ocean surface.

2. The maximum undiluted mud discharge rate shall not exceed 30 barrels per hour following setting of the conductor casing.

3. Mud shall be diluted by at least 10:1 (water:mud) prior to discharge.

Several chemical additives known to have adverse effects on marine organisms were totally banned for use during operations on Georges Bank. Other materials with the potential for causing harm to the environment had discharge limitations and monitoring requirements. Analyses for the presence of a specific list of metals as well as for petroleum hydrocarbons are also required by the NPDES permits. Only seven standard, oil-free drilling muds previously bioassayed for Mid-Atlantic drilling operations were allowed to be discharged in the Sale 42 area. Further bioassay of the muds intended for use in the Sale 42 area was required using test organisms known to occur on Georges Bank. Additional muds could have been used if bioassay results were submitted and the results approved in advance by EPA.

One of the most important requirements of the NPDES permits was the inclusion of the Georges Bank Biological Task Force (BTF) Monitoring Program[7] as a prerequisite to drilling. That program is summarized in another paper presented at Oceans '88.[8] Additions to the BTF Monitoring Program included requirements for the collection of water current and temperature data in each of three depth zones as well as detailed determinations of the type and amounts of discharged materials.

The Georges Bank Monitoring Program concluded that no substantially significant negative impacts on the benthic environment were seen as a result of the Sale 42 drilling.[8,9]

CONCLUSION

Sale 42 and resultant oil and gas activities have proven that given appropriate mitigating measures and a willingness to coordinate activities, the commercial fishing and oil/gas industries can coexist on the Outer Continental Shelf.

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INFORMATION ON FISHERIES RISK ASSESSMENT IN THE ALASKA OCS REGION

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ABSTRACT

The U.S. Department of the Interior--through the Minerals Management Service's Environmental Studies Program (ESP) in the Alaska OCS Region--has invested over $208 million in 465 environmental studies since the program was initiated in 1973. Over half of these studies have focused on fisheries-oceanography issues. The ESP has evolved from identifying resources at risk from potential oil and gas activities to determining the sensitivity of underlying ecological processes. The Alaska OCS Region currently is conducting coastal fisheries-oceanographic studies in both Arctic and southeastern Bering Sea waters.

1. INTRODUCTION

The U.S. Department of the Interior (USDOI), as part of Project Independence (a program to reduce the United States' dependence on imported oil), began leasing submerged lands on the Outer Continental Shelf (OCS) off Alaska for oil and gas exploration in April 1976 with OCS Lease Sale No. 39 in the northeastern Gulf of Alaska. Since then, USDOI has conducted 14 OCS lease sales and leased 3.2 million hectares, and industry has drilled some 67 exploration wells in Federal waters offshore Alaskan. Oil in economically producible quantities has been found under State waters in Cook Inlet and under Federal and State waters in the Beaufort Sea--some 8 wells have been classified as producible in the Federal OCS portion of the Beaufort Sea near Prudhoe Bay.

In addition to the legal mandates guiding the Department's activities (1), Departmental managers recognize that the harvest of marine resources--primarily fish--plays an important part in cultural and commercial activities within Alaska. They, therefore, have directed considerable resources to assessing potential conflicts between traditional uses of these resources and the exploration for oil and gas resources. The following provides brief histories of marine-resource harvesting, scientific research (including that supported by MMS), and fisheries studies currently being supported by MMS.

2. BACKGROUND

The harvest of marine resources--including fishes, marine mammals, and sea birds--off Alaska has continued for nearly nine millennia (2). Europeans became aware of the area's marine wealth in 1648-1649 when commercially significant quantities of walrus ivory were found along the Bering Sea coast by promyshlennikis (Cossacks) Stadukhin and Dezhnev (2). The real awareness began, however, when survivors of Vitus Bering's last voyage (1741) returned with sea otter and fur seal pelts. During the ensuing century and a half, the commercial harvest of natural resources concentrated on the region's abundant marine mammal populations, including the great whales.

Commercial fishing (cod and salmon) by the American fishing fleet began in the eastern Bering Sea during the latter part of the 19th century and continues today. The Japanese fishing fleet began harvesting bottomfish and crab from the eastern Bering Sea in the 1930's; however, their efforts were halted by the second World War.

Following World War II, fishing fleets of the United States, Canada, Japan, and Russia expanded their operations into Alaskan waters. Following establishment of the 200-mile exclusive economic zone, the Canadian, Russian, and Japanese fishing fleets have been, for the most part, excluded from these waters. The American fleet has expanded to harvest salmon, crab (king and tanner), shrimp, halibut, cod, herring, and bottomfish (for local markets and through joint ventures with foreign processing companies).

Scientific research in Alaskan waters appears to have begun with the
expedition commanded by Vitus Bering, during which Steller described many of the hitherto unknown species from the "Far Eastern Sea" (Bering Sea) (2 and 3). The next major expedition into the area was during the last voyage of Captain James Cook in 1787.

Following Cook's voyages, numerous expeditions visited Alaskan waters and collected natural history material, but the next major expedition into the area did not occur until 1880 when--under a broad program of the 10th Census--the steamers "Yukon" and later the "Albatross" spent several years exploring the area. These cruises, unfortunately, ceased shortly after the turn of the century; and fisheries research in the area was not resumed until 1938. At that time, the U.S. Congress approved funds for the U.S. Fish and Wildlife Service (USFWS) to gather information on the migration of salmon in western Alaska, particularly those of Bristol Bay origin. The program was expanded in 1940 to include studies of king crab and bottomfish but was terminated by World War II.

Fisheries research in Alaskan waters was resumed by the United States in 1947, with much of the work being done by the National Marine Fisheries Service (NMFS) (formerly the Bureau of Commercial Fisheries, USDOI) and the International North Pacific Halibut Commission.

Research conducted by other countries included that sponsored by Russia and Japan. The Pacific Scientific Institute of Ichthyology (TINRO) of the Soviet Union sponsored extensive voyages into the Bering and Chukchi Seas during 1932 and 1933; and the Soviet Bering Sea Comprehensive Scientific-Commercial Expedition initiated by TINRO in 1958 provided a wealth of information (3). Japanese scientists have been conducting fisheries and oceanographic research off Alaska since World War II.

3. ALASKA OCS REGION'S ENVIRONMENTAL STUDIES PROGRAM

In 1974, The Minerals Management Service (MMS) initiated the Environmental Studies Program (ESP) to support the OCS oil- and gas-leasing program off Alaska. The ESP--which is conducted by the Alaska OCS Region--is the largest, single-agency, mission-oriented, marine-studies program in the Federal Government.

The purpose of the ESP is to establish information needed to assess and mitigate potential effects that proposed oil and gas leasing and development might have on the human, marine, and nearshore environment--sound lease-management decisions are enhanced when pertinent information is available in a timely manner. Since its inception, the ESP has conducted some 465 environmental studies at a cost of over $208 million. Over half of these studies have focused on fisheries-oceanography issues. Information acquired through this program is in the forefront in subarctic and arctic studies and is used to support offshore leasing and management decisions.

Program activities are coordinated with two other studies programs that focus on offshore oil and gas development--these are the industry-sponsored studies that are usually coordinated by the Alaska Oil and Gas Association and focus on specific operational problems and the MMS-sponsored Technology Assessment and Research Program (TARP). The TARP is an engineering-oriented program that provides information for permitting decisions for offshore operations. The three programs complement one another in the process of bringing offshore oil and gas resources into production. Portions of the ESP are managed by the National Oceanic and Atmospheric Administration's (NOAA's) Outer Continental Shelf Environmental Assessment Program (OCSEAP) office located in Anchorage, Alaska. The MMS directly contracts for certain studies, including those for endangered species, monitoring, and pollutant transport as well as social and economic studies and conducts the annual Beaufort Sea bowhead whale aerial survey.

An Alaska Regional Studies Plan (RSP) is prepared annually to guide MMS and NOAA in accomplishing program objectives. Information needs are identified and reviewed by diverse organizations and committees, including the Scientific Committee of the National OCS Advisory Board, the State of Alaska, and several Federal agencies (for example, U.S. Geological Survey, the Environmental Protection Agency, USFWS, NOAA, and MMS); and further critiques result from program reviews and disciplinary workshops. The RSP identifies existing and potential offshore-management decisions and specifies relevant studies' objectives to aid in making those decisions. Both OCSEAP and MMS contract for studies to fulfill these data needs. Principal investigators are drawn from universities, State and Federal Government Agencies, and private organizations.

4. FISHERIES STUDIES

The MMS-supported studies that relate specifically to fisheries can--for the purposes of this paper--be grouped into four general categories: (1) literature review; (2) distribution and abundance studies; (3) fisheries oceanography, which includes ecosystem and modeling studies; and (4) special studies. The MMS also has supported many studies on the fate and effects of petroleum on fish and fisheries, but these are not discussed in this paper.

Prior to the MMS ESP, information on the fisheries resources and fisheries ecology in the waters off Alaska occurred in numerous foreign and domestic publications and processed reports, making it difficult for fishermen, resource managers, and scientists to develop a comprehensive model of these resources. One of the first tasks of the ESP, therefore, was to conduct literature reviews of all available information about the marine waters off Alaska. These efforts included the acquisition, entry into the national database, analysis, and summary of all available fisheries data for Alaska. These data were obtained from the NMFS, International Pacific Halibut Commission, International North Pacific Fisheries Commission, and the University of Washington Fisheries Research Institute and included foreign and domestic commercial catches and fisheries research on pelagic and demersal fisheries resources from 1948-1976. (This effort continues to date.)

Also in conjuction with the ESP, MMS has conducted multidisciplinary meetings to assess and synthesize published and unpublished information--

including the data mentioned above--for each of the nine active OCS lease-sale planning areas off Alaska. Results from these meetings, coupled with the literature reviews, have provided MMS with a comprehensive perspective of resources--including fish and an initial understanding of the ecosystem processes at risk from oil and gas activities. Results of the syntheses are available in report form and are updated for each succeeding sale in an area.

Additionally, MMS contracted for the preparation of summary documents including "Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms, Volumes I and II" (4); "The Eastern Bering Sea Shelf: Oceanography and Resources, Volumes 1 and 2" (5); and "The Gulf of Alaska, Physical Environment and Biological Resources" (6).

Fisheries-resource-assessment surveys supported by MMS in the Gulf of Alaska and Bering and Chukchi Seas provided the first systematic and comprehensive information base on the seasonal and geographical distribution and relative abundance of demersal fishes and shellfishes found in these waters. The surveys also gathered information on the abundance and distribution of marine birds, marine mammals, benthic organisms, zooplankton, meroplankton, and oceanographic properties for correlative analysis. These surveys provided a baseline of information for assessing the resources at potential risk from OCS oil and gas activities.

Following the resource-assessment surveys, MMS focused its attention on conducting fisheries-oceanographic studies in lower Cook Inlet and off Kodiak Island. Conducted by multidisciplinary research teams, these studies documented the seasonal occupance (succession), diurnal movement, and distribution of maro and ichthyoplankton; and they correlated these observations with information on the spawning locations and times and the general migration routes of fish moving from deeper to more shallow waters as the seasons advanced and waters warmed. Also described were species interaction (trophic) and dependencies of major lifestages of important fish and shellfish populations and the dynamics of these interactions. Fisheries oceanography studies were coordinated with other oceanographic, marine bird, marine mammal, and feeding studies to improve the integration of study results. Similar studies currently are under way in the Bering Sea and are proposed for the Beaufort and Chukchi Seas. These studies are discussed below.

Results from fish, marine mammal, and seabird trophic studies supported by the ESP in Alaska provide comprehensive descriptions of trophic interactions and dependencies between the major components of the marine environment. These studies describe primary trophic pathways and key species in the ecosystems, provide an understanding of trophic dynamics, and provide a measure of how the effects of oil and gas activities on one component of the ecosystem may affect the entire ecosystem.

The MMS also has funded support studies such as development of a forage fish otolith and skeletal-remains key and a Gulf of Alaska, Bering Sea, and Arctic Ocean ichthyoplankton key.

--The skeletal remains and otolith key was an important contribution to the fish, marine bird, and marine mammal trophic studies. This information was required before the trophic studies could proceed and provided a common reference for all investigators involved in projects to describe the food habits of larger marine organisms.

--The ichthyoplankton key also provides a common reference for investigators involved in ichthyoplankton research and was required before the MMS plankton research could proceed.

In addition, a fish-pathology study to describe the prevalence, distribution, and characteristics of diseases in fish and shellfish populations in Alaskan marine waters was supported by MMS. This information serves as an indication of the incidence of disease in these populations before oil and gas leasing was conducted in these areas and will serve as a reference to determine the potential effect of oil and gas development on the health of these populations.

Another special fisheries project supported by MMS was the development and operation of a multi-species-interaction model that uses information gathered through the ESP to describe the interactions between major species in the Bering Sea as a function of their predator-prey relationships. This model is used to describe potential changes in the relative abundance of important populations as a function of changes in the abundance of a major prey species.
The potential effects of spilled oil on commercial fisheries in the Bering Sea were simulated with the use of fisheries information, the fisheries-interaction model, and other information and models developed through the ESP. The simulation study was prepared by NMFS (7) under contract to MMS. An objective of the study was to achieve maximum-effect conditions by simulating the following conditions:

1. The largest plausible oil-well blowout in one of three locations, releasing 20,000 barrels per day of Prudhoe Bay oil for 15 days, and a tanker accident releasing 240,000 barrels of automotive diesel (refined) at a rate of 10,000 barrels per hour in one of the same three locations: off Port Moller, 45-meter depth; off Port Heiden, 43-meter depth; and off Cape Newenham, 43-meter depth.

2. Winds, tides, mixed-layer depth, and temperature that produced the largest possible area of highest possible concentration (less than 1 ppm) of water-soluble fraction of oil in water.

3. The most unfavorable time with respect to the fishery resources (peak spawning time with maximum aggregation of fish per unit area and/or peak migration time).

4. The prevailing conditions affecting the sedimentation of the oil to the bottom were such that the highest possible quantity of oil accumulated on the bottom in the shortest possible time.

The authors of the study concluded that an extensive blowout or a unreasonably large tanker accident would have no measurable effect on offshore fishery resources in the eastern Bering Sea.

Based on the results of the spilled-oil/fisheries-interaction simulation study, MMS is concentrating current fisheries studies in the coastal areas where the risk of potential effects from oil and gas development are considered more likely.

5. CURRENT AND PLANNED FISHERIES STUDIES

The MMS currently is supporting a coastal fisheries-oceanography study in the North Aleutian Basin Planning Area (southeastern Bering Sea) and is planning to initiate a similar study in the Chuckchi and Beaufort Sea (Arctic) Planning Areas. The Bering Sea study includes objectives to describe the major ecological processes and biotic relationships occurring in the coastal zone; timing and stock identity, habitat use, environmental controlling mechanisms of juvenile salmon migrating along the Alaska Peninsula; environmental conditions and key habitat variables that affect the development, survival, and recruitment of larval and juvenile king crab; seasonal changes in habitat use by lifestages of important forage species; and seasonal changes in coastal circulation, temperature, salinity, and nutrients. This study--which began in FY 1984 and should be completed in FY 1990--is the first study of its type in the eastern Bering Sea and complements similar studies conducted by MMS in the Kodiak Island area and Cook Inlet. Results from the study will provide an information base for future decisions concerning coastal activities in the area should development occur.

An arctic coastal fisheries-oceanographic study is being planned by MMS for initiation in FY 1989. To assist MMS, an ad hoc coordinating committee--which included representatives of Federal, State, and local agencies; the University of Alaska; and the oil and gas industry--was empaneled to plan and help conduct a workshop. Objectives of the workshop were to review the current status of information on Arctic fish, to formulate a suite of study objectives for future research on fish in the Arctic, and to develop a network for coordinating current and future studies in the Arctic. The workshop was held April 4-7, 1988, in Anchorage, Alaska and MMS presently is preparing the workshop proceedings.

The MMS and NOAA are using the workshop to develop the first-year objectives for the study. The ad hoc coordinating committee is planning to serve as a conduit for coordinating future fisheries research in the Arctic.

Future studies supported by the ESP will build on the extensive information base collected through the program and that developed by other agencies and marine scientists. The program is expected to concentrate efforts in those areas where commercially producible oil and gas discoveries have been found and where development of these resources is expected. Therefore, the program is expected to shift focus from regional studies to more site-specific studies as the database permits and the pace of development dictates.

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GEOPHYSICAL SURVEY AND COMMMERCIAL FISHING CONFLICTS, ENVIRONMENTAL STUDIES, AND CONFLICT MITIGATION IN THE MINERALS MANAGEMENT SERVICE PACIFIC OCS REGION

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ABSTRACT

Geophysical exploration for oil and gas on the Federal OCS offshore California, Oregon and Washington is regulated by the Pacific OCS (POCS) Region of the Minerals Management Service. In recent years conflicts between commercial fishing and geophysical exploration activities in the Region have become an increasingly important issue, particularly offshore California. These conflicts have centered on space-use, gear damage, and fishery resource issues. Fishery resource issues, such as geophysical survey effects on fish behavior and catchability, and the egg and/or larval stages of fish and shellfish, have been the principal focus of environmental studies conducted within the POCS Region. Mitigation of space use conflicts in the POCS Region has been addressed principally through a special permitting and notification system. The need for mitigation measures specifically designed to minimize potential fishery resource conflicts are considered premature by the POCS Region.

1. INTRODUCTION

In recent years conflicts between the commercial fishing industry and geophysical survey activities permitted by the Minerals Management Service (MMS) Pacific Outer Continental Shelf (POCS) Region have become an increasingly important issue. Unlike exploratory drilling and development and production activities, which are also subject to MMS regulation and presently concentrated in only a few areas within southern California, geophysical survey activities and potential commercial fishing conflicts may occur throughout all four OCS Planning Areas in the POCS Region. Conflicts between the two industries may occur as a result of spatial preclusion and interference, gear damage and loss, and potentially from fishery resource impacts such as fish dispersal and reduced fish catchability, and direct effects on eggs and larvae. Because of public concerns raised over the potential for fishery resource impacts, the MMS POCS Region has directly funded or participated in several recent studies and others are planned in the near future. Due to the importance of geophysical survey exploration, and the controversy surrounding this issue in the POCS Region, this paper will discuss: (1) the types and general characteristics of geophysical survey activities that occur in the POCS Region, (2) the types of conflicts that may arise and the potential vulnerability of different commercial fisheries to these conflicts, (3) studies either conducted or planned by the POCS Region of the MMS to investigate the potential for geophysical survey effects on fishery resources, and (4) existing and/or potential mitigation for reducing conflicts between geophysical survey activity and commercial fishing in the POCS Region.

2. GEOPHYSICAL SURVEY ACTIVITIES AND POTENTIAL COMMERCIAL FISHING CONFLICTS IN THE MMS POCS REGION

Two types of geophysical survey operations are conducted on the POCS: (1) deep seismic surveys and (2) high resolution shallow geologic hazard surveys. Deep seismic surveys are designed to investigate subsurface geological formations for the purpose of exploration and may be either two-dimensional (2D) or three-dimensional (3D) in design. Typical 2D geophysical surveys are normally conducted during the prelease stage for regional exploration, as well as during postlease exploration on a smaller scale, whereas 3D geophysical surveys are used as a postlease tool when detailed information is required to determine locations for potential exploratory or production drilling activity. In contrast, high resolution surveys are generally conducted during postlease exploration and/or development to reveal shallow geologic details and potential drilling hazards necessary to safely site drilling rigs, platforms, and pipelines. For these reasons, 2D surveys may occur throughout the POCS Region, depending upon the MMS leasing schedule, while 3D and high resolution surveys occur only in southern California where postlease operations presently occur. The characteristics (e.g. acoustic sources, shot line spacing, survey duration) of these three basic types of geophysical surveys are quite different (table 1).

Table 1. Types and characteristics of geophysical surveys conducted in the Pacific OCS Region.

Survey Type	Phase	Acoustic Source	Cable Length	Shot Line Spacing	Survey Duration	Survey Area
Deep Seismic						
2D	Pre lease regional coverage	airgun/ watergun	1-2 mi	broad/ 1-3 mi	variable/ 1 or more months	variable/ medium to large
3D	Post lease pre/post drilling	airgun/	1-2 mi	close/ to 50 m	variable/ 1 or more mos	small/one to several lease blocks
High Resolution						
	Post-lease Explor./ Develop.	sparker/ sub bottom profiler/ sidescan	none to 100-1000'	intermed./ 300-500m or less	1 mo or less	site specific/ one to several lease blocks

For this reason, each type of geophysical survey has the potential to generate a different set of conflicts with commercial fishing activity in the POCS Region.

Geophysical survey activity in the POCS Region may potentially conflict with commerical fisheries through: 1) spatial or areal preclusion and/or interference, 2) fishing gear and/or vessel damage or loss, and 3) direct effects on the abundance of fishery resources (ie. eggs, larvae and/or adults), or on the availability (i.e. dispersal) of targeted resources. Conflicts of these types may secondarily result in fishermen being forced to move from the geophysical survey area to another fishing ground, loss of fishing opportunity, increased competition between fishermen, reduced catches and economic losses, and loss of fishery product markets. Additional issues raised by commercial fishermen include multiple geophysical surveys in the same areas, slow and/or difficult compensation procedures (either with the Federal Fishermen's Contingency Fund or directly with companies that are at fault), "straying" of geophysical vessels outside of their permitted survey boundaries, intentional damage of gear by geophysical vessels, and potential health and/or safety effects on commercial dive fishermen. Not all types of commercial fisheries that occur on the POCS are considered to be equally vulnerable to the potential geophysical survey conflicts listed above. In general, fixed gear fisheries are considered to be most vulnerable to conflicts with geophysical survey activities; however, there is considerable variability among the different fisheries (table 2).

3. ENVIRONMENTAL STUDIES CONDUCTED BY THE MMS POCS REGION ON POTENTIAL FISHERY RESOURCE EFFECTS

Commercial fishermen (and others) in California have claimed that the acoustic signals produced by airgun arrays and/or other types of energy sources used in geophysical surveys: 1) directly damage fishery resources at the egg and larval stages and therefore may result in reduced abundance of commercially harvestable adult fish or shellfish and 2) cause the dispersal of adult fishes resulting in lost fishing opportunity and/or the reduced catchability of fish targeted by fishermen. Direct damage of the egg and larval stages of commercially harvested fishery resources by acoustic signals has been raised as an issue by the fishing industry in general, although trapfishermen targeting lobster in southern California and Dungeness crab in northern California represent specific groups with this concern. Fishermen representing a wide range of fisheries (e.g. hook and line, trawl, drift gill net, troll) have raised the issue of fish dispersal effects; however, hook and line fishermen and salmon trollers, in particular, have probably been the principle groups concerned with this issue. In addition to fishermen and others in California, these questions are of concern in other areas or countries (e.g. British Columbia, Canada, and the North Sea). Because of the limited scientific evidence concerning these potential types of effects, and the high level of concern by fishermen and others in the POCS Region, the MMS has recently emphasized the study of these issues. This section provides a review of these studies, focusing particularly on those either sponsored by the MMS POCS Region or those in which the Region has participated.

Table 2. Sensitivity of commercial fisheries in California to potential geophysical survey conflicts

Fishery Type	Conflict Type: Space Preclusion	Gear Damage	Resource: Direct	Dispersal	Health/ Safety
Fixed Gear					
Trap	H	H	P	-	-
Hook/line	H	H	-	P	-
Set gillnet	H	H	P	P	-
Mobile Gear					
Trawl	L-M	L	P	P	-
Troll	L-M	L	-	P	-
Drift Gillnet	L-M	M	-	P	-
Purse Seine	L	L	P	P	-
Dive	P	-	-	-	P

H=high, M=medium, L=low, P=potential

a. Effects on Eggs and Larvae

Very few studies have investigated the effects of seismic energy source (i.e. airguns) exposure on the eggs and/or larvae of fish [1,2,3]. These studies have examined direct effects on survival, as well as sublethal effects on growth and histological condition in some instances. Results indicate that eggs and/or larvae suffer mortality or other adverse effects only when in close proximity (i.e. 5-10 meters or less) to operational airguns or waterguns. To date, no studies have been published concerning effects on shellfish eggs or larvae. Although the POCS Region of the MMS has not directly sponsored any studies on fish or shellfish eggs and/or larvae through the Environmental Studies Program, regional staff serve on an interagency-industry group known as the Egg and Larval Committee (ELC). The ELC, together with the American Petroleum Institute, directed the Tracor Applied Sciences (1987) study. The ELC consists of representatives of the commercial fishing, geophysical and oil industries, as well as the MMS POCS Region, National Marine Fisheries

Service (NMFS), California State Lands Commission, and California Department of Fish and Game.

In the study by [3], northern anchovy eggs and larvae (yolk sac and postyolk-sac larvae ranging from 1 to 22 days of age) were exposed to a range of peak pressure (1-5 bars) and cumulative energy levels using single airguns ranging from 10-300 cubic inches (CI) in volume and a small subarray consisting of four 300 CI airguns. The experimental exposure regime consisted of multiple airgun shots designed to simulate the approach, passage, and departure of an operational seismic vessel past the test organisms. Exposure to airgun signals under this regime resulted in statistically significant (at the 5% level) reductions in survivorship for eggs (up to 8%) and nonfeeding yolk-sac larvae (14-35%), although reduced survivorship was not detected in all experimental trials. The highest reduction in survivorship between test (45.5% survivorship) and control (68.6% survivorship) larvae was 35 percent in one experiment with 2-day larvae. However, this level of mortality only occurred at an acoustic energy or sound exposure level that was reported to be three to four times higher than that which would occur with a 40-gun array passing directly over the larvae at a distance of approximately 3 meters. While not statistically significant, there appeared to be a higher correlation between reduced survivorship and increasing cumulative energy exposure than with increasing peak pressure. There was no evidence that feeding larvae suffered a significant reduction in survivorship as a result of airgun exposure. At the higher peak pressure and cumulative energy levels, total larval length was significantly reduced in some experiments with larvae of ages 2, 4 and 22 days. While the authors reported no evidence of gross morphological or tissue damage based on histological evaluation of larvae, the tissue condition of approximately 6 percent of the larvae examined was similar to that reported for larvae that had fed poorly or been starved. The authors hypothesized that the observed tissue condition may have resulted from changes in feeding behavior and/or success due to airgun exposure.

The limited scientific evidence presently available [1,2,3] suggests that any effects on fish eggs and/or larvae would most likely occur only within close proximity (i.e. less than 10 meters) to an operational airgun array. A Science Panel convened by the ELC in January 1988 to review an experimental design proposed for a study on Dungeness crab larvae also concluded that potential effects on larvae would most likely occur only in the near field (i.e. within approximately 10 meters or less) of a typical airgun array. For this reason, the Science Panel concluded that a single shot, static exposure of larvae using a single linear array consisting of 6 to 8 airguns would best simulate the sound pressure or energy levels experienced by eggs or larvae during an actual geophysical survey. The conclusions of this Science Panel also suggest that the study by [3] may have actually overexposed larvae to acoustic energy since a multiple shot exposure protocol was used.

Given the spacing and pattern of shot lines during actual 2D and 3D geophysical surveys, the patchy distribution of eggs and larvae, and the movement of eggs and larvae due to currents and other transport processes, it seems unlikely that individual eggs and/or larvae would normally be exposed to more than one or two shots within the near field influence of an array during an actual survey.

Predicting subsequent population level effects on commercially harvestable fish and/or shellfish species resulting from egg and/or larval mortality associated with actual geophysical surveys is extremely difficult and probably is best approached by population modeling. This approach will require development of an acoustic model for various geophysical sources, experimental determination of survival rates for all larval stages, a geophysical survey model, and a population impact model. The ELC intends to pursue modeling efforts of this type following the completion of all the necessary field studies on Dungeness crab larvae.

Currently, the MMS POCS Region is not planning to exclusively fund future studies on the effects of airgun sources on the eggs and larvae of fish and/or shellfish, but will remain an active participant in such studies through the ELC. For example, the Battelle Memorial Institute, under the direction of the ELC, is currently studying the effects of acoustic signals from an airgun subarray on the zoea stage of Dungeness crab larvae. This study is expected to be completed during the summer of 1988. The MMS contributed direct funding of $70,000 to this project, as well as indirect funding of approximately $250,000 through Federal 8(g) payments to the State of California. Other groups contributing to the funding of this project include the National Coastal Research Institute, Arco, the Western Oil and Gas Association, the Provincial Government of British Columbia, and the Federal Government of Canada. In addition to this ongoing study, the ELC expects to fund additional controlled field experiments using the larval megalopae stage of Dungeness crab, as well as population and acoustic modeling studies to address the question of potential effects on adult crab populations.

b. Fish Dispersal Effects

There are at least two early field studies that suggested adult fish respond to airgun energy releases. According to [4] (as cited in [5]) Atlantic herring responded to airgun sound pressure levels of 180 dB (re 1 micro Pascal at 1 m) by swimming away from the airgun source. Similarly, [6] reported that airgun sound levels of 188 dB (with a source level of 220 dB re 1 micro Pascal at 1 m) caused whiting to change their depth distribution. A recent study conducted in the North Sea [2] also suggested that the distribution and abundance of adult fishes (i.e. a demersal mixed fish species assemblage and whiting) was changed by exposure to seismic energy or sound produced by a 40-gun airgun source used in a simulated 3D geophysical survey. However, the design of this study was confounded by differences in the time of day observations were made, the natural movements of fish during the presurvey, survey, and postsurvey periods, the elapsed time between the pre- and postsurvey periods of data acquisition, and the lack of a true control. For these reasons, a direct cause-and-effect relationship between the seismic survey operations and changes in fish distribution and abundance was not convincingly established. Because of the importance of the fish dispersal issue in California, the MMS POCS Region has actively been investigating the effects of airgun signals and geophysical survey activity on fish dispersal and catchability.

A joint industry-sponsored pilot fish dispersal study[7] was recently conducted off Point Conception under the auspices of a joint Seismic Steering Committee that included the POCS Region of MMS, the NMFS, various California state agencies, and the oil, geophysical and commercial fishing industries. The principal objective of this study was to investigate the purported dispersal of rockfish aggregations (or plumes) associated with rocky outcrops by geophysical survey operations. Several experimental trials were conducted with commercial fishing vessels monitoring the size, shape and distribution of rockfish plumes by fathometer while an approaching seismic survey vessel (the Arco Resolution) discharged a 28-gun (4,000 CI) array under normal operating conditions. The operational seismic vessel approached the target rockfish plumes from distances of approximately 10 nautical miles (nmi) to distances of less than 1 nmi. Sound pressure levels measured near the depth of target rockfish plumes ranged from 152 to 203 dB depending upon the distance of the seismic vessel from the target plume. Each experimental trial was essentially equivalent to a single line shot during a 2D or 3D seismic survey. Observations indicated that the height of some rockfish plumes decreased during experimental trials; however, both the height and distribution of some plumes changed in the absence of geophysical survey operations. Although the data suggested a possible effect on the spatial distribution (i.e. the height) of some rockfish plumes, the results were inconclusive. Additional controlled studies were recommended by [7] and the Seismic Steering Committee.

In response to the recommendation of the Seismic Steering Committee, the POCS Region of the MMS funded a followup study conducted by [8]. The study consisted of both behavioral observations on caged rockfishes and controlled field experiments targeting rockfish plumes associated with rocky outcrops. The acoustic source used for all experiments was a single 100 CI airgun operated at 450 psi. In the behavioral experiment, mixed species of caged rockfish were observed prior to exposure, during exposure (for approximately 10 minutes) at a range of sound pressure levels, and after airgun exposure ceased. Experimental exposures and observations were made at distances ranging from 5,800 to 11 m, corresponding to sound pressure levels of 137 to 206 dB (re 1 micro Pascal at 1 m), respectively. Behavioral observations indicated that several rockfish species elicited alarm and/or startle responses to sound pressure levels generated by the single airgun. The nature of the alarm responses varied with the different species, but a threshold sound level eliciting the observed responses was estimated at approximately 180 dB (re 1 micro Pascal at 1 m). The estimated sound level threshold for startle responses was higher (200 to 205 dB) for those species exhibiting such a response. These responses were not always maintained throughout the entire sound exposure period, and the fish appeared to return to presound exposure behavior within minutes following cessation of the airgun sound exposure.

The controlled field experiments with rockfish plumes were principally designed to investigate rockfish catchability; however, observations were also made of plume height and shape. The experimental field exposure consisted of a vessel firing a 100 CI airgun source every 10 seconds while circling a target rockfish plume for 60 minutes at a distance of approximately 165 m. The objective was to produce a sound pressure level at the rockfish plume of approximately 180-190 dB (the threshold sound level producing alarm and/or startle responses in the behavior experiment). Over this 60-minute exposure period set lines were fished for 20-minute periods and fathometer tracings were obtained before and during exposure to investigate catchability and plume height/area, respectively. Control experiments were conducted in an identical manner, but without the airgun emissions. Statistical analysis of the fathometer tracings produced conflicting results. No significant difference in the areal extent of rockfish plumes was found with airgun exposure, whereas a slight but significant decrease in the height of rockfish plumes was measured. Since no observations were made of rockfish behavior during these trials, it is unknown what (if any) behavioral changes were responsible for the decrease in rockfish plume height. Even though observations on changes in plume height and shape were somewhat equivocal, catch-per-unit-effort of rockfish by hook and line gear was found to be significantly reduced by approximately 50 percent as a result of the experimental exposure to airgun sound emmissions. Although this study experimentally demonstrated effects of airgun sound emissions on rockfish behavior, distribution, and catchability, the exposure regime used did not attempt to simulate sound exposure conditions that would occur during an actual geophysical survey, and may have represented an unrealistic overexposure to airgun sound pressure levels.

The studies conducted to date, including those in which the MMS POCS Region has been involved[7,8] are inconclusive. However, these studies do suggest that adult fish may respond to signals from airgun sources by moving away from the source, by eliciting identifiable alarm and/or startle response behavior, or by changing their distribution. The limited information suggests a threshold sound level that elicits behavioral responses may occur at 180 to 190 dB, that habituation of fish to, or recovery from, sound pressure exposure may also occur, and that catchability of adult fish may be reduced.

Although some questions have been answered by these studies, there are still many others that need to be resolved. Given the present level of information and design of these experiments, it is not possible to accurately assess the threshold distance or sound pressure levels at which these types of effects occur, the duration of exposure required to cause the effects, or the time required for recovery to preexposure conditions. To obtain additional information for impact assessment, the MMS POCS Region is funding a second study in 1988 to further investigate the effects of geophysical survey activities on commercial fishing in California. The objectives of this study will be to determine: 1) whether a representative acoustic source and survey pattern more typical of those used offshore California measurably reduces fish catch and, if so, the magnitude and duration of the reduction, 2) how reduced catch may vary as a function of the sound pressure level and/or distance from the source and as a function of the duration of exposure, 3) the duration of reduced catch following cessation of exposure to threshold sound pressure levels, and 4) underlying mechanisms responsible for reductions in reduced catch (e.g. behavioral changes in swimming patterns and/or feeding).

4. MITIGATION OF POTENTIAL COMMERCIAL FISHING AND GEOPHYSICAL SURVEY CONFLICTS IN THE MMS POCS REGION

a. Space Use and Gear Damage Conflicts

Based on past experience the MMS POCS Region has found that geophysical survey operations may conflict with the operations of commercial fishermen. To eliminate or minimize space use (i.e. spatial preclusion and interference) and/or gear damage conflicts on the California OCS, the MMS POCS Region has established a special permitting and notification system, which includes a requirement for negotiations designed to reduce conflicts between the permittee and commercial fishermen. This process includes a series of steps that must be followed by the geophysical survey permittee prior to the issuance of permits and during the actual survey period. At present, this process applies only to the California OCS where most geophysical survey activities occur in the POCS Region. This process has resulted in both the delay and spatial and/or temporal restriction of 2D and 3D geophysical surveys in California, either through the imposition of stipulations by the MMS POCS Region or as the result of joint negotiation between the two industries. The application and permit issuance procedures for geophysical (and geological) permits are published in a special Notice To Geophysical and Geological Survey Permit Applicants for the California OCS.

For the Oregon-Washington OCS Planning Area, individual Memoranda of Agreements (MOA's) have been established with each of these states to address potential conflicts between the commercial fishing and geophysical industries. The individual MOA's identify areas, depth ranges, and times of various types of commercial fishing activity, as well as times and areas of potentially high conflict. In addition, the MOA's provide for the Oregon and Washington Departments of Fish and Game to participate in the review of permit applications prior to approval.

b. Potential Fishery Resource Conflicts

Based on existing scientific information, the MMS POCS Region believes that the development and imposition of mitigation measures designed to minimize potential fishery resource conflicts are premature at this time. As discussed previously, the available scientific literature concerning the potential for fish dispersal and its effect on fish catchability is either equivocal or has failed to clearly demonstrate a direct cause-and-effect relationship between dispersal and actual geophysical survey activity. Similarly, the MMS does not believe that the available scientific information concerning the effects of acoustic airgun sources on fish eggs and larvae supports the conclusion that fishery resources are significantly affected by geophysical survey activity. Each of these issues requires further study, and the MMS POCS Region intends to take an active role in this process. The POCS Region is committed to further study of fish dispersal and reduced fish catchability issues as described above and intends to continue its participation on the ELC to better understand potential egg and larval effects resulting from airgun exposure, as well as the potential for effects on adult fish and shellfish populations.

If potentially significant effects on fish eggs and/or larvae, or fish dispersal and catchability are demonstrated by these and perhaps additional studies, the MMS POCS Region will need to consider the development and imposition of mitigation measures to reduce the conflicts. Although presently speculative, these measures could take the form of: 1) area and/or time closures (i.e. windows) for geophysical survey activity to avoid important spawning periods or areas and peak fishing periods or areas, and 2) the use of standoff distances between geophysical survey vessels and areas of commercial fishing operations.

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THE USE OF ALTERNATIVE DISPUTE RESOLUTION IN RESOLVING OUTER CONTINENTAL SHELF DISPUTES

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In recent years, the diverse parties and interests in a given OCS dispute arena have elected to try alternative dispute resolution approaches for addressing their differences.

Four case studies, three in California and one in Alaska, are described in detail. There have been both successes and failures, but most important, critical lessons learned that may be applied in the future.

Since the beginning of this decade, the number of challenges to the exploration and development of our outer continental shelf oil and gas reserves has dramatically increased. Concerns about effects on air quality, water quality, ecological balance and potential impacts on commercial fishing, tourism and other ocean dependent activities have been transformed into public opposition to leasing policies and to some of the current operating practices of the off-shore oil and gas industries.

Some of the Challenges have resulted in litigation. Other battles have been waged in the political arena. However, for many disputants, neither of these strategies have yielded solutions that are satisfactory. Most recently, the diverse parties and interests in a given OCS dispute arena have elected to try new approaches for addressing their differences that facilitate joint problem-solving, and face to face negotiations.

WHAT ARE SOME ALTERNATIVE DISPUTE RESOLUTION APPROACHES UTILIZED IN OCS DISPUTES?

Alternative disputes resolution processes have been applied in the labor relations and international affairs for many years. In the late 60's, professional mediators in these two fields began to experiment in applying these same approaches to public policy disputes. These initial efforts have evolved from being experimental to being a widely accepted option for dispute resolution.

The common ingredient in these approaches is the voluntary participation of the parties in addressing their differences through the involvement of third party neutrals who assist the parties in their deliberations. To date, disputants in OCS conflicts have engaged in policy dialogues, facilitated discussions, mediated formal negotiations, a negotiated rulemaking and scientific negotiations. The involvement of the neutral intervenor has ranged from that of **convenor**- helping the parties define the terms and conditions for negotiating, **facilitator**- assisting the parties in improving their communication at meetings and in recording the results of discussions, **mediator**- assisting the parties in jointly exploring their differences, exchanging proposals and helping them move towards their own consensus, and **process consultant**- designing and ad hoc process for deliberations and implementation of agreements that accomplishes the goals of the participants. The third party neutrals in the case studies described below were called upon to play one or more of these roles during the course of the processes that emerged.

This paper describes some of the situations in which voluntary, alternative dispute resolution approaches have been employed. Four case studies, three in California and one in Alaska, are described in detail. There have been both successes and failures; but more importantly, there

CASE STUDIES

Space Use Conflicts Between the Commercial Fishing Industry and the Off-shore Oil Industries

In 1983, after the period of intensive oil activity in the Santa Barbara Channel, the number of conflicts between the oil and fishing industries reached crisis proportion. Accepting the advice of the Sea Grant Marine Advisor, leaders among the two industries agreed to consider formal negotiations with the assistance of a mediation team to address both their immediate needs and long range concerns.

After six weeks of careful preparation and formulation of an agenda, the parties met in their first formal joint session. Agency representatives were present as observers. The press was excluded, since both sides wanted a full and frank discussion of the possibilities of establishing ongoing talks.

The outcome of this meeting was the formulation of the Joint Oil/Fisheries Liaison Committee or **The Joint Committee**, whose goal was to negotiate the issues that had been mutually agreed upon as potentially resolvable through formal deliberations. The Joint Committee, over several years time, has been credited with the following accomplishments:

Establishment of a Liaison Office to facilitate inter-industry communication on potential short-therm conflicts and long-term planning

Design and implementation of a vessel traffic corridor map to minimize at-sea interference between crew and supply boats and fishing vessels

Formulation of an areal preclusion mitigation program which provides for a vessel safety inspection and equipment program, a gear technology grant program, marketing assistance and a gear repairing and staging area.

The areal preclusion program, supported by both the Governor of California and key coastal legislators is directly tied to enhancing the ability of commercial fisherman to seek new fishing grounds and markets in the event that tradition fishing operations are interrupted by either short or long term oil activities.

The Eggs and Larvae Committee (Scientific Negotiations)

One of the issues that divided the fishing and oil industries in their deliberations was the question of possible effects by acoustic air gun signals on both fish behavior and the survival of fish eggs and larvae.

Recent attempts to resolve scientific issues on potential impacts had resulted in each faction questioning the credibility of a given research project, especially when it had been commissioned by an industry or agency perceived to have a self-interest to protect. Not surprisingly, studies undertaken under the auspices of industry or an agency perceived as having a pro-leasing or pro-oil stance would be branded as biased as were studies commissioned by opponents of individual projects.

The oil industry and fishing industry negotiators in Santa Barbara were determined not to replicate this situation nor to waste further funds or time on studies that would be rejected as biased. With the assistance of a mediator, they designed a process whereby both industries and all the key agencies - state and federal leasing agencies as well as resource protection agencies at the state and federal levels - would jointly design and oversee research studies that they deemed critical.

This multi-party committee was formed to determine if commercially valuable fish species were dispersed by geophysical acoustic airguns. The committee commissioned a pilot study based on the recommendations of a specially convened neutral panel of experts. The study results were then incorporated into a major study by MMS integrating the results of the pilot study.

Using the same model of deliberation, the group reconstituted itself, added new members and renamed itself the Eggs and Larvae Committee. This Committee's goal was to determine if there were any effects on the eggs and larvae of commercially valuable fish by the acoustic airgun signals. The Committee utilized the same approach as their predecessor committee: convening of panel of experts, preparation of a research design based on the advice of the panel, joint writing of an RFP, selection and monitoring of a contractor and joint issuance of the findings of their study.

To date, the Committee has undertaken two studies, one on anchovy eggs and larvae and a second on Dungeness crab. The results of these two field studies will then be utilized in a modeling study to determine if these observed effects translate into a significant impact at the population level.

Key to the success of the Eggs and Larvae Committee has been the involvement of mutually acceptable panels of science experts at each stage of the Committee's deliberations. The scientists selected were carefully screened to ensure that they would not be viewed as supporting one interest group or another based on previous contract work or reputation. The panel deliberations, which were also facilitated by a mediator, were viewed as "negotiations within a negotiations", since the scientists were asked to develop sets of consensus recommendations to the Committee.

Bering Sea Lease Sale Deliberations

A small group of oil industry representatives and environmentalists, who were concerned about the unending controversies over off-shore oil development and the seeming lack of solutions, agreed to met in Washington, D.C. to explore approaches for improving the lease sale process. This meeting resulted in the formation of a steering committee.

The committee, assisted by staff from the Institute for Research Management which had served as the convenor for the initial meeting, decided to sponsor a conference to further discuss the issues that separated industry and environmentalists but also to broaden the participation of groups interested in problem-solving in the OCS arena. Based on the input from the conference, the steering committee concluded that it was preferable to jointly identify priorities early on in the process thus giving more predictability to both sides. Joined by some of the key interests who had participated at the conference, they decided to choose a potential lease sale area to see if this approach would work as an alternative to lobbying in Congress. They selected the Bering Sea as their "test" case.

The oil industry did a survey of needs among 19 companies who were asked to rate tracts into four categories ranging from greatest interest to least interest. A coalition of environmentalists, which included native Alaskans and fishermen, were asked to undertake a similar process. Price Waterhouse, which kept the raw data confidential, consolidated the material into a map which identified where high priority areas overlapped and where there were lesser degrees of potential conflict.

At an intensive two day meeting, the negotiators pieced together a map which indicated which tracts should not be leased and which were appropriate but would require further negotiation of conflict areas. The group then began to work out stipulations for leasing this latter category.

Unfortunately, after a series of follow-up meetings, several of the participants withdrew because of disagreement on some of the provisions being negotiated. The final agreement was not signed by all, but the dissenters submitted letters indicating where there was consensus and where there was not.

The negotiated agreement was submitted as part of the public comment on the 5 year plan for the Bering Sea and was reflected in one of the three preferred alternatives in the EIS.

The negotiating committee that had remained in tact set up an ongoing group, The Bering Sea Resources Association, whose role was to work out the specifics on each upcoming sale. They were active during the first sale and are expected to continue their efforts and respond to all the additional sales that are currently scheduled.

Negotiated Rulemaking on Air Quality Standards for the OCS in California

The Department of Interior and State of California, in an attempt to settle longstanding litigation on air quality rules for oil and gas operations off California, convened a group of twenty-five negotiators representing approximately fifty separate interests to prepare a consensus rule. Such rulemakings had been convened by OSHA, the FAA and EPA and were viewed by many officials as a viable alternative to the long, protracted traditional administrative process which more often than not ended in litigation.

Conceptually, the parties that would normally play an active role during the public comment phase on a proposed federal rule would instead participate in a series of meetings to draft rule provisions deemed acceptable to all the parties in the process. During the public comment period, the negotiators would be expected to comment favorably to the agency assuming the rule embodies the provisions of the negotiated consensus document.

Because of the confidentiality agreement governing the OCS Negotiated Rulemaking, one cannot discuss the substantive content of this process in great detail, other than to describe the structure of the Negotiating Committee.

Five caucuses or bargaining groups were established - the Federal Caucus (DOI, EPA, OMB, DOE AND DOJ), The State Caucus (Air Board and Coastal Commission), the Local Caucus (the coastal counties and central California coastal cities), Industry (represented by WOGA), and the Environmental Caucus (Sierra Club, NRDC, Santa Barbara environmentalists, Citizens for a Better Environment and Coalition for Clean Air). This framework was necessary to ensure that all the key groups interested in formulating the provisions of the rule were well represented in the process.

It was incumbent on each individual caucus to reach a consensus among its members as a prerequisite for conducting negotiations with the other interest groups. This delicate balancing of interests, although necessary to achieve an ultimate consensus, made the process even more complex and lengthy than had been originally envisioned. The mediation/facilitation team often found itself assisting in seven or eight simultaneous negotiations - five internal caucus deliberations, discussions between individual caucuses with similar interests or positions and then, of course, the negotiations of the total group.

Whether or not a consensus is ultimately reached, the negotiated rulemaking in California has provided a valuable experience for all the participants. They were able to share technical information with one another, propose solutions to problems in a manner that accommodated the needs of each interest and to work towards a common goal - reducing the conflicts that had been draining the time and resources of the parties who faced off for each OCS permit application.

APPLICATIONS FOR THE FUTURE

1. The accomplishments of the oil/fishing negotiations in Central California are readily replicable in other areas. Vessel traffic maps, project scheduling and ongoing conflict resolution mechanisms can be adapted to fit the individual locale in which communications are established between these two industries.
It is also recommended that this type of effort be established early in the process of exploring for oil and permitting permanent facilities. Responding while conflicts are occurring or after the fact is difficult and likely to be less successful.

All the participants in the oil/fishing negotiations still firmly believe that the voluntary approach to problem solving is mutually beneficial despite instances in which enforcement of their voluntary system have broken down. With a voluntary approach, changes can be made more readily to accommodate schedules, weather and ocean phenomenon such as El Nino. Although both sides occasionally wish that an agency could step in to play the role of enforcer, they both recognize that, in the balance, the benefits of a voluntary system outweigh those of formal government intervention. Government support for these types of efforts, however, is indispensable.

2. The experience of the Eggs and Larvae Committee has indicated the value of multi-party involvement in overseeing research efforts that affect policy decisions on controversial public issues. However, unlike the typical advisory committee, all the members of the Eggs and Larvae Committee share an equal role, responsibility and vote. Although time-consuming, their consensus decision-making approach (unanimity on all actions) is seen as critical to the acceptability of their research products. The scientists involved on the panels view these "scientific negotiations" as a positive, constructive use of their expertise and

several have agreed to continue to donate their time whenever requested by the Committee or groups to have decided to model the Committee's approach.

3. The Bristol Bay deliberations are an example of pre-conflict negotiations. The process that evolved enabled the parties to have more open communication and to discuss their real interests, rather than those that could bring them the best press coverage or gail the most public sympathy. The map/ranking exercise represents a unique approach for negotiated problem-solving that may be applied to other environmental arenas as well.

The neutrals, both the facilitators and the independent auditing firm, enabled the participants to share valuable, confidential and strategic information in a manner that benefitted both sides. Most importantly, it enabled the parties to deal with one another with respect.

The parties were able to narrow the size of the playing field and concentrate their efforts on those issues and areas that were most critical, instead of waiting until their positions were entrenched and resources wasted in fighting peripheral battles.

In adapting this approach in the future, one might consider broadening the base of participants even further to include the leasing authorities, and natural resource protection agencies at the state and federal level.

4. Each of the situations described in this paper involved the use of third party neutrals to facilitate communication, assist the parties in developing compromise solutions and designing conflict resolution mechanisms that provided the opportunity for all the participants to share in the decision-making.

Although the participants in each of these cases might have deliberated and negotiated on their own, the third parties played a valuable role in ensuring access of all the participants to the process and involvement in all the decisions. Unlike in labor-management where the parties have a formal relationship and negotiate routinely, the disputants in the OCS case studies relied on the facilitators/mediators to help them design a mechanism for communicating and deliberating with one another that accommodated their "ad hoc" relationship.

5. Success and failure in these alternative dispute resolution processes cannot be measured entirely on the production of a final consensus document, although all the participants certainly would have preferred this outcome. With or without a consensus, the participants believe that they have benefitted from the experiences. New and creative solutions to problems have emerged in all cases; cooperative working relationships have been developed that have continued in other settings. Most importantly, the participants have gained a greater understanding and respect for one another's positions and needs as organizations that is rarely achieved when one battles in the legal and political arena.

THE FUTURE OF THE DEPARTMENT OF THE INTERIOR OCS STUDIES PROGRAM

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ABSTRACT

For the past two years the Minerals Management Service has been evaluating the goals and implementation of the OCS Environmental Studies Program (ESP). This effort has led to the development of a Long Range Study Plan, which presents a blueprint for the future of the ESP. This is a comprehensive evaluation of our level of understanding concerning the environmental impacts of oil and gas development on the OCS, and the role the MMS should play in meeting future environmental data requirements. It is clear that we will be emphasizing process-oriented, interdisciplinary field monitoring programs in the future, in order to more fully evaluate long-term low-level impacts.

1. INTRODUCTION

The Minerals Management Service (MMS) is responsible for the leasing and supervision of offshore oil and gas operations on the U.S. Outer Continental Shelf (OCS). The MMS is committed to obtaining, and using, appropriate environmental information at all phases of the offshore oil and gas program. This commitment began even before the passage of the Outer Continental Shelf Lands Act (OCSLA) amendments in 1978 and remains a critical, and highly visible, component of the offshore program. The nearly $450 million expended since the inception of the Environmental Studies Program (ESP) in 1973 is indicative of the high level of commitment of the Department of the Interior.

While the ESP did begin in 1973, 5 years before the passage of the OCSLA amendments, the purpose of the program is defined by the provisions of that legislation. The Act, as amended, is intended to expedite exploration and development of OCS minerals; it also establishes constraints on these activities. One of these constraints is that the Secretary of the Interior must balance orderly energy resource development with protection of the human, marine, and coastal environments.

The OCSLA amendments also established the ESP, and gave it the objective of "establish(ing) information needed for prediction, assessment, and management of impacts on the OCS and the nearshore area which may be affected..." (43 CFR 3001.7). Within the guidelines established by the Act, the ESP strives to:

1.) Provide information on the status of the environment upon which the prediction of the impacts of OCS oil and gas development may be based.

2.) Provide information on the ways and extent that OCS development can potentially impact the human, marine, biological, and coastal area.

3.) Ensure that information already available or being collected under the program is in a form that can be used in the decisionmaking process associated with a specific leasing action or with the longer term OCS minerals management responsibilities.

4.) Provide a basis for future monitoring of OCS operations, including assessments of short-term and long-term impacts attributable to the OCS oil and gas program.

These general principles have always formed the basis of the ESP; however, there have been significant changes over the years in how the program has addressed each of them.

2. PAST ACCOMPLISHMENTS OF THE ENVIRONMENTAL STUDIES PROGRAM

In the early years of the ESP, between 1973 and 1978, the focus was primarily on baseline and monitoring studies that were intended to address basic questions concerning resources at risk. In retrospect, some of the program objectives of that time were naive. In 1978 large-scale baseline surveys were eliminated as being inappropriate and not statistically useful for interpreting potential impacts. Other early efforts to define the laboratory and field toxicity of oil, characterize the biological resources at risk, and work on physical oceanography and modeling were more successful and made a substantial contribution to the scientific literature. This decision was influenced by a U.S. General Accounting Office (U.S. GAO) review of the program (1) and by the results of a National Research Council (NRC) study of the existing program's scientific merit (2). Subsequent to the NRC review, a program management document was prepared that documented the restructuring of the ESP and required a clear relationship between a study and OCS issues and decisions (3). That guidance document continues to be in effect today, although it is presently under review to see if it requires updating.

In the succeeding years, the ESP supported a broad range of studies oriented towards refining our understanding of the potential impacts of operational discharges from both exploration and production platforms as well as the consequences of oil spills. Because of the high interest in exploring the OCS off Alaska in the mid-1970s, MMS, in cooperation with U.S. National Oceanic and Atmospheric Administration (NOAA), undertook a major effort to evaluate the ecological and social impacts of such development. A significant effort was also supported in the North Atlantic in response to concerns over the proposed exploration of the Georges Bank area. Efforts in the Pacific and the Gulf of Mexico, while significant, were not as extensive during this period.

From 1978 through 1985, the program's content was fairly consistent. Individual studies varied from year to year and regional emphases changed, but there was little programmatic restructuring. There was a considerable emphasis on field studies in physical oceanography and marine biology to characterize the ecological resources at risk in the various planning areas and to provide the data necessary for circulation modeling, which also received considerable support. Toxicity studies were undertaken, primarily to define lethal effects of both petroleum compounds and operational discharges from drilling rigs or production platforms. Monitoring programs were developed or initiated by all of our regional offices to determine the extent of operational impacts. Endangered species, marine mammals and seabirds also received considerable attention. In Alaska, social and economic studies were also a significant part of our program.

It is difficult to summarize the results of the ESP during this period. In the first years of the program (1973-1977), a total of 137 contracts were completed. In the next 8 years (1978-1985) 546 contracts, four times the number for the first 5 years, were finished. In both cases the number of actual documents received was even greater, since many contracts produced multiple reports. This paper will highlight some of the more significant milestones that were achieved in these years. Of course, the Department of the Interior was not the only source of information related to oil and gas impacts in the marine environment during this period. This was a period of intense research activity worldwide, at least partially stimulated by the publication of a major review of the impacts of petroleum-related activities in the marine environment by the NRC in 1975 (4), which confirmed the need for additional data on many issues.

By 1980, the NRC concluded that many of the issues raised in their 1975 report needed reevaluation, and so the Ocean Science Board of the NRC began work on an update. For the next 4 years they worked to review and compile the relevant data, and in 1985, they published their results (5). Although not all of the issues raised in 1975 have been solved, they did conclude that considerable progress had been made. This 700-page report is the best available compilation of information on this subject currently available, and includes most of the research sponsored by the Department of the Interior through 1983.

A second review, undertaken somewhat later and sponsored by a number of Federal agencies, focused on the long-term effects of oil and gas activities in the marine environment (6). This document outlines the authors' approach to what they felt were the remaining scientific issues and attempts to prioritize them in terms of feasibility as well as importance. Both the NRC report (5) and that by Boesch and Rabalais (6), along with our conclusions based on the results of the ESP, are the key elements in the development of our future studies program. Based on these sources, what do we feel has been learned over the years?

First, the impacts of operation of an oil and gas platform or drilling rig on the OCS are localized and, except in areas where there are extreme concentrations of activity, are unlikely to have regional significance. The impacts in the immediate vicinity may be locally important, depending on hydrographic conditions and the presence or absence of sensitive biological communities, but usually are not a major problem. General conclusions concerning impacts can be extrapolated from appropriate studies to similar situations in other geographic areas. This has been demonstrated on several occasions by field monitoring programs, including those sponsored by MMS for exploratory drilling on the Georges Bank (North Atlantic) and on the mid-Atlantic shelf. It has also been supported by laboratory (and field) toxicity experiments, especially for operational discharges of muds and cuttings, as summarized by the NRC (7). Our research suggests, and a recent evaluation by a panel of scientists and managers assembled by the NOAA confirms, that operational discharges from offshore oil and gas facilities are, at worst, a low to moderate pollution problem (8). Other types of operational impacts, such as space-use conflicts with fisherman, may be locally significant, but have usually proven to be resolvable.

Issues related to oil spills from facilities on the U.S. OCS are a much more significant and intractable concern. While such events are extremely rare, the impacts of oil spills are serious and disruptive to the environment; however, most temperate habitats recover from spill events within several years. Even in arctic and tropical areas, or in temperate areas of special sensitivity such as marshes or estuaries, most, if not all, oil spill impacts appear reversible and similar in impact and magnitude to natural disasters. Again, location and climate play a significant role in determining severity. The NRC report (5) contains an excellent summary of the effects of several major oil spill events, which supports these general conclusions. Evaluation of oil spill impacts is a key environmental issue where ESP data can help define the risks and consequences more clearly. Unfortunately, research efforts are hindered by the fact that oil spills are both probabilistic and rare, which makes them difficult to study. The use of planned controlled spills, at least on the U.S. OCS, is not feasible at this time. Even if additional studies are conducted, it is clear that data alone will not resolve the issue of what constitutes an acceptable environmental risk.

While most researchers agree that acute impacts from operational discharges from OCS oil and gas facilities are minor or resolvable, there is less certainty concerning chronic, sublethal effects. Such impacts are hard to detect and quantify, and were not a high priority in the early days of the ESP when the acute impacts were not well defined. Now, these issues have become more critical as research topics, as documented by both the NRC (5) and Boesch and Rabalais (6).

3. FUTURE DIRECTIONS FOR THE ENVIRONMENTAL STUDIES PROGRAM

By 1985, the MMS had concluded that it would be appropriate to reevaluate the focus of the ESP. As part of that evaluation, the NRC was asked to review the ESP for a second time and to offer advice on the future direction of the program, as well as its progress to date. That process is now ongoing and the first portion of their review, involving the ESP physical oceanography program, should be available in the fall of 1988. The entire project will not be completed until late 1989. In addition to requesting the NRC review, MMS felt it was appropriate to try to develop an integrated, long-range management plan for the ESP.

Intermittently, MMS has compiled 3 to 5 year projections of study needs, primarily for internal management use. While these products have been referred to as "plans" they were not true management documents because they were not prepared in response to preestablished goals and objectives, and they were not integrated on a programmatic basis. When the planning for the Long-Range Study Plan began in 1985, it was envisioned as a link between the ESP, from a national perspective, and the anticipated events in a specific 5-year period.

Early in this effort it became obvious that the long lead time for planning environmental studies, along with the time necessary to complete many field studies, did not lend itself to a five-year planning window. Instead, the MMS chose to try to focus on likely events, both pre- and postlease, for the next 10 years, as best as they can be defined, to determine studies needs. These needs must be considered in the context of existing information, and so it was also decided that the document would present an analysis of the current status of knowledge for each area of proposed studies. The MMS could then concentrate on issues of high priority that were amenable to resolution by the scientific method and areas where additional data would clearly be beneficial to all parties concerned with the environmental effects of oil and gas development. At present, we intend to review and update the Long-Range Studies Plan in coordination with the preparation of each new 5-year Leasing Program.

The second draft of this document is now in internal MMS review. We expect to release it for public comment in the late fall of 1988. Based on the public comments, a final plan will be issued. We do not intend for this plan to offer detailed descriptions of all anticipated studies. Instead, we are focusing on information "goals" and "objectives". In the context of this effort a "goal" is defined as the ultimate accomplishment to be achieved, while an "objective" is an intermediate point to be achieved to satisfy the intended goal. This information will then direct the annual planning effort, during which individual studies are identified and prioritized for funding.

Based on our preliminary draft, existing program guidance, and on the information contained in NRC (5) and Boesch and Rabalais (6), it is possible to summarize some of the expected future trends for the ESP. These may undergo some modifications, based on the results of the Long-Range Study Plan review and the results of the ongoing NRC review, but they represent an accurate encapsulation of the future ESP.

1.) The ESP will continue to shift towards the collection of environmental information for postlease decisions, rather than for prelease analyses. In frontier areas where environmental information is scarce and where the potential for oil and gas production and development exists, the MMS will continue the collection of descriptive information specifically for use in the prelease process. However, there are lease areas where there exists an adequate environmental database on which prelease decisions have been made in the past and can be made in the future. In these areas additional descriptive studies useful only for refining the baseline data for prelease decisions will not be supported.

2.) As sales are held and exploration begins in various planning areas, the ESP will focus on areas of known oil and gas resources. In areas where the potential for oil and gas development is low or nonexistent, no, or only limited, environmental studies will be undertaken.

3.) In areas of oil and gas development and production, studies will be needed to monitor the possible effects of oil and gas activities on the environment of the area. Studies will concentrate on evaluating the long-term, low-level cumulative impacts of oil and gas development on the environment. A long-term monitoring program is already underway in the Pacific Region, and one is being planned in the Gulf of Mexico. Similar studies will be undertaken in other areas as appropriate. Emphasis will be placed on process-oriented studies that will allow explanation of the mechanisms at work to cause observed impacts.

4.) Studies in all areas will be phased to provide information at the appropriate point in the decisionmaking process. While MMS is committed to providing appropriate environmental studies, we must also operate within a restricted budget. Each phase of the oil and gas program, culminating in production activities, has unique information needs and offers unique study opportunities. For example, it is unreasonable to begin any type of monitoring activity in an area prior to determining if producible hydrocarbons are present and where they are located. Critics of the ESP have, on occasion, requested that detailed, site-specific information be developed prior to a lease sale. This is impractical to do on an areawide basis, given the localized nature of the potential impacts. While it is relatively common for questions related to operational impacts to arise during the prelease evaluation process, all such issues cannot be resolved at that time. In addition, much of the available data from other regions is useful in interpreting potential impacts. Appropriate prelease studies emphasize more generalized characterization, while more site specific studies are appropriate during exploration, development, and production.

5.) MMS will try to support studies to evaluate oil spill impacts whenever the circumstances suggest that a study would be appropriate, and our resources are sufficient to cover the costs. Since opportunities for this type of study occur infrequently, and are not predictable, each situation will be evaluated on its own merits.

6.) Efforts to improve data accessibility and/or utility -- including synthesis reports, state-of-the-art summaries and technical position papers -- will have a high priority.

Currently, one of the greatest concerns of the MMS is our inability to effectively communicate the results of the ESP (as well as other relevant research) to concerned citizens and non-MMS decision-makers. Many of the concerns raised about OCS oil and gas activities are overstated, especially when considered in the context of other activities on the OCS. Simply collecting further scientific data cannot resolve disputes involving value judgments. MMS can improve the process, however, by including information dissemination and management as a priority within the ESP. While having well-designed, focused studies with testable hypotheses is critical for the scientific community, it is equally important that we develop mechanisms to ensure that the information is used effectively. In the absence of effective communication, even the best studies are not fulfilling the goals of the ESP.

This paper contains only a brief summary of where the ESP is today and where it will be directed in the future. The final Long-Range Study Plan will provide much more detail. In addition, by incorporating the public's comments, as well as summarizing our experience to date, the MMS will create a mechanism that should improve our ability to provide information in support of the effective management of our mineral resources on the OCS.

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AIR QUALITY ISSUES, ENVIRONMENTAL STUDIES, AND CUMULATIVE IMPACTS IN THE PACIFIC OCS REGION

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ABSTRACT

Past and current air quality study needs were driven by the following issues: (1) the modeling requirements of the Department of the Interior's air quality rule (30 CFR 250.45), and (2) the need to accurately assess the potential effects of Outer Continental Shelf (OCS) oil and gas development on onshore nonattainment areas.

The early studies sponsored by the Minerals Management Service were directed toward developing the necessary modeling tools for impact assessment, while recent study efforts have been directed at understanding the OCS contribution to onshore air quality. An overview of several pertinent studies is presented. Selected results of the Joint Interagency Modeling Study are discussed with emphasis on the cumulative effects of OCS oil and gas activities on onshore ozone air quality.

1. INTRODUCTION

The Minerals Management Service (MMS), by virtue of the Outer Continental Shelf Lands Act and the Submerged Lands Act, and pursuant to delegation by the Secretary of the Interior, has jurisdiction over the Outer Continental Shelf (OCS) submerged lands. Since the MMS is the managing agency for these submerged Federal lands, it has certain regulatory responsibilities over offshore oil and gas development activities to balance energy resource development with protection of the human, marine, and coastal environments. One of these responsibilities is regulating oil and gas activities so that they do not significantly affect onshore air quality.

Air quality issues in the Pacific OCS are presented in Section 2. Studies addressing these issues are discussed briefly in Section 3. The paper concludes with a discussion of the cumulative effects of OCS oil and gas development on air quality in one area of the Pacific Region as determined by a photochemical modeling study.

2. AIR QUALITY ISSUES

The reason for conducting an air quality study is to satisfy the needs of the decisionmaker for appropriate information. An air quality study must be necessary for or contribute to an OCS leasing or permitting decision. Past and current air quality study needs were driven by the following issues:

- the modeling requirements of the Department of the Interior's (DOI) air quality rule (30 CFR 250.45), and
- the need to accurately assess the potential effects of OCS development on onshore nonattainment areas.

Significant Environmental Studies Program funds were also spent estimating potential air quality impacts from Pacific OCS Region lease sales. The results of these studies (or assessments) are not discussed here since they do not advance the understanding of air quality, but merely provide information regarding specific lease sales.

a. *Air Quality Modeling Requirements of 30 CFR 250.45*

To insure that onshore air quality is not significantly affected by OCS oil and gas development, the DOI established an air quality regulatory program as set forth in 30 CFR 250.45. The program is summarized in figure 1 and is basically a three-step process. The first two steps include a set of screening procedures to determine whether a particular OCS facility could significantly affect the onshore air quality of an adjacent State. The third step stipulates the air quality mitigation required under specific impact conditions and the attainment status of the impacted area. Modeling is an important part of steps two and three. An air quality modeling tool for estimating impacts from offshore sources did not exist when 30 CFR 250.45 became effective, so one of the first air quality study goals was to develop a model capable of simulating pollutant dispersion overwater.

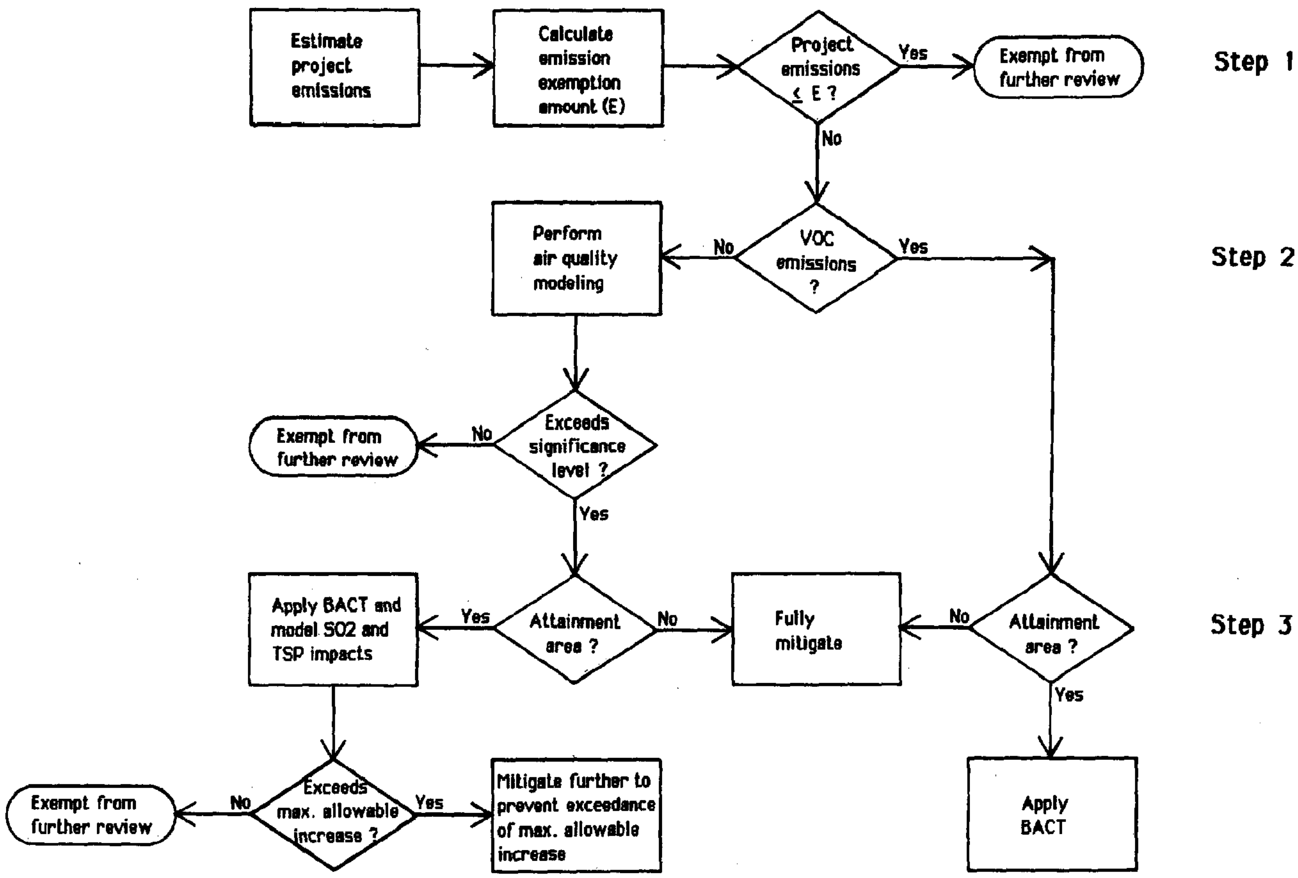


Figure 1. Department of the Interior Air Quality Regulatory Scheme.

MMS outlined a three-step process to meet this goal. In 1980, temporary guideline models were adopted in the interim. Then, MMS sponsored two coastal tracer experiments over the period 1980 to 1982 to better understand the dispersion conditions offshore and near the shoreline. By 1985, the data from the tracer studies had been used to develop and evaluate an overwater dispersion model. The tracer studies and the model developed from those studies are discussed in more detail in Section 3.

b. Effect of OCS Development on Onshore Nonattainment Areas

The Southern California Planning Area (SCPA) extends from the Monterey and San Luis Obispo County line southward to the U.S. and Mexico border. There are 21 existing platforms and 6 proposed platforms in the SCPA. Additionally, in the 5-Year Leasing Plan[1] two lease sales are scheduled for the SCPA by 1992, which could potentially result in nine additional platforms in the Planning Area.

Most of the onshore coastal areas in southern California do not meet the National Ambient Air Quality Standard (NAAQS) for ozone and are thus classified as nonattainment for this pollutant (40 CFR 81.305). The 1977 Amendments to the Clean Air Act require that nonattainment areas take the steps necessary to comply in a timely fashion with the NAAQS. These steps include applying additional controls on existing pollutant sources and requiring more stringent controls on future sources.

Because most of the Pacific OCS oil and gas activity has occurred and is likely to continue in the SCPA, its proximity to onshore nonattainment areas makes air emissions from current operations and future OCS development a sensitive and controversial issue. Recently, the

MMS has funded several studies to estimate the cumulative contribution of the OCS to onshore ozone concentrations; these studies are discussed in the next section and the results of one of those studies are presented in Section 4.

3. STUDIES RESULTING FROM AIR QUALITY ISSUES

Studies designed to address the issues discussed previously are presented in this section. The early studies sponsored by the MMS were directed toward developing the necessary modeling tools for impact assessment, while recent study efforts have been directed at understanding the cumulative effects of OCS oil and gas activities on onshore air quality.

a. Tracer Studies and the Development of the OCD Model

In the early 1980's, the MMS funded two tracer experiments in southern California. The first experiment occurred in September 1980 and January 1981 in the coastal area between the cities of Ventura and Oxnard and was performed by AeroVironment Inc. and the Naval Postgraduate School[2]. The second experiment was performed by SRI International and the Naval Postgraduate School and took place along the coast south of San Luis Obispo in December 1981 and June 1982[3]. The tracer experiments were designed to (1) evaluate the performance of dispersion models adopted by the MMS on an interim basis, (2) develop and evaluate a dispersion model for offshore pollutant sources, and (3) expand the understanding of overwater dispersion.

The experimental design of these experiments was as follows. An inert tracer gas (sulfur hexaflouride, SF_6) was released at a known rate offshore and its concentrations measured downstream. The sampling pattern included fixed ground-level samplers along the coast and inland and mobile samplers offshore along the coast and inland. The mobile samplers included vans and fixed-wing aircraft. The vans performed continuous ground-level sampling inland and the aircraft performed continuous sampling aloft at multiple levels. The tracer concentration data collected by the fixed ground-level samplers and the vans were used to describe the horizontal dispersion of the gas, and the aircraft-collected data were used to describe the vertical dispersion. Supporting meteorological measurements were made offshore and inland, near the surface, and aloft.

The most important result of the tracer studies was the development of the Offshore and Coastal Dispersion (OCD) model. It was built upon the framework of an existing U.S. Environmental Protection Agency (EPA) guideline model. OCD incorporates overwater transport and dispersion and considers plume fumigation* near the shoreline. Using the data collected from the MMS-funded tracer experiments, it was shown that the OCD model was superior to the interim MMS guideline model[4]. On March 28, 1985, the model was approved by the MMS for estimating inert air pollutant impacts from OCS facilities (50 FR 12248), and recently OCD was accepted by the EPA as a preferred model (53 FR 392).

* Fumigation is the rapid vertical mixing to ground level of an elevated pollutant layer.

b. Joint Interagency Modeling Study (JIMS)

In the early 1980's, Santa Barbara County predicted it would meet the federal 1-hour ozone standard by 1987 in time to meet the Clean Air Act requirements for attainment. However, the County's projections for county-wide growth and future OCS oil and gas activity were underestimated and it became apparent that Santa Barbara County would not meet the federal ozone standard by 1987. The Joint Interagency Modeling Study (JIMS) was conceived in 1984 for the purpose of correcting the deficiencies in the growth projections and OCS activity projections and assessing "the cumulative impacts to the California onshore ozone concentrations in the Santa Barbara Channel area from present and future OCS development"[5]. Study participants included: EPA, Region IX; MMS; California Air Resources Board (CARB); and the Counties of Santa Barbara and Ventura. The JIMS consisted of two phases: (1) develop the data base necessary for photochemical modeling and perform the model evaluation; and (2) apply the photochemical model to assess the impacts from future OCS development.

The first phase collected or generated the necessary topographic, meteorological, air quality, and emissions data for three two-day modeling periods in September 1980 (11-12, 25-26, and 28-29). Model evaluation was then performed for the three two-day periods. September 25-26, 1980 was chosen for the future impact assessment for meteorological reasons and because its emission inventory was presumed more accurate[6]. The MMS funded future year impact assessments for the two periods not considered under JIMS[7]. Selected JIMS results[8] are discussed in Section 4.

c. South Central Coast Cooperative Aerometric Monitoring Program (SCCCAMP)

One concern of the participants in the JIMS was that the models tended to substantially underestimate maximum ozone concentration at inland stations[6]. The South Central Coast Cooperative Aerometric Monitoring Program (SCCCAMP) is an attempt to improve upon the photochemical performance noted by past modeling studies, such as the JIMS.

The SCCCAMP is a multiphased program whose overall purpose is to "develop a means for assessing the aggregate impact of offshore petroleum industry sources on onshore ozone and NO_2 concentrations"[9]. The SCCCAMP, like the JIMS is a cooperative effort. The participants include all the agencies involved with the JIMS plus industry through representatives of the Western Oil and Gas Association.

To date, the following has been accomplished under the Program. Since it is a cooperative effort, communication among Federal, State, and local regulatory agencies and industry has improved. A major field experiment was conducted in the Santa Barbara Channel area from September 3rd to October 7th, 1985[10] for the two-fold purpose of: (1) improving our understanding of the atmospheric processes that lead to high onshore ozone concentrations and (2) collecting a comprehensive meteorological and air quality database to improve the performance of existing photochemical models. Through MMS funding, the SCCCAMP 1985 field data have been archived and are publicly available[11]. The field data are currently being analyzed by Sigma Research Corporation and their major subcontractor Systems Applications, Inc. under an MMS contract; final reports will be available by the end of 1988. Santa Barbara County and the CARB are using the SCCCAMP 1985 data archive for the photochemical modeling being performed to support the County's Air Quality Attainment Plan update. The MMS recently funded a study to evaluate an existing photochemical model using the data archive. The data archive will be used to support future OCS leasing and permitting decisions.

4. CUMULATIVE EFFECTS OF OCS OIL AND GAS ACTIVITIES ON ONSHORE AIR QUALITY

In this section, the cumulative effects of OCS activities on onshore ozone air quality in the Santa Barbara Channel area for 1990 are summarized from Haney et al[6]. The impacts represent those that might occur in a particular meteorological situation. Also, the 2-day period September 25-26, 1980 was chosen for the future impact assessment.

Table 1 compares the projected NO_x (nitrogen oxides) and VOC (volatile organic compounds) emissions by source category for 1990. NO_x and VOC emissions are shown since those compounds are the primary precursors to the formation of ozone. OCS activities account for 9 percent and 2 percent of the basinwide NO_x and VOC emissions, respectively. Contrast this contribution to that of on road vehicles, which account for 41 percent and 22 percent of the basinwide NO_x and VOC emissions, respectively. OCS oil and gas activities are not even the primary NO_x and VOC emission source in Federal waters; channel shipping is the primary source of NO_x and natural seeps are the principal source of VOC in the OCS.

The OCS contribution to the 1990 ozone concentrations are shown by the series of isopleth plots given in figure 2. The plots were developed by first running the photochemical model excluding OCS sources. Then OCS emissions are added to the inventory and the model executed again. The results of the former are subtracted

Table 1
Comparison of 1990 Emissions by Source Category[8]

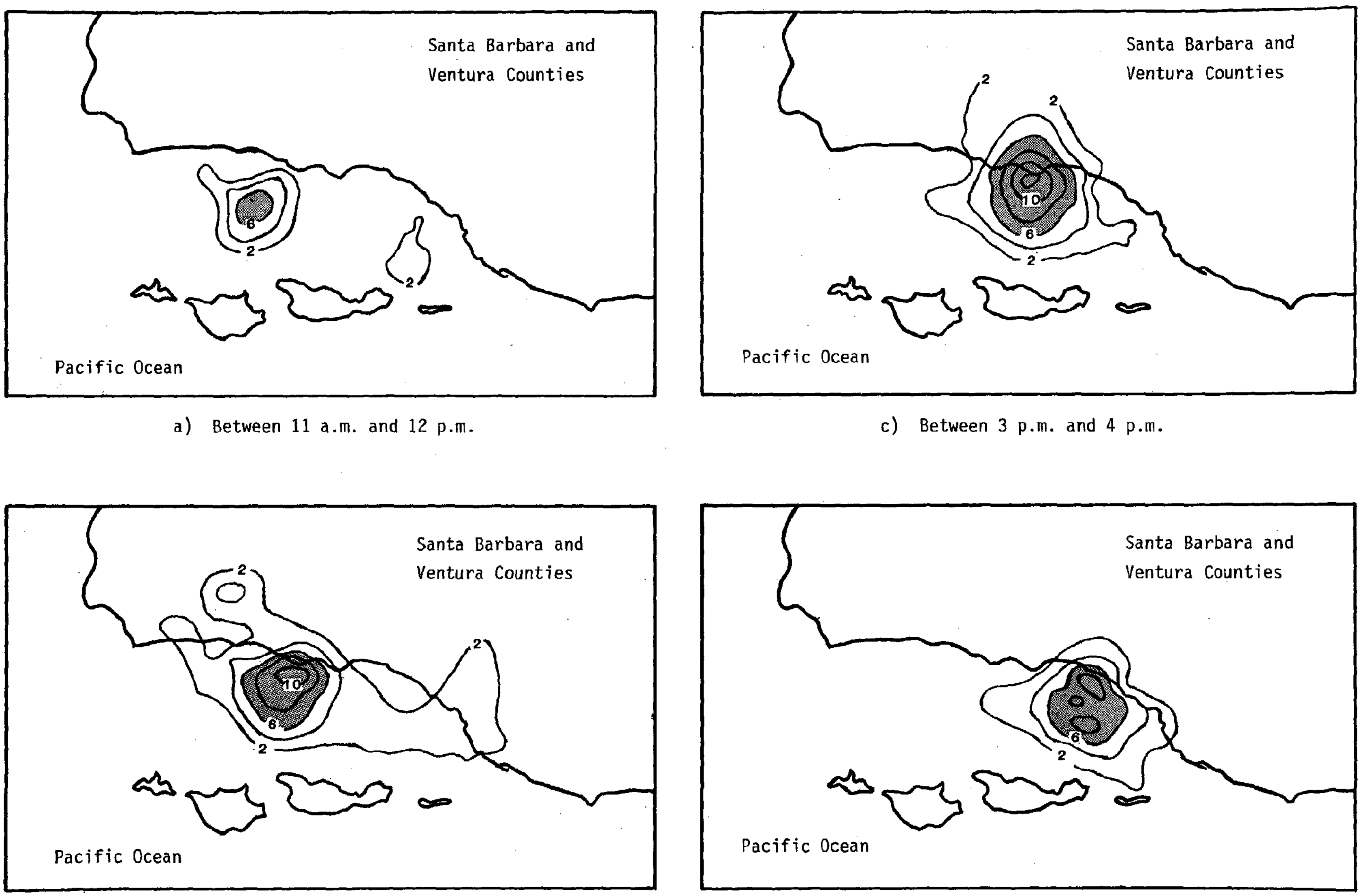
Source category	Emissions (tons/yr)	
	VOC	NO_x
Fuel combustion	1.88	28.38
Waste burning	0.44	0.54
Solvent use	20.94	0.00
Petroleum process, storage, & transfer	29.78	0.05
Industrial processes	0.62	1.33
Misc. processes	42.92	4.73
On-road vehicles	43.73	72.39
Other mobile	13.97	14.71
Natural seeps	40.48	0.00
Channel shipping	1.03	32.15
OCS and related sources	3.37	15.41
Tideland platforms	0.56	7.42
Unspecified sources	0.04	0.03
Total	199.74	177.13

from the latter to give the series of isopleth maps in figure 2. OCS contributions greater than 6 parts per billion (ppb) have been shaded in the figure. The Federal 1-hour ozone standard is 120 parts per billion (ppb). Therefore, the highlighted area represents incremental impacts slightly greater than 5 percent of the standard.

The area of greatest impact begins in the center of the Santa Barbara Channel (figure 2a) and gradually migrates northeastward until it reaches the coast south of Goleta at 2 p.m. (figure 2b). The wind observations[6] show that the peak impact area is due to existing and proposed development in the Santa Ynez Unit (SYU). The peak impact area then drifts eastward (figures 2c and 2d) for the rest of the time shown. Peak incremental impacts due to OCS oil and gas activities reach their maximum value of 12 ppb between 2 p.m. and 4 p.m. and occur just off the coast, south of Santa Barbara (figure 2c). This incremental impact represents approximately 10 percent of the Federal standard. The area highlighted (> 6 ppb) occurs in only a small portion of the modeling domain and the remainder of the region is largely unaffected by OCS activities with incremental impacts less than 2 ppb.

Several events have reduced the magnitude of the OCS incremental ozone impacts shown in figure 2. The SYU Project has changed substantially since the completion of the JIMS. As a result of these changes, emissions from that project have been reduced significantly (see table 2). For example, NO_x emissions, a precursor to ozone formation, have been reduced by over 70 percent.

DOI is also proposing a new, more stringent regulatory program for OCS facilities adjacent to the State of California. A proposed notice of



a) Between 11 a.m. and 12 p.m.

b) Between 1 p.m. and 2 p.m.

c) Between 3 p.m. and 4 p.m.

d) Between 7 p.m. and 8 p.m.

Figure 2. Incremental impacts (ppb) for September 25th using 1990 emission estimates (modified from Haney et al.[8]). Shaded area indicates impacts greater than 6 ppb.

Table 2
Changes in NO_x Emissions Resulting from Changes in the SYU Project[12,13]

	NO_x emissions (tons/yr)	
	1990	1995
Original project (as modeled in the JIMS)	2263	1302
Approved project (1988)	595	217

rulemaking was published this past summer. Important aspects of the proposed rule that will reduce existing and future OCS emissions are as follows.

- Best Available Control Technology is required of all new facilities regardless of their pollutant burden.
- Existing OCS facilities will be subject to retrofitting Reasonably Available Control Technology within 3 years of the effective date of the new rule.
- The number of exploration vessels operating at any one time is limited and the air emissions from those vessels are limited.

The MMS is committed to reducing air emissions from its facilities on the California OCS as evidenced by its proposed new, more stringent air quality rule. In addition, the Technology Assessment and Research Branch is funding a study that is compiling and ultimately testing promising NO_x control technologies. The end product of this research will be a list of proven NO_x control equipment for consideration on future OCS facilities.

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GEORGES BANK MONITORING PROGRAM:

A SUMMARY

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ABSTRACT

The Georges Bank Monitoring Program was designed to determine both near- and far-field environmental impacts from exploration wells. The results of this study indicated that no significant changes in the benthic infaunal community structure could be attributed to the eight exploration wells drilled on the Georges Bank.

INTRODUCTION

In 1981, in response to the concerns about the exploration program on the Georges Bank, a Biological Task Force was established by the Federal Government. The purpose of the Task Force was to recommend to the Supervisor of Oil and Gas Operations, the design of an environmental monitoring program that would provide early warning of adverse effects of oil and gas exploration on the Georges Bank environment [1].

Program Design

Near- and far-field environmental impacts of petroleum exploration activities were considered in the design of the Georges Bank Monitoring Program. Three transects were located in a north-south direction perpendicular to local depth profiles at approximately 60-, 80-, and 100-meter water depths. The net water movement over the southern flank of the Bank at all depths is toward the southwest. The eastern transect (I) was located in an upcurrent position relative to the drilling activities and represents a reference transect. Transect II passed through the drill site location, and Transect III was located downcurrent from the drilling location. Other regional stations (see figure) were located at sites of possible deposition of drill cuttings. These sites included the heads of Lydonia and Oceanographer Canyons (stations 7 and 9), the shelf-slope break (station 8), the Gulf of Maine (station 14), the top of the Bank in shallow water (station 15), and the Mud Patch (station 13). Station 7 was moved from the side of the Lyondia Canyon to the Axis (7A), a second station 14A was moved to an area of finer grained sediment (14A), as shown in the figure [1]. Two well sites were selected for near-field monitoring of drilling discharges on the benthic environment, Shell 410 and Mobil 312. An array of 29 stations was located in a radial pattern around regional station 5, the site of the Mobil 312 exploration well, as shown in the figure. One station was located within 200 m of the drill site and two stations were located approximately 2 km upcurrent and downcurrent, respectively. Additional sites were located at 0.2, 0.5, 1, 2, 4, and 6 km from the rig site. Nineteen of the stations were designated as primary locations, and all samples from these stations were analyzed. The remaining 10 stations were designated as secondary stations from which all samples collected were archived. All the stations were sampled four times per year on a seasonal basis for 3 years. At each station, six replicate 0.04 m^2 biology samples and three replicate 0.1 m^2 chemistry samples of undisturbed bottom sediments were collected with Van Veen grabs. Subsamples of the biology grabs were taken for carbon, hydrogen, nitrogen (CHN), and sediment grain size analysis; the remainder was washed through 0.3 mm screens and preserved for infauna analysis. Still photographs of the bottom were taken at each station to document microtopography and epifaunal densities and in an attempt to detect possible accumulations of drilling mud and cuttings. Dredge and trawl samples were collected at certain regional and site-specific stations to obtain fish and mollusc (ocean quahog Arctica and islandica) samples for chemical analysis. These samples were used to obtain representative specimens of epifauna and demersal fish for a voucher collection used in identifying species observed in bottom photographs. Measurements of salinity, temperature, and dissolved oxygen in surface and bottom water were taken at all regional stations [1].

Changes made to the study were to add (1) a detailed analysis of the size-class structure of populations of selected species at certain stations (life history task); (2) a study to determine the linkage of benthic infaunal production to demersal fish populations (benthic production and fish feeding task); and (3) analysis of infaunal samples collected at three U.S. Geological Survey stations on Georges Bank prior to commencement of drilling (Benthic infauna at long-term mooring sites task).

Field and Analytical Methods

The field and analytical methods used in the Georges Bank Monitoring Program are described in detail by Maciolek-Blake et al. (1985) [1], Bothner et al. (1984) [2], Payne et al. (1985) [3], Phillips et al. (1987) [4], and Neff et al. (1988, in press) [5].

DISCUSSION

Sediments

On the southern flank of Georges Bank, the surface sediments are predominantly quartz sands with minor amounts of gravel, pelecypod shell, and echinoderm test fragments, silt, and clay. The sands are noncohesive, medium to fine grained, rounded to subangular in shape, and translucent to light brown (iron oxide coated). Those areas with unusually high silt and clay content, 25-90 percent, include the head of Lydonia Canyon (station 7A), the region west of the Bank known as the Mud Patch (stations 13 and 13A), and the area north of Georges Bank in the southern Gulf of Maine (station 14A), as shown in the figure [1].

From a regional perspective, there was a slight increase in the percentage of material finer than 0.125 mm in sediments with increasing water depth. Fine-grain sediments were particularly abundant at the heads and on the flanks of Lydonia and Oceanographer Canyons. In addition, a clear gradient of increasing silt and clay occurred from northeast to southwest along the 70-to-80 meter depth contours for Stations 2, 5-1, 11, 13, and 13A [1].

Over the course of the 3 years of the Monitoring Program, a 10-20 percent by weight increase occurred in the less than 0.125 mm fine fraction at the canyon head stations (station 7A and 9), at the Mud Patch stations (stations 13 and 13A), and at station 16 near rig site Block 410 (see figure). Seasonal trends in sediment grain-size distribution show the percentage of the course fraction increases during the winter months and decreases during the summer. Such seasonal patterns are most likely the result of storm-induced resuspension and transport of the fine-grained sediment during winter months. Still photographs of the bottom, taken at most stations on most cruises, showed that stations at similar depths exhibited similar patterns of microtopography and sediment type. At many stations, primarily the deeper ones, in the spring and summer, sediments were smooth with a uniform coverage of detritus. However, during the winter the detritus was absent and the bottom showed ripple marking and scouring suggesting a seasonal change in bottom micromorphology [1].

Bothner et al. (1984) [2] reported a change in the concentration of barium in the upper 2 cm of bulk sediments from 32 to 183 ppm between the first predrilling and sixth postdrilling cruises in the monitoring of the drill rig at Block 410. It is significant to note that a second increase in the barium concentration occurred long after the drilling operation ceased. This concentration was, however, within the range of predrilling concentration of 28-300 ppm measured at other regional stations. No drilling-related changes in the concentrations of chromium or of the 11 other metals (Ba, Al, Cd, Cu, Fe, Hg, Mn, Ni, Pb, V, Zn) were observed in bulk sediments at any of locations including station 5-1 located 200 m west of the rig on Block 312.

Aromatic hydrocarbon concentrations were determined for regional stations 2, 7a, and 13 as well as for near-rig stations 5-1, 5-18, and 5-28 [4]. No seasonal trends or changes in the total aromatic equivalent concentrations due to drilling activities were apparent at sites 7a and 13. Methylnapthalenes through perylene were detected in quantifiable concentrations by gas-chromatography mass-spectrometery in sediment samples collected during drilling. A very small increase was noticed from a predrilling range of 0.007 to 0.102 ppm total aromatics to a post-drilling range of 0.097 to 0.575 ppm. Such concentration levels of low-to-medium molecular weight hydrocarbons are not believed to be toxic to benthic organisms [6]. Where traces quantities of petroleum-derived hydrocarbons were detected in the sediments, such concentrations rapidly returned to normal background values after drilling was completed. There was no accumulation of hydrocarbons or metals in the tissues of two ocean quahogs Arctica islandica or four spot flounder Paralichthys oblongus during or after drilling that could be attributed to the discharge of drilling muds [3,4].

Benthic Infauna

Taxonomic studies conducted during the Georges Bank Monitoring Program revealed that a total of 959 taxa of benthic marine animals was identified. Polychaetes were represented by 372 species or 38.8 percent of all taxa identified. A total of 49 polychaete families was recorded with spionids, syllids, maldnids, and paraonids best represented. A total of 124 polychaete species new to science was identified, some of which represent new genera. Thirty-two species of oligochates were identified, 18 of them previously undescribed and 1 representing a new family [1].

The arthropods were represented by 189 species and accounted for 19.7 percent of all taxa identified. Amphipods were the dominant group of arthropods with 99 species, at least one of which is new. Molluscs were represented by 144 species, accounting for 15 percent of all taxa identified. A total of 24 species of echinoderms was identified, representing 2.5 percent of all recorded taxa [1].

Throughout the course of the 3-year monitoring program, the average seasonal densities at site 5-1 were higher in years 2 and 3 (postdrilling) than before and during drilling in year 1. In comparison, there was very little variation in density during the 3 years at site-specific station 16. Furthermore, clear seasonal patterns of density were not apparent at most stations. The changes in abundance that were observed are believed to be related to changes in sediment grain size probably induced by storms rather than by drilling-related activities. For the most part, those stations located at the same water depth had similar benthic communities [1].

During the 3 years of the monitoring program, the replicate infaunal samples from each regional station showed an exceptionally high degree of homogeneity. Cluster analysis demonstrated that all of the replicates from any one regional station were more similar to each other than to replicates from any other station. The benthic community at any particular station was always distinct from the community at any other station. When replicates from each sampling data were summed, the samples from each of the 12 sampling periods clustered together before joining with samples from any other station. Biomass varied over time and among stations. At some stations biomass increased significantly between the first and second years. Clams Arctica islandica and sand dollars Echinarachnius parama dominated the biomass when they were present. When A. islandica and E. parma were absent, polychaetes and arthropods dominated the biomass. Levels of wet-weight biomass found in this study were similar to estimates from other studies [1].

A highly significant correlation between community parameters and percent fine sand was observed. Although stations within the site-specific array in Block 312 had a homogeneous community structure over most of the area, species composition was different at two stations located to the west of the rig site where the proportion of fine sand was higher than at other stations in the array. These results indicate that discharges of drilling fluids and cuttings did not measurably impact the benthic fauna in Block 312 [1].

CONCLUSION

During the 3-year monitoring program no significant changes in the benthic infaunal community structure could be attributed to the drilling of eight exploration wells on the Georges Bank [1].

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*

The principal investigators and scientists on whose research this review paper is based are:

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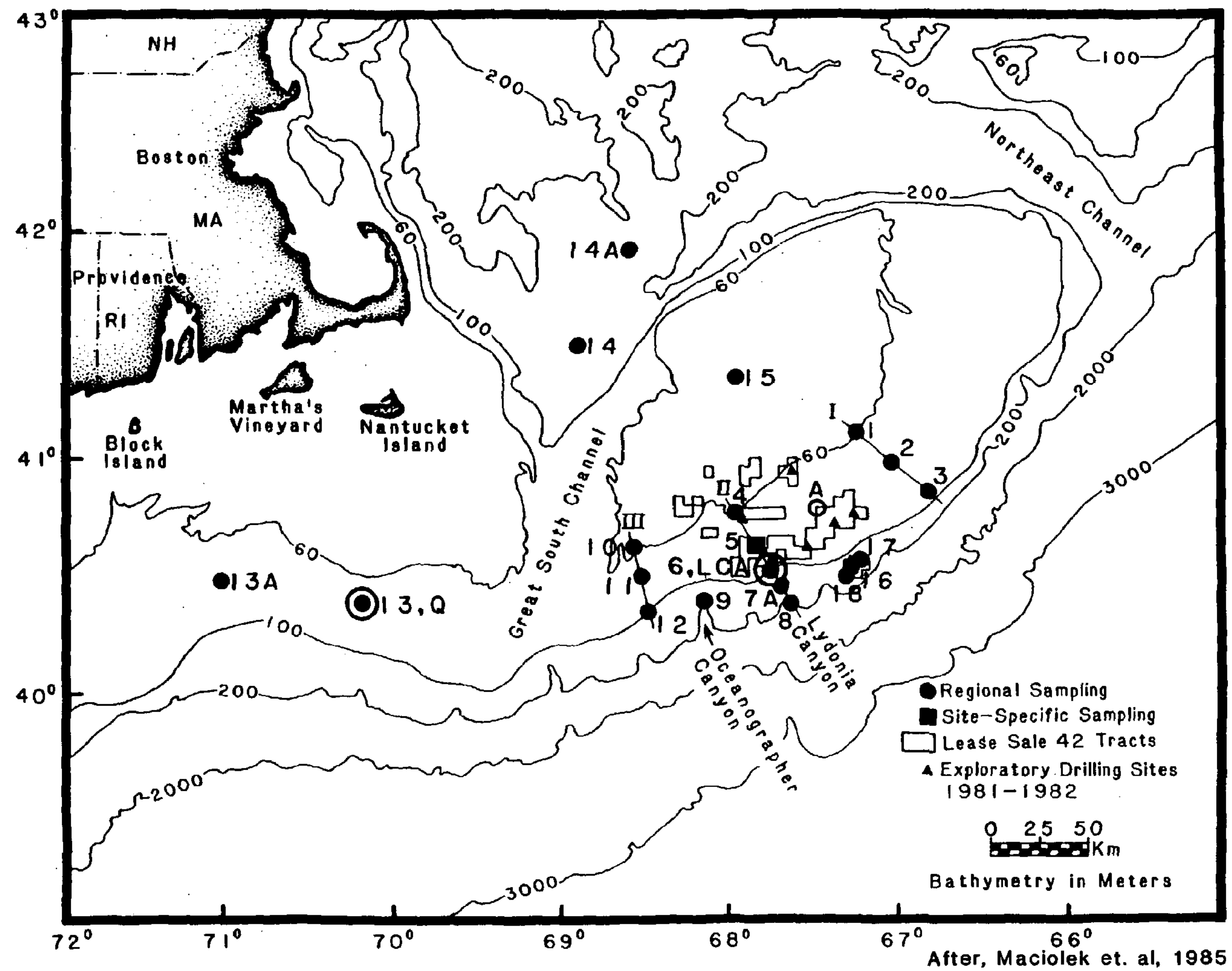

Figure 1. Georges Bank Monitoring Program regional stations and USGS Stations A, Q, and LCA.

THE ROLE OF THE SCIENTIFIC ADVISORY COMMITTEE OUTER CONTINENTAL SHELF PROGRAM OF MINERALS MANAGEMENT SERVICE

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ABSTRACT

The Scientific Advisory Committee gives advice to Minerals Management Service on the Studies Program of the Outer Continental Shelf oil and gas leasing Program. The SAC has aided the development of the OCS Studies Program at MMS, helping to shift its focus away from general surveys and toward process oriented studies, to more universal publication of results, to focus of more of the research on long-term effects, and to concentration of effort in regions of the OCS where there are most likely to be effects.

1. INTRODUCTION

The Scientific Advisory Committee (SAC) was established under the Outer Continental Shelf (OCS) Lands Act as the third part of the OCS Advisory Board. SAC's purpose is to advise the director of Minerals Management Service on the feasibility, appropriateness and scientific value of the Environmental Studies Program. In practice, the committee has been concerned almost exclusively with oil and gas activities; only in the last 18 months have discussions regarding hard mineral leasing become a part of the Committee's agenda.

The Committee consists of about 15 members appointed by the Secretary upon recommendation by the MMS staff from nominations from a wide variety of sources: the scientific community, academia, industry, states, conservation organizations, etc. Under current policy, individuals serve for 2 years and may be reappointed twice. Members are chosen to represent the full range of scientific expertise appropriate to MMS's mission in the OCS: physical oceanography, chemistry, geology, biology, economics, sociology/anthropology. In biology, for example, there is an effort to include experts on benthic ecology, marine mammals, and fisheries. Members are also chosen on the basis of geography; thus membership is approximately equally divided among East Coast, Gulf Coast, West Coast and Alaska.

The Committee generally meets three times per year, although frequency can vary. Most of the meetings conform to the MMS budgetary cycle. The meetings are held around the country to take advantage of the experience and expertise of the regional MMS offices, to provide an opportunity for Committee members to observe at first-hand the OCS activities of that region, and to allow the public to make presentations to the committee with regard to their perceptions of information and research needs.

2. FUNCTIONS

The committee has established subcommittees (which have varied over the years) to address current principal concerns. At present, these committees are 1) social and economic effects, 2) environmental effects and 3) study design and information transfer.

Review of Proposed Studies

The committee reviews proposed studies every year. The studies are proposed by the regional offices of MMS, and by the Regional Technical Working Groups. By the time the proposals get to the SAC they have been reviewed by the Regional and National Studies Offices and ordered according to established priorities. The ranking includes an indication of the proposals which could be funded within the budget. The SAC reviews the proposed studies considering both the needs of MMS and how the proposed studies would contribute to scientific knowledge.

MMS must write an adequate Environmental Impact Statement for a lease sale and regulate activities once a sale has occurred. In the early days of the program, the effort was concentrated on the Lease sale and EIS for the lease sale. The notion that one must know everything about the ecology of an area to write an adequate EIS - an extreme view - was common among individuals and groups critical of oil and gas leasing. This belief influenced the type of studies carried out - the baseline studies of the early years of the program. The extent to which we can understand any ecosystem is debatable. Even our ability to acquire a complete list of an ecosystems inhabitants is very limited, especially underwater where observation is difficult and expensive. The baseline approach was severely criticized and has been abandoned for the most part.

The belief that complete information is needed before action should be taken is still encountered (although usually in a modified state). One area in which it has some validity is in physical oceanography and meteorology. If we are going to predict where oil spills will go, we have to have adequate knowledge of the currents and winds. On the other hand, a prediction is always statistical and so the question arises as to how much knowledge of the variability is enough. Physical oceanographers familiar with a region can always claim with perfect legitimacy that more data on variability in their region would be useful. Thus the SAC must review study plans to try to achieve a balance between the amount of knowledge available and the public's and regulators' desires to be as certain as possible. Then we must consider where it makes the most sense to spend the limited budget.

The question of background knowledge also continues to arise in relations to limited, special environments. The Flower Garden reefs off the Texas coast are a good example of a very special environment -- a coral reef community in an otherwise soft sediment dominated region. Most people share the desire to protect such special habitats which obviously implies detailed knowledge and, thus, study of them. But how far should we go in focusing attention on special habitats? One that is truly unique, or even unique within a large region such as the northern Gulf of Mexico, deserves considerable attention. On the other hand, should we give equivalent consideration to each isolated hard bottom community along the southern and mid-Atlantic Coasts? These environments, of which there a number, occupy a small fraction of the total shelf area which is again dominated by soft sediments. To understand the potential impact of oil and gas activities in a region, it is more important to know the impact on the dominant environment within the area than on special but relatively rare systems. And so one must balance the need to understand the dominant ecology with the desire to protect specialized, restricted environments.

The other area where there is pressure to know everything before doing anything has to do with species of particular concern such as cetaceans, pinnepids, sea birds and, along the Pacific coast, sea otters. The problems that arise in relation to these animals have more to do with study design than of the need for the study because marine mammal studies are often mandated by the Marine Mammal Protection Act. For example, it is very difficult to track or count populations of whales. The obvious solution, the development of which is well under way, is a tag which would both identify the individual and its position in the ocean. However, there has been continued pressure to fund studies on whales even though the only techniques readily available were inadequate to achieve the desired results.

We have moved away from the general survey approach and now concentrate on supporting studies of the processes which control marine ecosystems and the ways in which oil and gas activities would effect those processes. A good example of a process study was the Georges Bank Monitoring Study which investigated the ways in which drilling muds and cuttings were dispersed from an exploratory drill rig. The research also considered the effects of those materials on benthic organisms. The study was carefully designed so that the results would be statistically significant. It had the benefit of a scientific advisory panel to review the project as it proceeded. Results showed no statistically significant impact of exploratory drilling on benthic communities. But because of careful planning and design, along with the result of "no significant impact" (which is useful to the agency but scientifically uninteresting) the study acquired good information on sediment transport and benthic biology.

Besides the impact on ecosystems, the studies program deals with socioeconomic impact analysis. Thus the studies program is concerned with effects of OCS activities on fisheries as well as upon fish, with the impact upon traditional ways of life, particularly the cultures of native Americans, as well as upon society in more heavily populated areas. Most of the studies budget for socioeconomic studies have been spent in Alaska on native populations and on fisheries.

The SAC is also concerned about the distribution of studies throughout the OCS regions. Most of the leasing and production occurs in the central and western Gulf of Mexico and Southern California, but some of the most pressing demands for studies come from frontier areas. I have been an advocate of studies, such as the Georges Bank Study, which potentially could follow the effects in a pristine area from exploration through full production. But that can only occur if there is production. Given the history of production and geological knowledge and interest of the oil industry, we can be reasonably confident that production will follow exploration in much of the central and western Gulf of Mexico and in parts of California, so it makes sense to design research programs to take advantage of this. Studies to prepare for leasing in areas with little potential for leasing have a lower priority.

Studies Recommendations

The SAC can recommend study areas that it feels should be given additional attention. Two examples of these are in socioeconomics. The effects of changes in the industry have had enormous effects upon segments of our industrial society as can be seen in coastal Louisiana, where the downturn in offshore activity brought about by the downturn in oil prices, has produced widespread un- and under-employment. This is certainly a very large impact of offshore activity but it is little studied and poorly linked to leasing policies.

The other area in which there is little information has to do with the public use of scientific data on the impact of OCS oil and gas activities. There seems to be a poor general understanding of the results of studies of the impacts of oil and gas activities in the OCS. Three non-exclusive explanations are possible:

1) the results of the investigations really are poorly known.

2) the results are known but are believed not to apply to the region under consideration. This is likely to be important in frontier areas where people are reluctant to apply results obtained in other areas.

3) the results are known and people are willing to extrapolate them to their area, but their objections to exploration and possible development are not based upon environmental considerations, but upon political and social ones. Therefore, citizens ignore the results of the studies program, or claim they are inappropriate, to delay the leasing program regardless of the value of the studies.

In all these cases it would be useful for the design of the studies program to understand better what moves opposition to OCS leasing, how people perceive risk from OCS oil and gas activities, and how and why their attitudes to OCS activities change. When or if my first consideration is operating, then better public information is desirable. In the case of number 3, the studies program could be less concerned with further studies that provide additional details of what is already known since the results are not likely to be instrumental in solving conflicts. Instead the limited funds could be concentrated in areas of knowledge or geography where the largest uncertainties still exist.

In the case of process studies, beyond pointing out additional studies in traditional areas that are needed, eg. better information on physical oceanography in the Gulf of Mexico, the SAC has promoted two types of studies: onshore effects and long-term studies. In the first case, for example, SAC pushed for a study of the effects of OCS pipelines on the Louisiana marshes. This was completed last year. In the second case, SAC has been working for a number of years both to point out the need for long-term studies and to define the areas in which this knowledge was lacking. Such studies will necessarily be conducted primarily in the Gulf of Mexico and Southern California. The MMS is currently trying to make arrangements with a university in each area to take the lead in conducting long-term studies. Careful research design will be particularly important in these studies to distinguish between long-term effects of OCS oil and gas activities on the one hand and long-term changes from other causes, including natural variability on the other.

Information Transfer

The SAC has worked toward getting the results of studies into the published scientific literature. This should help to make the study results available to the public although we recognize that few knowledgeable laymen read scientific journals. But the SAC still feels that encouraging or even requiring publication as a part of a study contract stimulates better research than might take place in the absence of publication. Papers submitted to scientific publications are reviewed for rigor in methods and analysis. Knowing that such a review process is goning to occur makes for better planning, fieldwork and write-up. And the research results become a readily available part of the public record, known to scientists and potentially to anyone.

3. SUMMARY AND CONCLUSIONS

The SAC has been a part of the development of the OCS Studies Program at MMS. The SAC reviews proposed studies for coming years. It may suggest changes in priorities and deletion of studies depending upon available information in the scientific literature and upon how it sees the needs of the leasing and management programs. The SAC may also recommend studies such as the increased emphasis on long-term studies in producing areas and studies in socioeconomics. It has put considerable emphasis on the desirability of better publication of study results in the reviewed scientific literature.

There is a need for a better mechanism for bringing the results of the Studies Program into resolving conflicts that arise in OCS leasing activities. I do not believe this should be a part of the SAC mission, partly because we are not particularly suited for conflict resolution, and partly because scientific results are not always germane to the conflict or its solution. But there is a large and growing body of scientific knowledge about the consequences of OCS leasing and production for marine ecosystems and for onshore effects on both natural and human systems. It is a shame that this cannot be better and more fully used.

THE MINERALS MANAGEMENT SERVICE BOWHEAD WHALE MONITORING PROGRAM AND ITS APPLICATIONS

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ABSTRACT

Aerial surveys of the fall migration of bowhead whales are conducted annually by the Minerals Management Service (MMS) in the Beaufort Sea. Survey methods and Fall-1987 results on the population distribution, the relative abundance, and the timing of the bowhead whale migration are briefly summarized. Application of this information is discussed relative to management decisions affecting oil and gas operations. Incidental sightings of other marine mammal species and a preliminary assessment of Fall-1988 survey applications also are presented.

1. INTRODUCTION

Every year since 1979, the U.S. Department of the Interior (DOI), Minerals Management Service (formerly Bureau of Land Management) has funded aerial surveys of endangered whales in the Arctic Ocean. The surveys were initially performed under interagency agreements with the Naval Ocean Systems Center and through subcontracts to SEACO, Inc. Beginning in the fall of 1987, MMS staff scientists conducted these surveys in the Beaufort Sea, with continuing aircraft support obtained through an intra-agency agreement with DOI, Office of Aircraft Services.

The primary focus of endangered whale studies in the Beaufort Sea is the bowhead whale. The bowhead (Balaena mysticetus) is a large baleen whale (adult body length can exceed 16 meters) that migrates each fall from its summer feeding grounds in the Canadian Beaufort Sea, across the Beaufort and Chukchi Seas north of Alaska, en route to wintering areas in the Bering Sea.

Historic populations of bowhead whales were decimated worldwide by commercial whalers for whale oil and whalebone (baleen), with the largest population--the Spitzbergen stock--effectively hunted to extinction. Following an intense period of hunting by yankee whalemen (1848-1915), the Western Arctic stock of bowhead whales has only recently shown signs of recovery. The present estimate of the bowhead population adopted by the International Whaling Commission (IWC) is 7,800. Bowhead whales are presently hunted only for Eskimo-subsistence purposes, subject to quotas derived by the IWC and the Alaska Eskimo Whaling Commission.

The Marine Mammal Protection Act (MMPA) of 1972 (16 U.S.C. 1361-1407) recognized that certain species and populations of marine mammals are, or may be, in danger of extinction or depletion as a result of human activities and established a national policy that marine mammal populations should be protected and encouraged to develop to the greatest extent feasible, commensurate with sound policies of resource management. The Secretaries of the Departments of the Interior and Commerce are charged with all responsibility, authority, funding, and duties under the MMPA.

The bowhead whale received additional protection when it was designated an endangered species under the Endangered Species Act (ESA) of 1973. The ESA requires that major Federal actions do not jeopardize the continued existence of listed species or result in the destruction or adverse modification of habitats determined to be critical. It also requires interagency consultation regarding potential jeopardy, alternatives to proposed actions, and information needs.

The current Oil and Gas Leasing Program indicates that additional lease sales are planned for the Beaufort and Chukchi Seas. Information from endangered whale studies will be used to prepare draft and final environmental impact statements (EIS's) related to these sales. Baseline information will be used to write postlease EIS's for development and production in offshore arctic waters. Such information also will be integral to documents related to the ESA Section 7 consultation.

The present goals of the ongoing endangered whale-survey program are to:

1. Provide real-time data to MMS and the National Marine Fisheries Service (NMFS) on the fall migration of bowhead whales for use in implementing overall seasonal-drilling restrictions and seasonal limitations on geological/geophysical exploration.

2. Provide real-time, site-specific data on endangered whales for use by MMS Resource Evaluation in day-to-day regulation of seismic-exploration operations.

3. Continue collection of data to describe temporal and spatial trends in the distribution, relative abundance, habitat, and behaviors of endangered whales in arctic waters;

4. Continue data collection and between-year trend analysis of the median depth (or distance from shore) of the migration axis for bowhead whales;

5. Record and map nonendangered marine mammals observed incidentally to endangered whale surveys; and

6. Determine seasonal distribution of endangered whales in other planning areas of interest to MMS.

2. METHODS

The overall annual survey program is based on a design of random field transects within established geographic blocks in and adjacent to Chukchi and Beaufort Sea sale areas offshore Alaska. The present study (1) was focused on the bowhead whale migration from 1 September 1987 to 31 October 1987 between 140°W. and 154°W. longitudes, south of 72°N. latitude. Occasional flights involved survey coverage in Canada as far east as 137°W. longitude.

Survey blocks were divided into sections that were 30 minutes of longitude wide, and each section was divided into 10 equal segments. Starting and/or turning points were chosen within each section by selecting two numbers from a random-number table and matching them to the numbered segments. A transect line was then drawn between the two segments. The same procedure was followed for each section of the survey block, and all transect lines were then linked together with connecting lines at top and bottom. This methodology permits later analyses of median water depths at bowhead sightings based on line-transect information (2). It also is compatible with analyses of population densities based on strip-transect theory (3).

3. RESULTS

There were 76 sightings of 110 bowhead whales made during Fall-1987 surveys in the study area. A daily index of relative abundance or whales per unit effort (WPUE) was calculated for bowhead whales during 149.34 hours of survey effort, which included 63.20 hours on random transects. When calculating relative abundance, all whale sightings were used regardless of the type of survey being conducted.

The day-to-day timing of the bowhead migration through the overall study area is shown in Figure 1.

The initial sighting of a whale was made 6 September east of the study area. The first bowhead sighted in Alaskan waters was on 9 September. The number of sightings per unit effort (SPUE) increased to 1.02 sightings per hour of effort on 11 September and peaked at approximately three sightings per hour on 27 September and 29 September. The SPUE decreased to 1.30 on 6 October. Between 14 and 31 October only three sightings were made, for an SPUE ranging from zero to 0.29. The last sighting of a bowhead in the study area was made on 30 October.

The main differences in the charts showing the number of whales per hour of survey effort and the SPUE for all areas surveyed occurred on 16 September, when a single sighting of three bowheads within only 0.95 hours of survey effort resulted in what probably is an artificially high relative abundance of 3.16 WPUE. The higher WPUE's (relative to SPUE) on 6 and 7 October are due to large pod sizes recorded on those days. The midpoint (median) of the fall migration of bowhead whales through the study area (when 50% of all sighted whales had been recorded) occurred on 29 September, with a peak relative abundance (mode) of 4.94 on 7 October.

Of the 37 bowhead whales seen on line transects during September to October 1987, the median water depth at the sightings was 31 m. The depth was within the range of similar median values for previous years and was considered typical of median values for Years 1982, 1984, 1985, and 1986. Thus, the data suggest that the position of the migration corridor did not change in 1987.

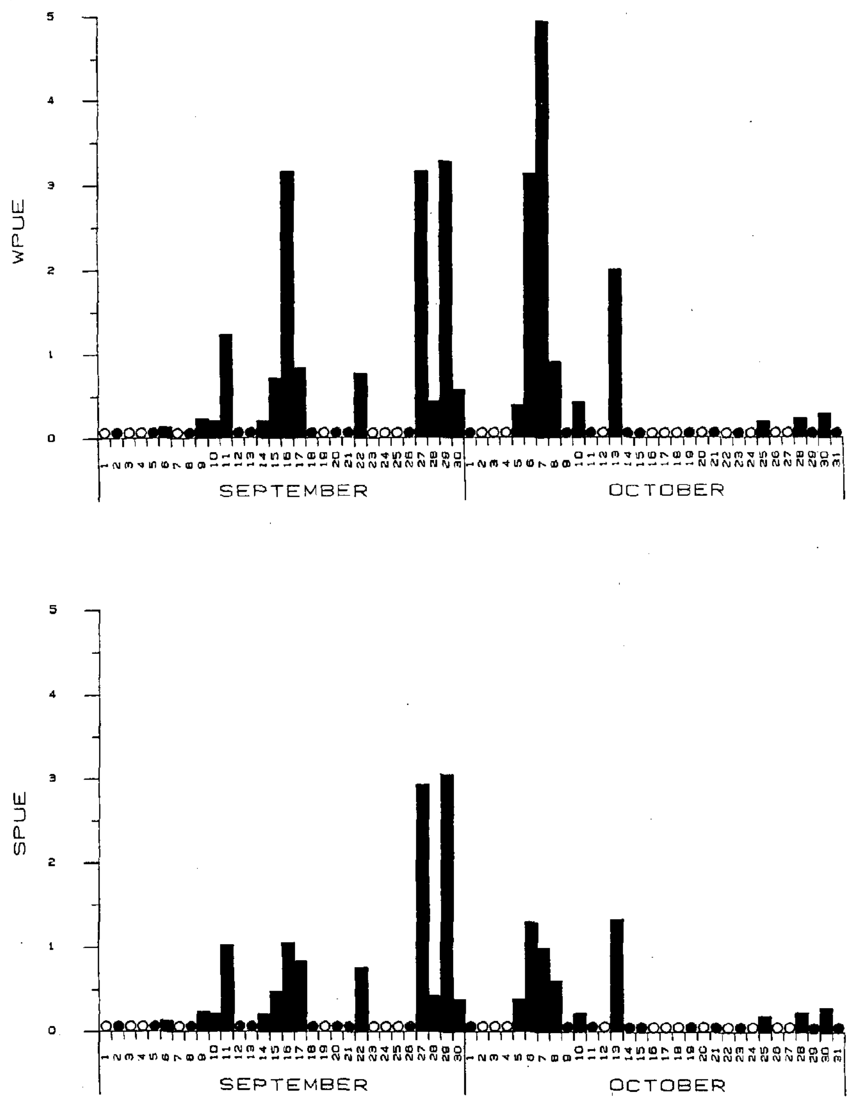
A total of 150 beluga whales were seen during the Fall 1987 surveys. The beluga (or belukha) is a medium-sized cetacean known primarily for the obvious white color of the adults. Each year many belugas share a migration schedule similar to that observed for bowhead whales.

A total of 13 bearded seals (referred to as "oogruk" by the Eskimos) were observed in Fall 1987. The bearded seal is the largest seal found in arctic waters and--like the bowhead and beluga whales and the ringed seal--is widely hunted for subsistence in Alaska's Eskimo communities.

The total number of ringed seals for the 1987 survey (285) was the highest number noted in the 1982-1986 MMS-funded arctic whale surveys (previous high = 167 in 1984). The ringed seal is the smallest marine mammal found in arctic waters.

4. MANAGEMENT USE OF 1987 FIELD INFORMATION

During 1987 MMS issued eight permits to industry for seismic exploration in the Beaufort Sea. Only six of the permits were used between 24 July 1987 and 26 October 1987, primarily in the eastern Beaufort Sea. The permittees followed stringent restrictions--including a provision to stop seismic operations when whales are visible from the vessel--as the bowhead whale migration progressed through the area of operations in order



Source: MMS. Alaska OCS Region.

Figure 1. Total Bowhead Whales Counted per Hour (WPUE) and Sightings per Hour (SPUE), by Calendar Day (Fall 1987)

to prevent potential operational effects on subsistence whaling. Daily summaries of survey information were transferred from the field to Anchorage for use by MMS Resource Evaluation and by NMFS in implementing areawide permit restrictions on high-energy seismic operations during periods of limited visibility.

On 13 September 1987, Tenneco Oil Company emplaced a Single Steel Drilling Caisson (SSDC) at 70°06.6'N. latitude and 142°47.1'W. longitude, east of Barter Island. The main body of the structure is approximately 162 m long, 53 m wide, and 25 m high. In order to determine with high resolution the number of whales in the immediate area of the SSDC, two systematic survey grids with parallel transect lines 4 km apart--permitting up to 100-percent survey coverage--were conducted on 20 September 1987 and 13 October 1987.

Based directly on daily summaries of survey information provided by the Fall- 1987 study, and on subsequent management decisions about the end of the bowhead migration made by MMS Field Operations and NMFS, the SSDC well in this location was not spudded until 2 November 1987.

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IMPACT OF OFFSHORE OIL OPERATIONS IN THE NORTH SEA

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The North Sea is an intensively used, multipurpose resource. It is important for commercial fishreries, seabird conservation, tourism, shipping and other commerce, as well as mineral extraction. There was therefore great concern about the possible impact of developing oil and gas fields there in harsher climatic conditions and deeper water than had previously been attempted. The oil and gas industry has been closely regulated and under constant scrunity in its activities. While there have been some accidents--one blowout and several pipeline fractures--gross oil pollution damage has been avoided. Earlier anxieties about the threat to seabirds, sea mammals and fisheries have proved to be unfounded, and identified environmental damage is limited to the seabird within 1 km or less of the platforms.

IMPACT OF OFFSHORE OIL OPERATIONS
IN THE NORTH SEA
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Oil and gas extraction in the North Sea takes place in an intensively used, environmentally and politically sensitive sea area which also receives the wastes from much of central and western Europe. There is a substantial consensus among European scientists about the minor contribution of offshore oil operations to stresses on the North Sea. Offshore operations are responsible for 29kt yr^{-1} of a total input of 71-150 kt yr^{-1} petroleum hydrocarbons. 90 percent of the offshore oil input is residues of oil-based drill muds on cuttings dumped on the seabed. The only detected environmental impact of North oil and gas extraction is limited to the sea bed fauna within 1 km of the platforms.

Introduction

The North Sea is a very intensively used international body of water. It supports a highly productive fishery, includes the most heavily trafficked sea-lanes in the world, its coasts are important for tourism, and it provides wintering grounds for a significant proportion of arctic ducks and seabirds as well as supporting a large resident seabird population. It also receives the wastes by direct outfalls and dumping from the 31 million people living in its coastal zone, but also by atmospheric inputs and notably by the rivers Rhine, Elbe and Scheldt, from much of central and western Europe. And there are major offshore oilfields in the northern sector and gas fields in the southern half of the North Sea.

In recent years, there has been growing concern about the North Sea ecosystem to withstand the pressures placed upon it, and certainly there have been episodes of anoxia in bottom waters of the German Bight and damaging algal blooms in the Skagerrak and off the Norwegian coast which indicate that some parts, at least, of the North Sea are severely overloaded with organic wastes and plant nutrients.

The political strength of the environmentalist lobby varies among the North Sea states and, understandably, there has been a considerable divergence of views about the seriousness of the impact of human activities on the North Sea and about what remedial actions, if any, should be taken. In this climate, it has been difficult to get objective scientific data, let alone agreement on how it should be interpreted.

There have been two meetings of Environmental Ministers of the North Sea states to try and resolve these issues, and in preparation for the second, held in London in November 1987, a Scientific and Technical Working Group of senior scientists from all the member states was commissioned to draw up a report on the Quality Status of the North Sea.

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This group reported in September 1987 (Department of the Environment, 1987) and revealed a remarkable degree of unanimity, never seen before, about the inputs to the North Sea and their impact. As a prelude to this enquiry, the Royal Society of London organized a two-day discussion meeting on the environmental effects of North Sea oil and gas developments (Hartley & Clark, 1987). These two documents offer the most authoritative and objective view of the health of the North Sea and in particular, the environmental impact of offshore oil and gas extraction, that is available at the present time.

Oil Inputs

The total input of petroleum hydrocarbons to the North Sea is currently estimated to be 71-150 kt per annum, excluding illegal discharges from shipping for which there is no agreed estimate. Most of this input is from land-based sources unconnected with the oil industry, and is dissolved, dispersed or adsorbed. Offshore oil and gas production is estimated to account for 29 kt of this total (DoE, 1987).

About 90 percent of the input from offshore platforms is currently residues of oil-based drill muds (OBM) contaminating drill cuttings which are dumped on the seabed around the platforms. OBMs have been increasingly used in the North Sea, from 36 percent in 1981 to 77 percent of wells drilled in 1985 (Bedborough et al., 1987). Initially, these were diesel-based, but low toxicity oils were introduced in 1981 and had completely replaced diesel by 1985. Future inputs of OBMs will depend on drilling activity in the North Sea and that is not altogether predictable at present.

Production and displacement water accounted for an input of 3 kt of oil in the U.K. sector in 1981 and is expected to peak at around 4 kt in the mid-1990s. Platforms are required to comply with a monthly oil-in-water standard below 40 mg 1^{-1} and their performance monitored by the Department of Energy (Bedborough et al., 1987). Most of the platforms operate well below this standard, but are expected to approach it as the water flow rate increases to the design capacity of the control equipment in later stages in the life of the oilfields.

It is inevitable that there will be accidental spillages of oil at offshore platforms. The most serious of these in the North Sea was the blowout in Ekofisk field in the Norwegian sector in April 1977 when 20,000-30,000 t of oil was released before the well was brought under control. Some spraying of the resulting oil slicks with chemical dispersants was attempted but this was largely ineffective and the oil dispersed naturally; none came ashore. The explosion and fire on a production platform in the Piper field in the British sector in July 1988 also resulted in the uncontrolled loss of oil, but the quantity and fate of this is not yet known.

In the British sector, there were 335 accidental spillages of oil during the 6 years 1979-84. One spill was of 980 t, five others averaged 55 t each, and the remainder were in the range 1-3 t (Larminie, 1987).

In 1979, the U.K. government introduced a notification scheme for non-petroleum hydrocarbon chemicals used offshore and surveys were made in 1982 and 1984 of the quantities discharged to sea. In 1984, when 290 wells were drilled, 133 kt of drill fluids were discharged, of which, 75 percent were barites and bentonite which are inert and insoluble. The main lignosulphonate used is ferrochrome lignosulphonate containing 3-4 percent chromium. Chromium adsorbs strongly onto clay minerals in drilling muds and is expected to have no effect outside the settlement zone. About 5-6 kt of 'non-inert' chemicals were discharged in that year. Toxicity data exist for only about half of that mass, but the total mud system is required by law to have a 96 h LC_{50} greater than 6000 ppm to the brown shrimp *Crangon crangon* and it is predicted that for the great majority of the constituents have a 96 h LC_{50} of more than 1 ppm (Bedborough el al., 1987). Production chemicals discharged in the oil and gas fields account for only 1-2 percent of the total input of non-petroleum chemicals.

Contamination Levels

Hydrocarbon concentrations in uncontaminated offshore water are generally below 2 ug 1^{-1}. In the open North Sea, concentrations of 0.7-1.3 (mean 0.9) ug 1^{-1} have been recorded in sub-surface water south of the Auk and Ekofisk oilfields (Bessborough et al., 1987), 0.4-2.2 in the German sector, 0.01-0.4 in the Norwegian sector and 1-3 in the British sector (DoE, 1987). Much higher levels are recorded in coastal waters and estuaries, but these are not connected with the offshore oil industry. In the neighborhood of oil platforms, concentrations of petroleum hydrocarbons in sub-surface water are 0.4)2.2 ug 1^{-1} in the German sector, 0.05-1.7 in the Norwegian, and 0.7-7.5 (mean 2.7) in the British sector. Sediments beneath platforms using oil-based drill muds have very high levels of contamination, typically 10^3-10^4 times background levels up to 200 m from the platform, but oil concentration falls rapidly with increasing distance from the platform, reaching background levels within 3 km of the platform (DoE, 1987).

Seabirds

In a number of countries, the consequence of oil pollution that causes greatest public concern is the damage it inflicts on seabirds. Some tens, if not hundreds of thousands of birds are oiled each year in the northeast Atlantic and North Sea, but it is now clear that this chronic mortality is due almost entirely to the (usually illegal) discharge of oily waste by general shipping. The number of seabird casualties is not related to the quantity of oil spilled. The Ekofisk blow-out caused no known seabird casualties and major tanker accidents have made a relatively minor contribution to the annual mortality. The worst bird-kill on record was in the Skagerrak in January, 1981 when some 30,000 oiled birds appeared on neighboring beaches; small amounts of oil were involved, probably derived from shipping, but the source has never been confirmed (Clark, 1984).

Dunnett (1987) estimates that 4.5 million pairs of seabirds breed on North Sea coasts. In general, most of the 19 species have shown a steady increase in numbers in recent decades. Guillemots (murres) are the predominant casualties of oil pollution and, in common with a number of other species, have an extremely low reproductive capacity. It had been thought that on this account they might not be able to withstand the recurrent losses from oil pollution but, in fact, murres have shared in the expansion of the breeding populations. The underlying reasons for these changes are probably climatic, but the causes of seabird population fluctuations are poorly understood (Dunnett, 1987).

At one time, it was suggested that migrating land birds might be attracted to gas flares on the platforms when crossing the North Sea and so be killed (Sage, 1979). This possibility has been investigated and shown to be groundless.

Fisheries

The North Sea fisheries are among the most intensively studied fisheries in the world. Most fish stocks are over-exploited but continue to maintain their yield and, although there are fluctuations in annual landings, these can be explained by fishing intensity, class strength and growth rates (DoE, 1987). Fishermen are excluded from the immediate vicinity of oil and gas platforms and are not allowed to trawl over pipelines, some of which lie in traditional fishing grounds, but the total area in which fishing is prohibited is insignificant. This, of course, does not prevent fishermen from complaining. There are occassional instances of trawls fouling undersea pipelines or discarded construction debris on the seabed, but the compensation scheme operated by the oil industry, or in Norway by the Government until recently, is efficient and loss or damage of fishing gear from this cause is not regarded as a serious problem.

Benthos

Since sediments in the immediate vicinity of offshore platforms are by far the most contaminated elements offshore in the North Sea, considerable research effort has been devoted to studying the environmental impact of oil drilling on the benthic fauna. This has been conducted in mesocosms and also in field investigations in oil-contaminated sediments inshore and in a number of offshore oilfields.

The deposition of drill cuttings, whether oil-contaminated or not, smothers the seabed, cuts off the substratum from water exchange, reduces the redox potential, and increases the soluble sulphide level. The important role of sulphate-reducing bacteria in this sequence of events has been demonstrated by Sanders & Tibbetts (1987). In a mesocosm, these changes are associated with a substantial fall in the nematode population and the elimination of burrowing copepods, although epibenthic copepods appear to be able to survive smothering. If the cuttings are contaminated with diesel or high concentrations of low toxicity oil, the nematode population continues to fall over the year following a single deposition of the cuttings, but at low concentrations of low toxicity oils, they show an erratic recovery. In these circumstances, epibenthic copepods show an enhanced population, perhaps because of the fertilizing effect of the oil (Leaver et al., 1987).

These observations have been largely confirmed by studies at a number of offshore platforms, though in the field it is difficult to separate the toxic effects of the oil-based drill muds from those of the activity of sulphate-reducing bacteria, leading to the production of sulphides, in areas where the seabed is blanketed by cuttings and organically enriched by the presence of the oil-based muds.

Close to the platform where the greatest depth of cuttings accumulates, blanketing of the seabed is severe, but a short distance away (50-250 m) where cuttings are 10 cm deep, there is the greatest activity of sulphate-reducing bacteria and production of sulphides. Around the Beryl A platform, the meiofauna is impacted for a distance of 800 m (Moore et al., 1987), but viewing North Sea oilfields generally, the distance from the platforms over which there is an impact on the macrofauna (principally polychaete worms) is about 500 m (Kingston, 1987). It is anticipated that the impacted area would be smaller around platforms where there are strong bottom currents and dispersion of cuttings and oil-based drill muds would be greater, as in the southern North Sea.

An important finding of Kingston's survey is the extreme patchiness of drill cuttings around platforms. This may account for conflicting reports of contamination and impact based on inadequate sampling.

Discussion

The development of the North Sea oil and gas fields has been very recent and rapid. Gas extraction started in 1965 and the first oil platform was installed in 1969. In the last 20 years a chain of oilfields down the centre of the northern North Sea has been exploited in a most hostile environment and at unprecedented water depths. From the outset there were great fears that oil extraction under these circumstances might prove disastrous for other important commercial interests such as fisheries and tourism, as well as cause unacceptable environmental damage, to seabirds and other elements in the marine ecosystem. The oil industry has therefore had to work under strict controls and close public scruntiny. Pressures on the oil industry have become more severe as inshore oilfields, such as Beatrice in the ecologically sensitive Moray Firth, have been developed, and here very comprehensive monitoring has been carried out (Addy, 1987).

It may be argued that had the public concern been less, the oil industry would have been less careful, but whether that is true or not, it is clear that the development of the North Sea oil and gas fields has been achieved with minimal environmental damage. This not to say that there are no ecological problems in the North Sea; several coastal areas are seriously overstressed and demand urgent remedial action, but the offshore oil industry does not contribute to these problems.

The history of the North Sea oilfields shows that, given strict controls and constant vigilance, offshore fields can be exploited in environmentally sensitive areas without causing material damage.

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GEOLOGIC CHARACTERISTICS OF AN ATLANTIC OCS GAS DISCOVERY AND ITS IMPLICATIONS

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ABSTRACT

The most significant Atlantic OCS hydrocarbon discovery (gas and minor oil) lies 80 miles off the New Jersey coast. Drilled in eight locations with a 63 percent success rate, this structure has sufficient proven gas resources to be a viable field if additional resources can be identified to support a pipeline and other infrastructure. Due to the economic outlook and difficulties in predicting hydrocarbon occurrences on the structure, exploration during the early 1980's was halted. The geologic origin of the structure and of the hydrocarbon source has major implications to the exploration potential of Atlantic offshore grabens. With current interest in East Coast graben-related traps on and offshore, the geologic history and hydrocarbon potential of this structure should be carefully considered.

INTRODUCTION AND HISTORY

The most significant Atlantic OCS oil and gas discovery lies 80 miles off the New Jersey coast in 440 feet of water. This discovery, associated with a large, complexly faulted anticline, was drilled in eight locations with a 63 percent success rate (figs. 1 & 2). The structure on blocks NJ18-3 598, 599, 642, and 643 was leased by several companies during OCS Sale 40 in August 1976. Drilling was conducted from April 1978 to March 1981, commencing with the Texaco 598-1 and ending with the Texaco 598-4. Of the eight wells drilled, three (Texaco 598-2, 598-3, and 598-4) were dry (fig. 2). The four blocks were unitized in April 1982, with Tenneco Inc. designated as operator. Also in April 1982, the Minerals Management Service (MMS) declared the new unit producible, converting the unit from rental to royalty status, and granted a suspension of production until April 1984. During this extension, approximately 725 miles of 3-D seismic data were collected with the intent of gaining sufficient knowledge of the complex faulting and reservoir distribution to increase drilling success. Due primarily to the overall negative economic outlook for petroleum products, the unit was allowed to expire April 1984.

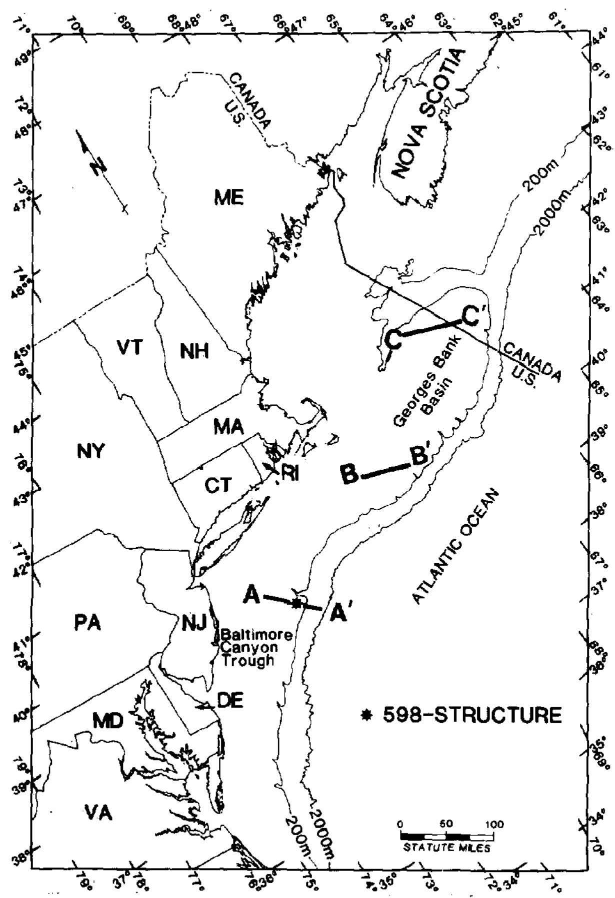

Figure 1. 598 structure and cross section locations.

HYDROCARBON TESTS AND SHOWS

Significant proven pays were encountered in five wells between approximately 11,700 and 15,000 feet,

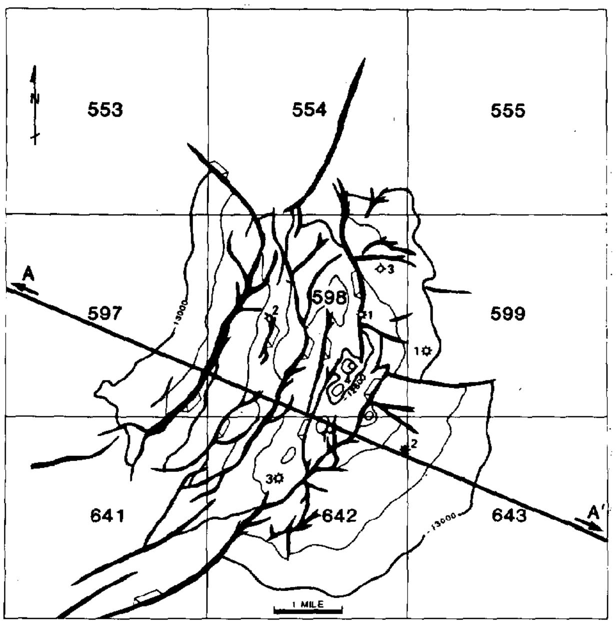

Figure 2. 598 structure and well locations.

(table 1). Significant untested gas also was present. In the 598-1 well, for example, log analyses indicated that as much as 660 feet of net gas pay, in 25 zones ranging in thicknesses from 10 to 90 feet, may be present (4). Additionally, in the 642-2 well, 8 feet of oil pay at the 8,320 foot level tested 630 bopd.

Significantly, an abnormally pressured gas-bearing zone was penetrated at approximately 17,800 feet in the Texaco 642-1 well. While drilling with 12.8 ppg mud, drilling was ceased to circulate and condition gas-cut mud using 14.5 ppg mud. Circulating mud weight was increased to 14.8 ppg and a 30 barrel slug of 21.5 ppg barite mud was pumped into the hole with no reduction of the gas flow. Ultimately, full control of the well was regained and the hole was sidetracked at 11,830 feet and drilled to 15,786 feet. This abnormally pressured, deep gas zone was not tested but may be indicative of significant, additional resources.

STRUCTURAL SETTING

At the time of leasing and exploration activity, the generally accepted explanation for the stratigraphic and structural development of this complexly faulted anticline was focused on the diapir (shale or salt) model. As a result, paleodepositional environments and the stratigraphic history tended to be related to the local setting, and

Well number	Drilling results	Flow test results	Total drilling depth (feet)
Texaco 598-1	Measured flows of gas	7.5 mmcfd 9.3 mmcfd	15,025
Tenneco 642-2	Measured flows of oil/gas	12 mmcfd 1 mmcfd 630 bopd	18,400
Texaco 642-1	Measured flows of gas	5.5 mmcfd 14.2 mmcfd 18.9 mmcfd	15,786
Exxon 599-1	Measured flows of gas	8 mmcfd 1 mmcfd 1.3 mmcfd	17,121
Tenneco 642-3	Measured flows of gas	6 mmcfd 3.65 mmcfd	16,475

mmcfd = million cubic feet per day.
bopd = barrels oil per day.

Table 1.

predictions for reservoir locations and hydrocarbon sources were formulated accordingly. Although the diapir model is a reasonable one, recent discussions by the author and Charles O'Hara (oral commun., 1986-88) on the origins of various Atlantic OCS structures indicate this complex structural anticline may be caused by faulting triggered by movement of, and subsidence around, a deeply buried crustal block resulting from passive margin, rift tectonics (fig. 3).

Mattick and others (5), in a seismic velocity and magnetic study, depicted a basement ridge near and on trend with the block 598 structure as a horst-like, fault-controlled structure. More recently, Rosendahl (6) related cross sections from the Tanganyika Rift depicting a horst and graben province (rift morphology) model to the evolution of the Baltimore Canyon Trough (BCT). The morphology of the crustal block (horst) is not known due to the lack of resolution in seismic records over the structure. Contributing to the poor resolution of seismic data are the complex faulting and prograding carbonate sequences (fig. 3) traversing the section at the 3.5-4.0 second level (7, 3). Depicted schematically in figure 3, the horst appears to be asymmetric with a steeply dipping face on the west and a shallower dipping face to the east. The steep dipping face is thought to represent the major border fault complex where under-lying blocks down faulted toward the axis of the BCT (O'Hara, oral commun., 1987-88). An extension of this border fault (fig. 3, fault D) cuts into the family of down-to-the-east, listric normal faults creating and dissecting the 598-642 structure.

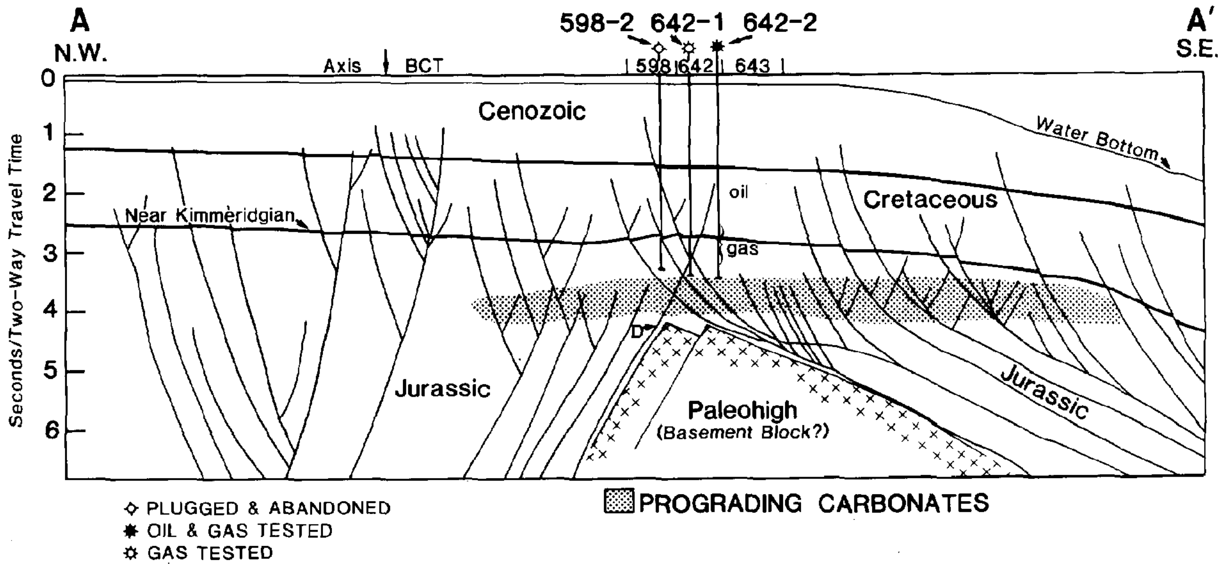

Figure 3. Composite dip cross section A-A' over 598 structure.

Generally, the structure resulted from a combination of differential sediment compaction around and over the tilted horst and relief of lateral confining pressure due to movement in faults to the east. The local depositional environment over the structure is interpreted to be transitional marine (shallow marine, sabkha) from late Jurassic through early Cretaceous (4). This environment resulted in the deposition of reservoir rocks that are scattered and difficult to exploit.

HYDROCARBON SOURCES

The hydrocarbon sources are not known. Kerogen analyses performed in the 642-2 well indicate thermal immaturity at the 8,300-foot level where oil was tested in Albian sands (2). Therefore, the oil is believed to have migrated from the more mature, marine Jurassic section to the east [preliminary geochemical finger-printing analyses of the oil suggest an algal carbonate source (2)]. Since light optical kerogen analyses indicate a somewhat immature hydrocarbon diagenetic environment at the depths where much of the gas is found, the gas must also have had a source from deeper in the section. The most likely sources are the thick, marginal marine and marine, post-rift Jurassic section immediately to the west (within the BCT) and, deeper in the section, synrift Triassic/Jurassic terrestrial and lacustrine deposits containing gas prone kerogens. Although the synrift Triassic and Jurassic deposits occur well below the gas generation window at present (approximately 23,000 feet, MMS unpublished studies), early migration might have preserved some of the hydrocarbons generated.

DISCUSSION AND CONCLUSIONS

The occurrence of hydrocarbons in a structure apparently formed as a result of post-rift deposition over early rift morphology, is significant. Rather than being treated as an isolated occurrence resulting from a set of special circumstances, this discovery must be analyzed on a regional scale within the framework of passive margin, rift tectonics. Doing so could open possibilities for further exploration on the structure proper and, more importantly, for exploration of horst and graben/half graben structural provinces throughout the Atlantic OCS.

Figure 4 is a composite section over a typical half graben, horst structure in the southern part of Georges Bank, and figure 1 shows the approximate location. Although lower in relief and less complexly faulted, the structure in the post-rift section above the horst is generically identical to the 598-642 structure. Figure 5, a composite section over a half graben province further to the northeast, shows an example of the type of structure found within graben fill.

Although recent exploration in the Atlantic OCS has focused on carbonate plays, the only significant discovery, one which most likely would have been produced if located near the necessary production infrastructure, is found in clastic reservoirs perhaps formed at the edge of a tilted horst resulting from rift tectonics. The current exploration interest in east coast rift basins bodes well for both the Atlantic OCS and the eastern onshore exploration industry.

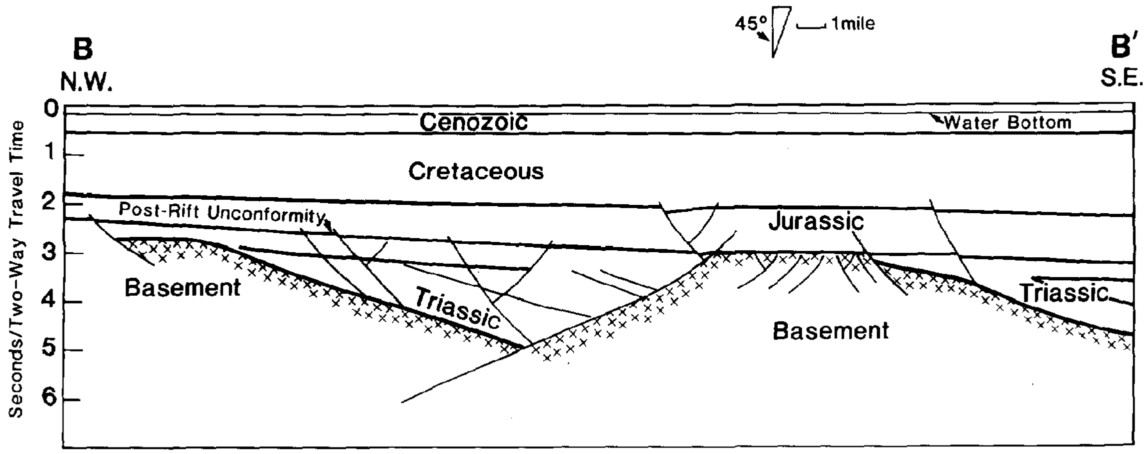

Figure 4. Composite dip cross section B-B' in Georges Bank Area.

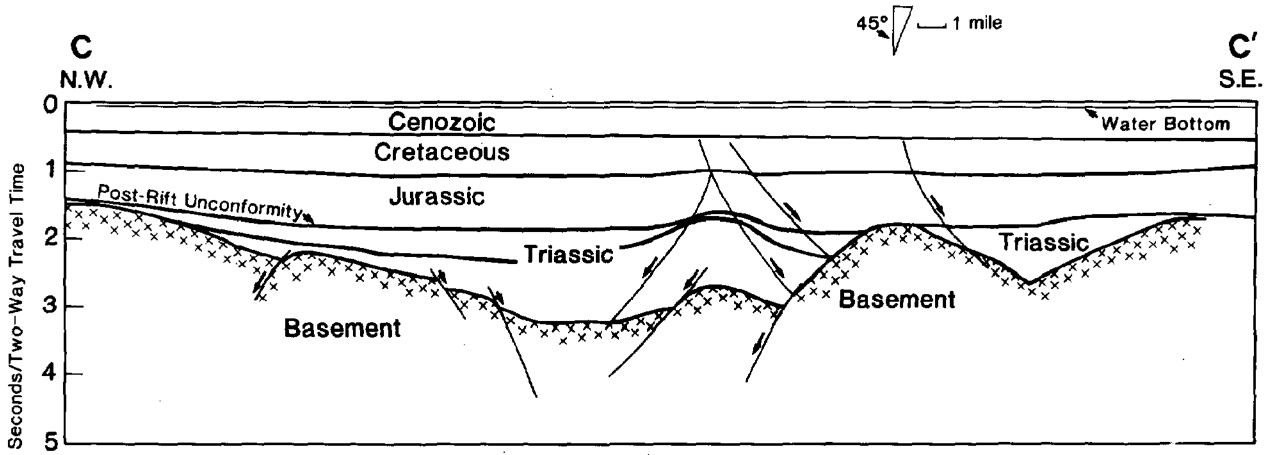

Figure 5. Composite dip cross section C-C' in Georges Bank Area.

ACKNOWLEDGMENTS

Figure 2. Modified from Lishman, F., and Smith, J. H. MMS unpublished data.

Figure 3. Compiled by O'Hara, C. J., and author.

Figure 5. Compiled by Johnson, R.

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HYDROCARBON POTENTIAL OF THE DEEPWATER (600 FEET)
GULF OF MEXICO

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ABSTRACT

The Continental Shelf of the Gulf of Mexico has been extensively explored up to an average depth of 10,000 to 12,000 feet. The potential of the deeper water areas of the Gulf is evaluated on the basis of dynamic stratigraphy of the Continental Slope, especially as it relates to subsurface salt movement, source rock and reservoir potential, and spatio-temporal distribution of reservoirs. Deep-water turbidites, interdomal basin fills, slumped shallower water deltaic sediments, and sediments associated with listric growth fautls of middle Miocene to Pleistocene age may provide suitable reservoir rocks. On the upper Continental Slope faulted anticlines associated with diapiric salts, rollovers and other structures associated with listric faults, and subtle traps associated with intraslope basins provide the trapping mechanism. The lower Slope is characterized by extensive lateral salt movement. Numerous structural and subtle traps associated with the salt movement, both below and above the tabular salt, provide an excellent trapping potential.

INTRODUCTION

The exploration and development of the Outer Continental Shelf (OCS) of the Gulf of Mexico has a long history, dating back to the 1930's. Since the introduction of Federal OCS lease sales on October 13, 1954, more than 25,000 wells have been been drilled. Currently, close to 20 million acres of the OCS are under lease. As of October 1987, there were 4,552 active leases, including 1,509 producing leases. Cumulative production is 7.26 billion barrels (Bbbl) of oil and condensate and 79.7 trillion cubic feet (Tcf) of gas from 704 fields of the Gulf of Mexico at the end of 1987 (Melancon, et al., 1988).

The economic importance of the northern Gulf of Mexico basin cannot be overstressed. According to Weise, Slitor, and McCord (1983), production from the Gulf of Mexico accounted for more than 90% of the total U.S. offshore production. The exploration and development activity of oil and gas of the Gulf basin responds to fluctuations in the price of oil and gas in a fashion similar to that of the U.S. in general. An anomalous high in drilling activity and production in the Gulf basin in 1984 and 1985 can be attributed to the introduction of areawide lease sales in 1983 (Pearcy and Ray, 1986).

Thousands of bore holes on the Continental Shelf have provided an enormous amount of data for the exploration, engineering evaluation, and development of the shelf area, which can be considered a matured hydrocarbon province. However, the data, rather than providing an unambiguous picture of the basinal framework and depositional facies, have proved the complex nature and high degree of variability of the geology within and between production trends. The data have unquestionably improved our understanding of the production trends of the shelf area, but a clear picture of the geology of the slope area where the future exploration activity is expected to be concentrated is yet to be developed.

HISTORY OF EXPLORATION

Leasing activity serves as an excellent indicator of the present and near-future exploration activity of the gulf. Pearcy and Ray (1986) indicated a decrease in leasing activity in shallow shelf areas (0-600 feet of water) and a steady increase in the leasing activity of the slope areas of the Gulf since 1983. Leasing of tracts in water depths exceeding 3,000 feet started in 1983 (figures 1 and 2). The bids on a large number of tracts in the deep-water Alaminos Canyon Area of the Western Gulf and Atwater Valley Area of the Central Gulf during 1987 lease sales (No. 110 and 112) indicate a strong industry interest in the exploration and development of the deep-water Continental Slope area of the Gulf of Mexico. Coincidentally, the advancement of industry interest to deeper water areas is in keeping with the historical exploration and developmental activity of the Gulf, as indicated by the yearly deployment of deepest water platforms (figure 3). Approximately every ten years since 1947, the oil industry has moved to develop the hydrocarbon resources of the next deeper geomorphic province, from inner shelf to the upper slope. It is well within reason to expect the development of the lower slope in the mid-to late 1990's, provided significant discoveries are made in that area.

The first Federal leasing of OCS Land of the Gulf of Mexico was held in 1954. To September 1987, 58 lease sales have been held. The number of tracts leased for each sale have varied significantly from sale to sale depending on economics and industry interest. Prior to 1983, only tracts that were nominated by industry were offered for lease by the government. The first areawide lease sale, in which all tracts within the Central, Western or Eastern Gulf of Mexico were offered for lease, was introduced in 1983. Since then, the leasing history of the gulf has changed dramatically.

The largest lease sale was held on May 25, 1985, when Minerals Management Service collected $3.5 billion in accepted bids for tracts in the central Gulf of Mexico. As a result of the economic depression of the mid-1980's, and because of the fact that most prime acreage was already leased during earlier sales, the leasing activity in the Gulf of Mexico declined through Sale 110 (1987). In Sale 112 (1987, Western Gulf of Mexico) the Minerals Management Service reduced the minimum per acre bid value from $150 to $25. The oil industry, speculating on an improved market in the future, reacted very positively to the change; 367 tracts of the Western Gulf received bids. Many tracts, that may be uneconomic under present market conditions, where new plays will be tested at greater depths, and that are in deeper waters (e.g., Alaminos Canyon Area), received bids. As of October 1987, there were 4,552 leased tracts, of which 1,509 were producing. Seven thousand five hundred fifty-five oil and gas wells were located on these tracts. Oil wells accounted for 54 percent of the total number.

The introduction of areawide lease sales in 1983, the lowering of minimum bids in 1987, the extension of lease terms from 5 to 10 years for deeper water tracts, and passage of the National Gas Policy Act (NGPA, 1978) have had a cumulative, positive impact on the leasing activity in the Gulf. The long-term economic and national strategic benefits derived from the new discoveries, resulting from the exploration and development of the vast amount of leased acreage, far outweigh a decline in bonus money from the leased tracts of the last few sales.

Leasing of relinquished tracts in the shelf areas of the Central Gulf averaged around 40 percent of the total tracts leased for a sale; but for the Western Gulf re-leasing tracts showed a steady increase from 13 percent during Sale 67 (1982) to 30 percent during Sale 84 (1984). This scenario is expected to change dramatically for both areas in 1989 when a large number of tracts that were leased during the first area-wide lease sale and have not been qualified for development become available for re-leasing.

It is clear from the leasing history that advanced drilling technology, superior geophysical data acquisition and processing techniques, and prospects for higher gas and oil prices in the future have propelled the industry to venture into the exploration of the frontiers of deep-water tracts and deeper prospects in the Gulf.

The drilling activity reflects the same trend of exploration activity in the OCS. Dodson and LeBlanc (1988) reported that 84 percent of the wells drilled between 1983 and 1987 were located in water depths of 300 feet or less. In the first quarter of 1988, this number dropped to 74 percent. The number of wells in the 600-to 3,000- feet water depth range accounted for 3 to 4 percent of the total wells drilled between 1978 to 1983. From 1984 to 1986, this number increased from 6 percent to 11 percent. In the first half of 1988, 13 percent of the wells were drilled in water depths ranging from 600 to 3,000 feet. Drilling in water depths beyond 3,000 feet in the Gulf of Mexico started in 1984. Since then, the number of wells drilled in that water depth increased steadily (figure 4). In 1987, 9 wells (1.1 percent) were drilled beyond 3,000 feet water depth. In 1988, a successful well was drilled in the Mississippi Canyon area at a water depth of 7,638 feet.

Information from wells that have been drilled on the OCS indicates that the Continental Shelf has been extensively explored up to an average depth of 10,000 to 12,000 feet (Ray and Pearcy, 1988). Ray (1988), on the basis of frequency analysis of over 12,000 reservoirs from the Continental Shelf, established that over 80 percent of discovered oil and gas reservoirs are located in sediments of Outer Shelf and Upper Continental Slope paleoenvironments. It is believed that more reservoirs may be discovered below 12,000 feet, where Miocene and Pliocene lower slope sediments are expected to be encountered. Since crude oil can be preserved up to a depth of 29,500 feet and thermogenic gas even at greater depths (Nunn and Sassen, 1986), it is evident that a large portion of the geologic column and a large geographical area of the Gulf of Mexico still remain to be explored (figure 5).

DYNAMIC STRATIGRAPHY OF THE CONTINENTAL SLOPE

The Gulf of Mexico Basin can be described as a small, old ocean basin that has remained tectonically undisturbed except for regional subsidence (Antoine and Bryant, 1969). Buffler and Sawyer (1985) estimated total tectonic subsidence of 13,000 to 16,000 feet on the shelf to more than 19,500 feet in the central part of the basin.

During the Triassic and Early Jurassic the Gulf of Mexico went through a stage of tensional stretching (Buffler and Sawyer, 1985) when rift basins formed. Possibly during the Callovian, when the Gulf was connected to the Pacific Ocean (Salvador, 1987), a 10,000- to 13,000-feet-thick, incompetent, ductile layer of salt was deposited. Emplacement of oceanic crust took place during the Late Jurassic, and the salt was separated into two widely spaced areas of the northern and southern Gulf. By the Early Cretaceous, the Gulf had taken its present shape, and carbonate platforms formed along the periphery of the basin. A basin-wide erosional-nondepositional unconformity formed during the Middle Cretaceous.

The Cenozoic history of the Gulf is marked by filling of the subsiding basin by a steadily prograding continental margin. The Cenozoic cyclic stratigraphic units typically grade seaward from thick continental, lagoonal, and deltaic sandstones, through inner neritic alternating sands and shales into thick outer neritic and bathyal-abyssal shales and turbidites.

Cenozoic depocenters often accumulated in excess of 20,000 feet of sediments and periodically changed geographic location. During Oligocene and earlier time the depocenter was located on the western Gulf Coast. The Miocene is marked by two widely separated deltaic depocenters of the Western and Central Gulf. The Pliocene and Pleistocene are of special significance to the history of the Gulf because at this time a large volume of glacially derived sediment became available, and the Mississippi River became the major supplier of sediments. The Plio-Pleistocene depocenters prograded as much as 50 miles (Woodbury et al., 1973).

The single most important process factor that profoundly affects and virtually controls the spatial and temporal distribution of reservoir-quality sands on the Continental Slope is the eustatic changes of sea level. During high sea level, associated with interglacial stage, the deltaic deposition is primarily restricted to the Continental Shelf area, and only fine grained-sediments are deposited on the slope. The Continental Slope and the abyssal floor, where submarine fans provide reservoir-quality sand, went through a dormant stage of evolution during the interglacial period. During falling sea level associated with the glacial periods progradation, upbuilding and retrogradational slumping through slope failure occur. The rivers get entrenched on the shelf, and active deltaic sedimentation takes place directly on the slope. Some of the coarse-grained sediments are trapped in the intraslope basin while a large portion of the sediments are deposited on the submarine fan.

As the prograding clastic wedges advanced seaward, Jurassic salt was squeezed seaward ahead of the depocenter due to sediment loading. A possible model for the flow of salt and formation of various structural forms is presented in figure 6. As a result of sediment loading, the salt layer is subjected to several forces, the principal ones being 1) the downward force of the overburden, which translates to lateral hydraulic force of the viscous salt; 2) the opposing resistant force of the sediment through which salt has to flow; and 3) the upward buoyant force. The resultant force propels the salt along a thrust plane which dips landward. On the Continental Slope, as the salt flows upward along the thrust plane, it uplifts the overlying sediments producing a bathymetric high and occasionally a pronounced scarp. The bathymetric high produces a sediment trap (scarp margin basin). An alternating landward downlapping and seaward onlapping seismic sequence in the scarp margin basins may suggest contemporary thrusting of the salt and basin filling. In some cases, when the updip location of the depocenter switches position, the flow of salt into the tongue ceases. Under such circumstances, if the loading in the scarp margin basin continues, the tongue may become separated from the mother salt and remain as an isolated salt lens. In some situations, the bathymetric high produces an unstable slope and is partially eroded by by submarine gravity slides. With continued progradation of subsequent clastic wedges, as the slope aggrades, many of the salt features are buried and and modified due to redistribution of overburden load. In many instances diapiric salt structures form as salt flows upward due to loading from intraslope basins and annular loading from the filling of peripheral sinks. During the uplift of the diapiric salt, if it encounters a weak zone, the salt flows laterally to form tabular salt tongues from the flanks and top of the salt dome.

In areas of listric growth faults, in some cases, the semihorizontal portion of the fault plane serves as a conduit for the flowage of salt as the diapirs reach that surface. The toe region of the growth-faulted sediments is uplifted over the salt, tilted landward, and thrusted over younger sediments. The growth-faulted block thus goes through a rotational motion as it subsides near the steep part of the fault and is uplifted and thrusted at the toe region. The uplifted toe area is eroded due to slope adjustment and other aqueous processes. The salt tongues formed by this process are less thick (measured in hundreds of feet) than the landward dipping salt wedges (which can be several thousand feet thick) that form large scarps at the lower slope. The lateral extent of thinner semihorizontal salt tongues is extremely variable; however, they can be as much as 30 to 40 miles in length. In other cases, however, the diapirs have been observed to pierce through preexisting growth faults.

The latest lateral flowage of salt, which resulted from the loading of the Pleistocene depocenter, produced the Sigsbee scarp (Wilhelm and Ewing, 1972). Many authors support the concept that the emplacement of the allochthonous salt in the slope is a direct consequence of sediment loading updip on the Continental Shelf at the depocenter (Amery, 1969; Humphris, 1978; Shih et al., 1977; Watkins et al., 1978; etc.). If we make a reasonable assumption that the overall sedimentologic regime on the Continental Slope has remained the same during Cenozoic time, it can be argued that salt scarps similar to the present-day Sigsbee scarp must have been associated with depocenters of earlier times. Possible locations of such scarps of Miocene and Pliocene age were reconstructed using a constant radius of curvature from the center of gravity of the depocenter (figure 7). The poor quality of seismic data below the salt makes the recognition of older scarps extremely difficult, especially in areas where the younger salt tongue formed above the older one. Blocked canyon clastics, which are typically turbidites and slumped deltaic sediments, provide suitable reservoir rocks. The majority of the salt tongues and salt wedges formed during Miocene to Pleistocene time. Since salt provides an excellent seal, the potential for trapping hydrocarbons that expulsed and migrated during late Miocene to post-Miocene time is excellent in the structure below the salt.

It is well established that the Gulf of Mexico has not gone through any regional tectonic compressional regime since Paleozoic time. It is, however, believed that compressional forces of local significance can be generated by the intruding salt that is driven by lateral flowage. Numerous structural and stratigraphic traps form as a result of the lateral flowage of the salt, both below and above the intrusive salt layer. Various types of traps that have been observed on seismic lines from the Continental Slope are shown in figure 8.

Since the salt wedges and often the salt tongue intrude into the sediment layer at an angle, truncation of sediment layers against the bottom surface of the salt provides an excellent trapping mechanism. Erosional truncation of sediments associated with uplifting that results from the intrusion and thrusting of salt wedges and salt tongues, and pinchouts associated with scarp margin basin fills, provide potential stratigraphic traps above the salt layer. Folds and faults formed due to uplifting and tensional stretching in the sediments overlying the front edge of the lateral salt and structures formed by compressional deformation ahead of the salt provide potential traps. Sediments below the salt layer are often affected by compressional forces generated by the lateral movement of the salt and are folded into anticlinal traps. Literature on hydrocarbon traps associated with diapiric salt is extensive and will not be discussed here. However, it should be mentioned that sediment layers below overhangs of salt domes are usually upturned and often overturned (figure 8D). In salt domes that grow contemporaneously with sedimentation, the sediment layers pinch out against their flanks. In either case, when overhangs form at late diapiric or post-diapiric stages of growth, excellent traps form below the salt. In some recently drilled wells that penetrated overhangs and salt tongues on the Outer Continental Shelf and upper Slope, a reversal of biostratigraphic sequence was observed below the salt. Such reversal of sequence helps in interpreting the time of formation of overhangs or salt tongues and lends support to the concept of the evolution of diapirs explained in figure 8D.

PRODUCTION TRENDS

The well established Cenozoic production trends are shown in figure 9. Discussion of the trends follows.

Miocene

The Miocene trend extends from the Viosca Knoll Area to the east to the North Padre Area of the Western Gulf. This trend can be subdivided into three subparallel trends: Lower, Middle and Upper Miocene. Lower Miocene production is primarily restricted to State waters of the Gulf. In Federal waters, Lower Miocene production is reported from the inner shelf of Mustang Island to the East Cameron and Viosca Knoll Areas. The Middle Miocene (Eponides 14 to Robulus L) subtrend is located seaward of the Lower Miocene trend and is separated from it by a series of growth faults. Laterally, the Middle Miocene trend extends from the North Padre Island Area of the Western Gulf to the Eugene Island Area of the Central Gulf. Middle Miocene production is also reported from the Breton Sound, Main Pass, and Mobile Areas of the Central Gulf. The Upper Miocene (Robulus E to Textularia L) trend is not well defined in the Western Gulf. In places where it is defined, it is separated from the Middle Miocene trend by growth faults. In the Central Gulf, this trend is better defined and is located in the inner shelf area. Upper Miocene production is reported from all areas of the Western and Central Gulf except the Brazos, Sabine Pass, Breton Sound, and Viosca Knoll Areas. However, the major reserves are reported from the West Cameron to Main Pass Areas.

The objectives of the Miocene production trend are mainly restricted to structural closures associated with salt diapirism, shale and salt uplifts, and growth faults. Upper Miocene production is also reported from stratigraphic traps in the Matagorda Island Area of the Western Gulf and the South Pass to Chandeleur Island Areas of the Central Gulf. These stratigraphic traps are often defined by bright spots on seismic lines.

Both oil and gas reservoirs of the Miocene trend account for a very small percentage of the total hydrocarbon reservoirs of all ages. Bigenerina A (Upper Miocene) oil and gas reservoirs of the Central Gulf and Bigenerina H (Middle Miocene) gas reservoirs of the Western Gulf are the dominant contributors to the total Miocene reserves in the respective areas. The average depth of Upper Miocene production increases steadily from 4,000 feet in both west and east to more than 12,000 feet in the Ship Shoal and South Timbalier Areas. The production depths of Middle Miocene and Lower Miocene similarly increase eastward from the Western Gulf area toward the Eugene Island and East Cameron Areas. The average size (ACFT/RESV) of the Middle and Upper Miocene reservoirs of the Western Gulf ranges from 5,000 ACFT to 10,000 ACFT, except for Eponides 14, Textularia L and Discorbis 12 reservoirs. In each of these cases a low number of reservoirs contributes to the anomalous values. The Middle Miocene (Cibicides Opima to Bigenerina 2) and Upper Miocene Discorbis 12 reservoirs of the Central Gulf are larger than 10,000 ACFT. The rest of the Middle and Lower Miocene reservoirs of the Central Gulf range from 5,000 to 10,000 ACFT. Cristellaria K, Bigenerina A, and Robulus E reservoirs are generally smaller than 5,000 ACFT.

The Lower Miocene reservoirs account for an insignificant amount of the total Miocene oil reserves. High Island, Sabine Pass, West Cameron, and Mustang and Matagorda Island are the only areas with producible Lower Miocene oil reserves. The largest reserve of Middle Miocene oil is located in the West Cameron - Eugene Island Areas and Main Pass. The Upper Miocene reservoirs are the major contributors to the total production from the Miocene trend in the Central Gulf. They contribute 3.0 Bbbl of oil and 22.7 Tcf of gas to the total 3.7 Bbbl of oil and 44.5 Tcf of gas reserves of the Miocene trend of the Central Gulf. In the Western Gulf, however, Middle and Lower Miocene reservoirs account for the major portion of the total Miocene reserves and production: 100 million barrels (MMbbls) of oil out of 115 MMbbls Miocene oil reserve and 9.9 Tcf of gas out of 10.5 Tcf Miocene gas reserve.

The Middle Miocene Bigenerina H trend of the Western Gulf is called the Corsair trend. It is located on the downthrown side of a large growth fault system that marks the boundary between the Lower and Middle Miocene production trends. Numerous rollover structures are associated with these growth faults. The production depths range from 8,000 to 16,000 feet. The total reserve of this trend has been estimated to be 2 Tcf of gas. The Bigenerina H section in this trend is greatly expanded in the downthrown side of the growth fault system. Huge sand sections up to 2,000 feet thick are recorded in many of the wells in this area. Typically, 20- to 50-foot-thick sand layers are separated by shale.

Pliocene

The maximum thickness of Pliocene sediments is observed on the middle and outer shelf off central and eastern Louisiana. The thickness of the Pliocene (Buliminella 1 to Textularia 6) sediments ranges from 4,000 feet off Texas to 8,200 feet off Louisiana. Even though a minor amount of hydrocarbons is produced from the High Island Area of Texas, the majority of Pliocene production comes from the Continental Shelf off Louisiana. The western limit of the Pliocene trend is not well defined; however, based on the current production data, the trend's western limit has been set at the Texas-Louisiana border (figure 9). In its eastern end it possibly continues up to the Lower Cretaceous trend. In the downdip direction the Pliocene remains productive below the Pleistocene trend.

The Pliocene trend, like the Upper Miocene and Pleistocene trends, produces both oil and gas. The Pliocene reservoirs of Textularia X and Buliminella 1 constitute a major percentage of the total oil and gas reservoirs of the Central Gulf. Even though there are large numbers of producing Pliocene reservoirs, they are generally smaller (3,000 ACFT) than either Pleistocene or Miocene reservoirs. The average thickness of these reservoirs ranges from 17 to 25 feet. The average depth of production ranges from 4,500 feet in Viosca Knoll to about 11,000 feet in South Timbalier Area. The depth of production, in general, increases from east and west towards the central part of the trend.

The area from Eugene Island to Main Pass has the highest concentration of Pliocene recoverable reserves of oil. The highest reserve of gas is located between Vermilion and Main Pass Areas. Pliocene production is also reported from the Continental Slope of the Mississippi Canyon Area.

Pleistocene

The Pleistocene trend is located in the Outer Continental Shelf and Slope of the Central Gulf and the Galveston South and High Island South Areas of the Western Gulf. The Pleistocene trend terminates against the Lower Cretaceous trend to the east. The seaward and the westward boundaries are yet to be defined. At its depocenter, the thickness of Pleistocene sediments may exceed 20,000 feet. Some of the wells drilled at the depocenter failed to reach Lower Pleistocene sediments even at a subsea depth greater than 16,000 feet.

The Pleistocene trend is highly affected by salt and shale tectonics, and a majority of hydrocarbon occurrences are associated with salt and shale structures and growth fault systems. Stratigraphic traps with their associated bright spots, by virtue of their shallow depths, are attractive prospects of the Pleistocene trend.

The majority of oil and gas reservoirs of the Western Gulf are of Pleistocene age. The number of Angulogerina B and Hyalinea B reservoirs is less than that of Valvulineria H, Lenticulina 1 or Trimosina A reservoirs. In the Central Gulf, the number of Pleistocene reservoirs of different biostratigraphic intervals follows the same trend. The average depth of production ranges from 4,000 to 7,500 feet on the Continental Shelf. The average depth of production, as in the case of Miocene and Pliocene trends, increases from east and west toward the South Timbalier Area. The average size of the Central Gulf Pleistocene reservoirs ranges from 3,500 to 5,800 ACFT. The reservoirs of the Western Gulf, with the exception of Lenticulina 1, are larger than those of the Central Gulf. The average thickness of the Pleistocene reservoirs of both the Western and the Central Gulf ranges from 20 to 40 feet.

Gas reservoirs of the High Island, West Cameron, and East Cameron Areas are mainly of Lower Pleistocene age. Upper Pleistocene reserves are mainly located in upper slope sediments of the East Breaks, Green Canyon, and Mississippi Canyon Areas. The majority of Pleistocene oil reserves are reported from the area between Vermilion and South Timbalier. More than 250 MMbls of oil reserve have been estimated for the High Island Area. A recoverable reserve of 100 to 200 MMbls of oil is demonstrated from the Green Canyon and Mississippi Canyon Continental Slope areas. The majority of Pleistocene gas reserves are located between the High Island and Grand Island Areas.

The Plio-Pleistocene trend in the upper slope areas of Louisiana and Texas, popularly known as the Flexure trend, is one of the most prospective plays of the Gulf. This trend is known for its thick oil pays. Net pays range from 75 to more than 200 feet. The average depths of Pliocene and Pleistocene reservoirs, in their deepest part in Green Canyon, are about 13,000 and 9,000 feet respectively. Hydrocarbon-bearing sands of Pliocene and Pleistocene age include blocked canyon intraslope deposits, slump and other mass-wasting deposits, and possibly proximal turbidites. The sand layers are highly variable, both in thickness and in lateral extent. Since 1983, especially during the last two lease sales, numerous tracts in the lower slope and continental rise areas have been leased. Seismic study of the Continental Slope off Louisiana (Ray and Cooke, 1987) revealed that the lower slope below the salt scarp is significantly different from the upper slope in its structural and stratigraphic complexity. Deepwater Upper Miocene sands, which may be promising prospects, are within the limits of drilling in these areas.

HYDROCARBON POTENTIAL

The Continental Slope of the Northern Gulf of Mexico presents an area of high hydrocarbon potential. Exploration of the shallow water portion of the slope has met with extreme success. At least 16 oil and/or gas fields have been discovered between East Breaks and Viosca Knoll at water depths between 600 and 1,500 feet. Recent drilling at water depths exceeding 7,600 feet clearly indicates that the exploration of the entire Continental Slope is well within techological limitations.

The reservoir rocks in the slope areas are Cenozoic clastics, consisting of turbidite sands, slump and other mass wasting deposits, and intraslope blocked canyon sediments. Reservoir-quality sediments are expected to be present in the entire geologic column from the Mesozoic to Quaternary. However, the Quaternary section, except in the Mississippi fan area, thins considerably in the deeper water areas. The Lower Miocene and Early Tertiary sections in the east Central Gulf are also extremely thin and totally absent in some cases. The Mesozoic reservoir rocks are expected to be reefs, reef talus, limestone, and dolomites.

Dolan (1986) presented a cursory look at the structural styles and traps of the Continental Slope of the Northern Gulf Basin. He indicated that the structures of the area between East Breaks and western Green Canyon are related to intense vertical and lateral salt movements. He also emphasized the importance of stratigraphic traps in the Mississippi Canyon Area. Based on the interpretation of thousands of miles of CDP seismic lines, limited releasable well logs and published literature, certain generalizations can be made regarding the future hydrocarbon prospects for the Gulf of Mexico slope (figure 10).

The future hydrocarbon prospects for the East Breaks area may range from Miocene to Pleistocene in age. Structures related to dip reversal near mid-to upper slope seem to be very prospective. The Alaminos Canyon Area contains large scale structures. Foote et. al. (1983), in describing the Perdido Fold Belt, suggested Oligocene to Miocene as the time of uplifting of these structures. Presence of possible Middle Miocene submarine canyons in the Brazos Area, as interpreted from seismic data, suggests possible conduits of reservoir-quality deep-water sands for the Alaminos Canyon Area. Even though both suitable structures and reservoir rocks are present, the hydrocarbon exploration of the upper slope area of Garden Banks has not been as successful as in the Green Canyon and Mississippi Canyon Areas. Future discovery potential of hydrocarbons from Mississippi Canyon, Green Canyon, and Atwater Valley Areas is high. Both suitable structures and reservoir rocks are believed to be present in these areas. In addition to structural traps, stratigraphic traps are of equal importance in this area. In the lower slope portion of this area, the section below salt tongues may also have high potential.

CONCLUSIONS

1. Jurassic to Early Tertiary sediments possibly provide the source rocks for the hydrocarbon in the basin. Reservoir rocks that meet the geological and geochemical suitability criteria for storage and preservation of hydrocarbon are believed to be present in the entire geologic column of the Gulf. Reservoir rocks include deltaic, strand plain, and their associated sand bodies of the paleo-shelf, blocked canyon intraslope basin, slump, masswasting, submarine fan and other turbidite sand bodies, and carbonate deposits of Cretaceous and Jurassic age.

2. Areawide lease sales, 10-year lease terms for deep water tracts, the Natural Gas Policy Act, and the recent reduction of minimum bids have had a positive impact on the leasing activity of the Gulf. In recent years, industry interest in the Gulf has shifted to deeper water (slope and beyond) and deeper prospects. The Continental Slope of the Gulf is expected to be the area of most active exploration and drilling in the future.

3. The paleo-shelf and paleo upper slope environments of the Cenozoic production trends have been explored extensively on the present day Continental Shelf to 10,000 to 12,000 feet. However, deeper water paleoenvironments of various trends are yet to be fully explored.

4. The structures responsible for trap formation are related to salt movement (which has been sporadic throughout Upper Tertiary and Quaternary), growth faults and their associated antithetic faults, and other faults resulting from slope failure. Stratigraphic traps are primarily related to pinch outs, unconformities, and lenticular sand bodies in a sand-shale sequence.

5. If the timing of hydrocarbon generation and expulsion is Cretaceous and Early Tertiary, and if a strong secondary migration is invoked, a large portion of the stratigraphic section and geographic area yet remains to be explored.

6. Closer attention needs to be paid to the exploration of stratigraphic traps and structures associated with lateral movement of salt on the slope, especially below the base of the salt.

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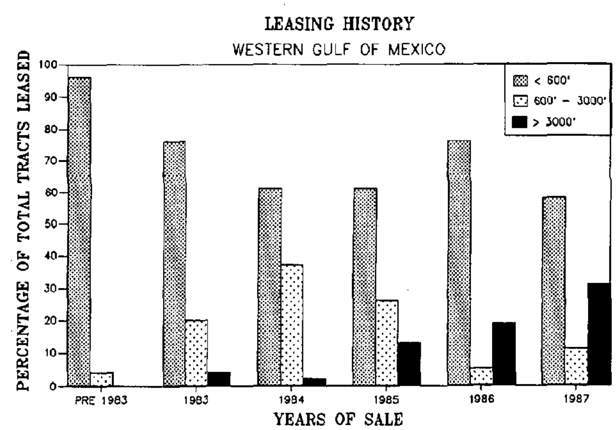

Figure 1. Percentage of tracts leased at various water depths.

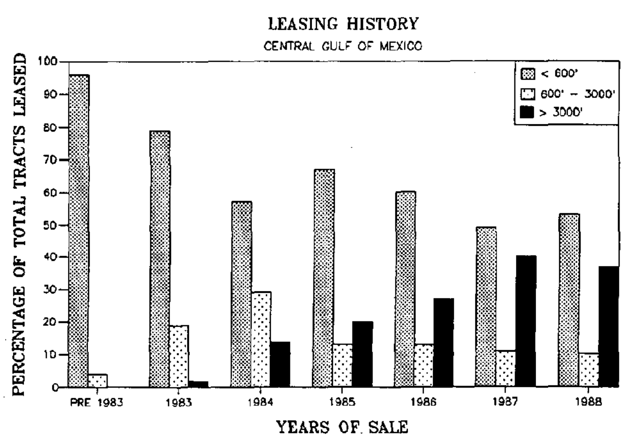

Figure 2. Percentage of tracts leased at various water depths.

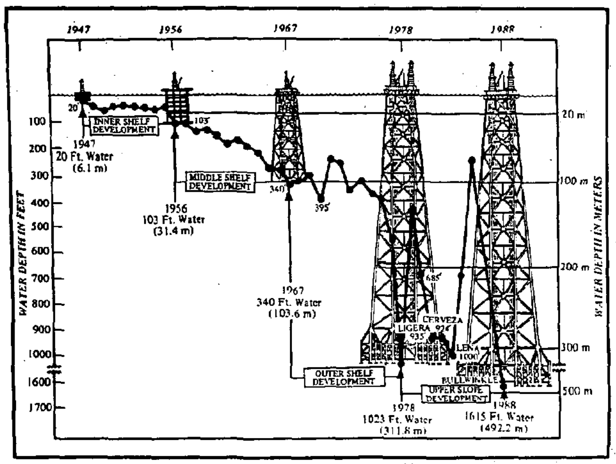

Figure 3. Deployment of deepest production platforms. During 1947-1956, 1956-1967, 1967-1978 and 1978-1988 the Industry concentrated on the development of the Inner, Middle and Outer Shelf and Upper Slope respectively.

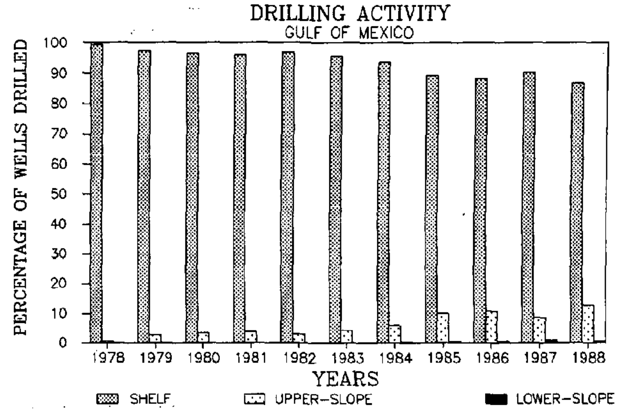

Figure 4. Percentage of wells drilled in a specific geomorphic province of the OCS. Drilling in the Lower Slope started in 1984. 1988 data represents the first half of the year.

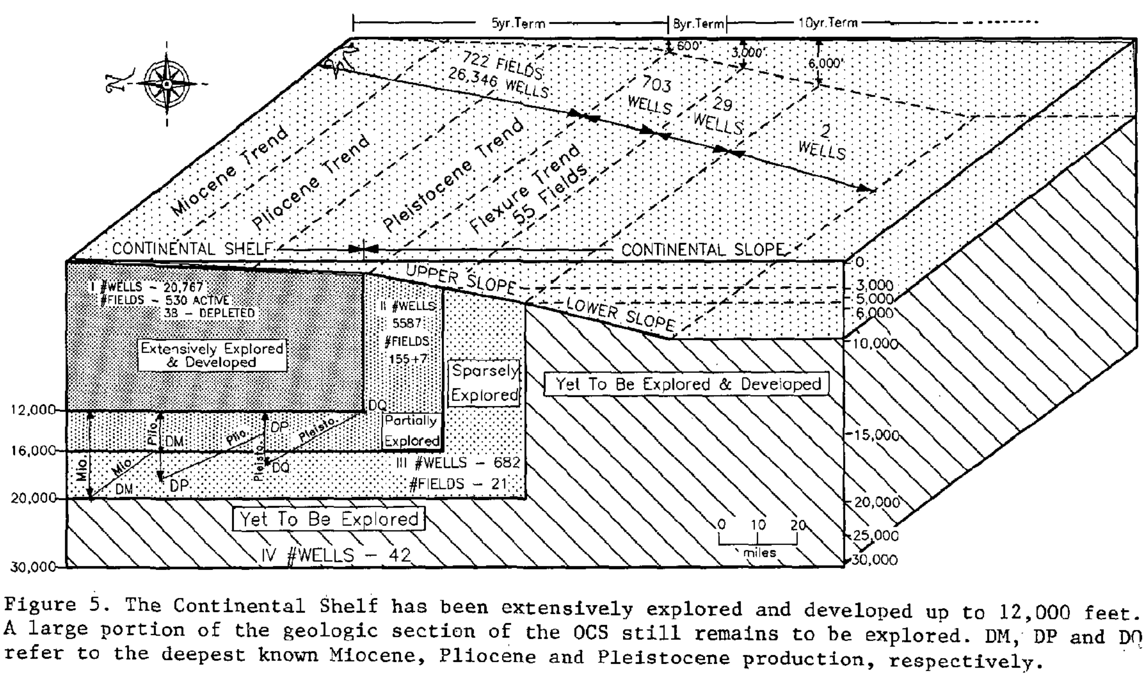

Figure 5. The Continental Shelf has been extensively explored and developed up to 12,000 feet. A large portion of the geologic section of the OCS still remains to be explored. DM, DP and DQ refer to the deepest known Miocene, Pliocene and Pleistocene production, respectively.

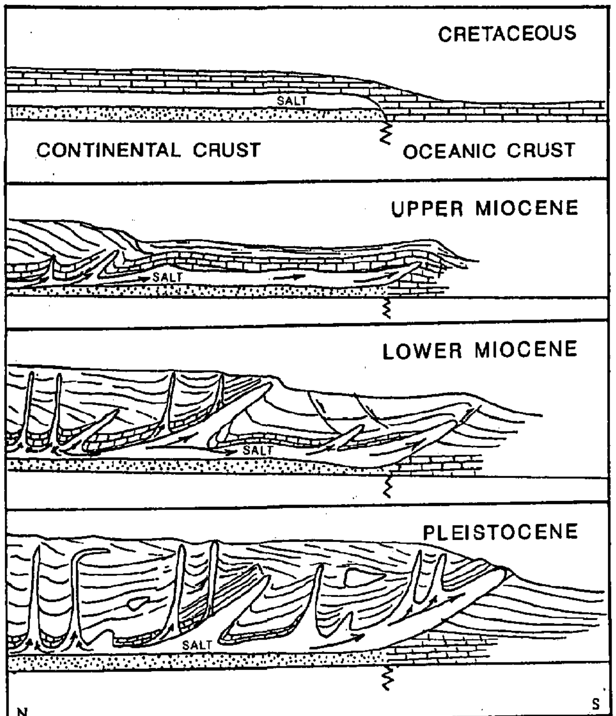

Figure 6. Evolution of the geologic section of the Northern Gulf of Mexico. Note the lateral movement of the salt.

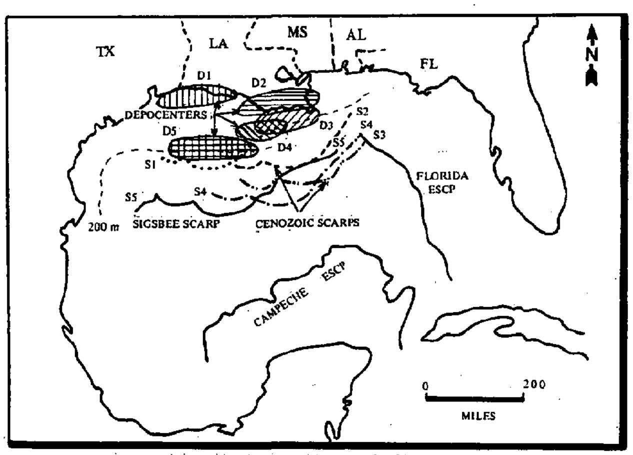

Figure 7. Locations of the Cenozoic depocenters (D) and their possible associated scarps (S). Numbers 1-5 refer to Lower, Middle and Upper Miocene, pliocene and Pleistocene respectively.

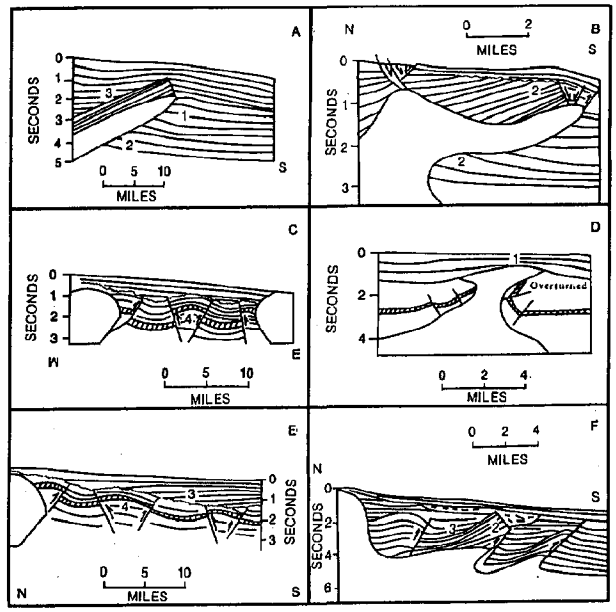

Figure 8. Examples of types of traps.

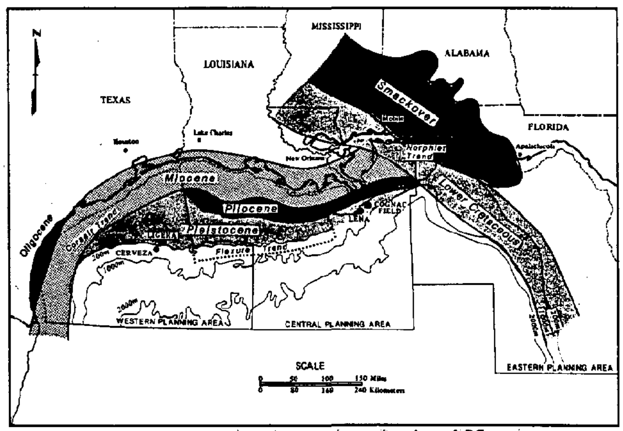

Figure 9. Production trends of the OCS.

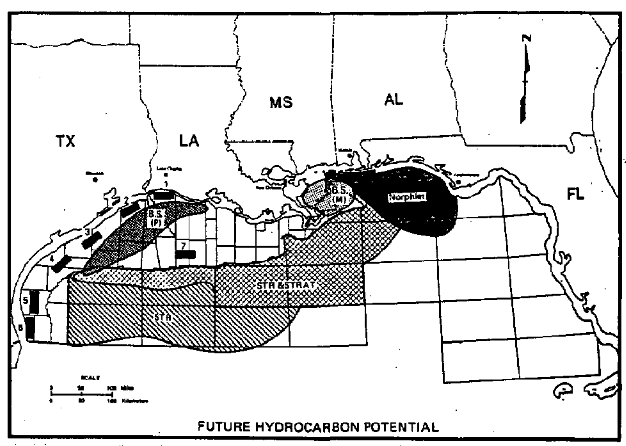

Figure 10. Future hydrocarbon potential of the deepwater OCS. Prospective areas are shaded.

CORRELATION OF CENOZOIC SEDIMENTS
GULF OF MEXICO OUTER CONTINENTAL SHELF

W. E. Sweet and J. C. Reed

Minerals Management Service

ABSTRACT

For several years, under the Resource Evaluation Program, the Minerals Management Service (MMS) has been conducting detailed stratigraphic correlations of the Texas-Louisiana Outer Continental Shelf (OCS). The program was designed primarily to assist the resource evaluation effort involved in the large, areawide leasing program.

Regional structural, stratigraphic, and production maps and cross sections delineate 26 identified productive intervals in the northwestern Gulf of Mexico. Part 1 of this study extends from Galveston Area offshore Texas through Vermilion Area offshore Louisiana. It encompasses portions of the most productive trends on the Federal OCS including a stratigraphically complex Miocene Trend and the prolific Pleistocene and its complex depocenters.

Data base includes 1,500 well logs, 1,000 paleontological reports, 152 well velocity surveys and 2,000 miles of seismic data.

INTRODUCTION

The Minerals Management Service (MMS) of the Department of the Interior has completed the first part of detailed stratigraphic studies of the Texas-Louisiana Outer Continental Shelf (OCS). The work was performed by geologists, geophysicists, and paleontologists under the Resource Evaluation program in the Gulf of Mexico OCS Region office in New Orleans, Louisiana. This study, which includes the important hydrocarbon producing region of the Galveston Area, offshore Texas, through the Vermilion Area, offshore Louisiana (fig. 1), has been published as an atlas, OCS Report MMS 87-0026.

The Federal Government's Resource Evaluation Program for the OCS began in 1968 in the Conservation Division of the U.S. Geological Survey.

Between 1968 and 1983 the Resource Evaluation effort in the Gulf of Mexico supported a series of oil and gas lease sales that usually included only tracts with a relatively high degree of industry interest as expressed by multiple company nominations. This leasing policy generally limited the size of each sale to between 1 and 1.5 million acres. Most Resource Evaluation work consisted of detailed presale, tract-specific geological and geophysical mapping and economic evaluation of all tracts selected for a particular lease sale.

In 1981, the Department of the Interior, under revised offshore leasing policies, initiated planning for the areawide leasing concept whereby all unleased acreage within certain specified large "planning areas" would be offered for lease. The tracts receiving bids would be evaluated and bid acceptance or rejection decisions made within 90 days after the sale. The new system presented MMS with the problem of evaluating a greatly increased number of tracts in a limited period of time. It was apparent that a more comprehensive understanding of regional structural and stratigraphic conditions would assist in the postsale evaluation of tracts receiving bids. In 1982, Resource Evaluation began the basin-wide correlations and mapping necessary to implement regional stratigraphic/structural studies.

The first priority of the Regional Mapping Program was to establish a series of well log and seismic correlations across the Louisiana and Texas OCS.

This correlation grid was prepared to

1. Develop a series of regional, structural, stratigraphic and production maps and cross sections to delineate 26 identified production intervals in the northwestern Gulf of Mexico.

2. Provide the geological framework necessary for stratigraphic mapping as the Gulf of Mexico OCS develops into a mature oil and gas province.

3. Publish regional cross sections and maps to support the continued economic development of the OCS, and provide a comprehensive data base to promote future research and publications.

STUDY AREA

The central and western Gulf of Mexico were divided into three study areas (fig. 1). Study Area 1 was selected for publication first because it is centrally located and includes portions of most of the productive trends on the Federal OCS. It includes a stratigraphically complex Miocene Trend characterized by the transition from the deltaic sedimentary sequences of the central Gulf of Mexico to the offshore bar and deltaic sedimentary sequences of the western Gulf of Mexico. Also, the most prolific Pleistocene production and its geologically complex depocenters are located in this study area.

DATA BASE

A total of more that 1,500 well logs, 1,000 paleontological reports, and over 12,000 line miles of seismic data are used to establish the regional stratigraphic framework for Part I. Two hundred forty-seven well logs and 2,000 line miles of seismic data appear on the published sections. A well data summary is included for each well on the section; also included are 183 paleontological reports and 142 seismic time depth charts. Forty-three geophysical contracting companies and oil companies granted MMS permission to use proprietary data in this publication. This study could not have been published in its present form without the generous cooperation from industry.

CROSS SECTIONS

The correlations of regional stratigraphic horizons are presented on closely paralleled electric log and seismic cross sections (fig. 2). The correlation grid includes 7 east-west and 12 north-south electric log cross sections, which are presented on 33 sheets. The seismic cross sections include 6 east-west and 12 north-south lines, which are presented on 38 sheets. Color is used to identify equivalent stratigraphic markers on the electric log and accompanying seismic cross sections. The electric log cross sections are illustrated at a vertical scale of 1 inch equals 1,000 feet and a horizontal scale of 1 inch equals 10,000 feet. The seismic cross sections are illustrated at a vertical scale of 2.5 inches per second (half-scale) and a horizontal scale of 1 inch equals 1 statute mile. The large scale and line orientations of the cross sections are selected to provide a working data base that can be easily used to correlate and integrate additional electric logs and seismic sections into the grid.

REGIONAL GEOLOGY

The Gulf of Mexico as described by Antoine and Bryant (1969) is a small ocean basin that has been subjected to regional subsidence since Late Mesozoic. The present form has resulted from early rifting and intrabasin sedimentary tectonic processes. Graben basins resulting from basin rifting were formed and filled with terrestrial sediments during the Triassic. More than 10,000 feet of salt were deposited during the Jurassic, and by Late Cretaceous the present shape of the Gulf was established. Since then as much as 50,000 feet of sediment have been added to western and northern parts of the basin in successively younger, offlapping wedges of strata. As the northern and western Gulf prograded seaward, the depocenters shifted laterally eastward in response to a change in sediment source from the Rio Grande to the Mississippi drainage system. The major shift occurred between Oligocene and Miocene time (Winker, 1982). The lower Tertiary strata are thickest in the Rio Grande embayment of Texas, whereas the Miocene is thickest in Louisiana (Shinn, 1971; Woodbury, et al., 1973). The thickest Pliocene strata occur in the Central Shelf area. The Pleistocene depocenters are located seaward near the present day outer shelf from the High Island Area to the South Timbalier Area.

STRUCTURE

The study area is located on the northwestern flank of the Gulf Coast Geosyncline. Prominent structural features are related to basinal subsidence and salt or shale movement in response to sediment loading. In general, the regional structural features include deep-seated anticlinal uplifts, salt and/or shale diapirs and ridges, withdrawal synclines with associated contemporaneous growth faulting, and numerous flexures with associated listric normal faults and glide planes. The majority of the structural traps discovered in the northern Gulf are associated with salt and/or shale diapirs and ridges. Regional down-to-the-basin fault systems (figs. 3 and 4) are contemporaneous with deposition and commonly attain displacements greater than 5,000 feet. These systems often consist of a series of interconnected arcuate faults paralleling regional strike. Regional faults are oriented parallel to flexures associated with paleo-shelf margins (Winker, 1982). Many of these fault systems flatten with depth into a common glide plane. The down-to-the-coast faults are usually singular and result from stress relief due to diapiric growth and depositional subsidence. The most pronounced structural feature in the area is a broad uplift referred to as the High Island Ridge. It closely parallels the Pleistocene depositional strike and can be traced southwestward beyond the shelf break in the Galveston Area and eastward into the West and East Cameron Areas. It is a deep-seated structure that probably formed during the middle Miocene seaward of the Brazos fault system. A large influx of clastic sediments during middle Miocene caused the seaward movement of underlying salt or shale beds resulting in an uplift of the seaward edge of the depocenter. The dip along the southern flank of the ridge is vague and difficult to detect on seismic data. Numerous regional fault systems oriented parallel to Pleistocene flexures or ancient shelf margins occur along the seaward flank of the High Island Ridge. A glide plane fault system has been interpreted at the top of the Miocene section south of Cross Section TLS-9. Movement along the system was initiated by Pleistocene deposition. About nine miles of basinward movement of sediments along this decollement zone can be observed on Cross Section TLS-11 between Cross Sections TLS-14 and 18. The surface of the glide plane is distorted by diapiric uplift and salt withdrawal synclines (some nearly 20,000 feet thick) seaward of each flexure. The movement of sediments along a horizontal glide plane develops a wedge of upthrust sediments where the continental slope and fault plane converge. The upthrust section forms a ridge-like dam trapping sediments on the shoreward side (fig. 5). Increasing overburden initiates subsidence within the depopod and the underlying salt and/or shale is squeezed into a basinward direction. Continued movement along the glide plane can initiate tilting of the distal strata in the depopod forming a tilt block of sediment dipping shoreward on the flanks of the ridge.

Within the study area many of these structures were subaerially exposed and extensively eroded during low stands of sea level in the lower Pleistocene. These structures and fault systems were subsequently overlain by thick Pleistocene deposits. These "buried" structures and associated unconformities may provide excellent hydrocarbon traps in the deep Miocene sediments in the southern third of the study area.

STRATIGRAPHY

Sediments included in the study area range from Miocene through Pleistocene in age and represent an offlapping sedimentary sequence. The Miocene, Pliocene, and Pleistocene producing trends are subdivided into 26 stratigraphic horizons (markers) based on the first occurrences of regional index fossils (table 1). Key wells, usually chosen from thicker, downdip sequences, are selected to provide as complete a sedimentary section as possible. The wells have the paleontological information, nearby seismic control, and seismic velocity data necessary to integrate the log markers with equivalent seismic horizons. Paleontological information is used to establish equivalent markers on both sides of major fault systems. The stratigraphic horizons are based on first occurrences of regionally recognized foraminifera in washed samples, which are considered to be regional extinction points of specific foraminifera. First occurrences of regionally recognized foraminifera can be correlated along strike in most of the study area. However, correlations in the updip direction are often difficult because of limited fossil-bearing shales in shallow water/nearshore environments. Regional correlations based primarily on electric logs are also often inaccurate. The thick clastic deposits in the study area lack regional marker beds to aid correlation. Apparent log correlations are often inaccurate and cross time lines because of the lateral accretion and coalescence of multiple deltaic sequences that exhibit similar SP and resistivity characteristics. Consequently, electric log correlations supported by seismic data are used as the primary means of correlation once the reference section is defined by paleontological information.

MIOCENE

Miocene sediments are present in the onshore and offshore Texas-Louisiana coastal areas. The Miocene stratigraphic units gradually thicken basinward and change from prolific oil- and gas-bearing sand/shale sequences to mostly deep-water shales. The total thickness of Miocene age sediments in the study area is estimated at 20,000 feet. The most prolific Miocene production is confined to the inner shelf areas in the northern third of the study area (north of Cross Section TLS-5). However, exploratory drilling on the outer shelf and upper slope beginning in the late 1970's has penetrated Miocene sediments at depths less than 10,000 feet in several wells seaward of the High Island Ridge. During the Miocene-early Pliocene, a low stand of sea level (Vail, Mitchum, and Thompson, 1977) exposed the shelf areas to extensive erosion. Upper Miocene sediments were subjected to erosion over the exposed parts of the High Island Ridge and adjacent shelf areas to the south (table II). An angular unconformity is observed between Miocene and Pliocene sediments on the seismic sections across the crest of the structure. As a result of the High Island Ridge, the Miocene shelf in the High Island Area is believed to extend at least 20 miles farther seaward than previous studies have suggested (Martin, 1975, and Bearden et al., 1986). The late Miocene shelf edge extends northeastward from the southern flank of High Island Ridge, parallel to Pleistocene faults bounding the northern limit of the Pleistocene depocenter (fig. 6). The major fault systems are associated with paleoshelf margins. The regional glide-plane fault systems commonly observed in the southern part of the study area (Cross Sections TLS-11, TLS-16, TLS-18, etc.) are interpreted to be associated with the late Miocene paleoshelf margin. The extension of an upper Miocene shelf, south of the High Island Ridge, may be of significance to the petroleum explorationist in projecting potential reservoir sands in deep waters. Miocene sands, though silty, are encountered in several wells in the High Island, South Addition Area and adjacent slope.

PLIOCENE

Isopach maps of the study area indicate that Pliocene age sediments attain a maximum thickness of 4,500 feet off Texas and 5,500 feet off Louisiana. Across the High Island Ridge, Pliocene sediments were deposited in a relatively deep-water environment. Any significant progradation of the shelf margin during the Pliocene is evident only in the main depocenter east of the study area. The Pliocene shelf break west of the Vermilion Area is believed to be coincident with the late Miocene shelf break.

PLIOCENE-PLEISTOCENE BOUNDARY

There is a complete lack of agreement as to the location of the Pliocene/Pleistocene boundary. The extinction of Globoquadrina altispira is used by many to define the Plio/Pleistocene boundary in the Gulf of Mexico. Some paleontologists contend that the extinction of Globoquadrina altispira occurred at the beginning of the Pleistocene and use it to define the Plio/Pleistocene boundary. Paleontological analyses and seismic interpretations indicate that Globoquadrina altispira persisted into the early Pleistocene. The Buliminella 1 biostratigraphic marker mapped as upper Pliocene (UP) is considered the major marine transgression within the upper Pliocene stage. Also, there is seismic evidence of a chaotic sequence directly overlying Buliminella 1 sediments and within Lenticulina 1 (LPL-2) and Valvulineria "H" (LPL-1) time. These chaotic beds indicate a glacial period and support the concept of a major unconformity between Buliminella 1 and the lower Pleistocene. Therefore, for practical purposes the Lenticulina 1 marker and, where present, the Valvulineria "H" marker are considered in the lower Pleistocene stage and the Buliminella 1 marker is considered in the upper Pliocene stage.

PLEISTOCENE

During the Pleistocene, sedimentation was profoundly affected by continental glaciation. Sea level fluctuations of more than 600 feet (Akers and Holck, 1957; Beard, 1969) exposed the Continental Shelf to subaerial erosion out to the shelf edge. Chaotic zones, channel cuts, erosional surfaces, and major flexures are commonly observed on seismic records throughout the Pleistocene Trend. Basins containing more than 20,000 feet of Pleistocene sediments with sand sequences over 2,000 feet thick are developed within this trend. The lower Pleistocene section is subregionally divided into two units: the Lower Pleistocene Unit 1, consisting of Valvulineria "H" age sediments, and the Lower Pleistocene Unit 2, consisting of Lenticulina 1 age sediments. On seismic records, the lower Pleistocene section is frequently characterized by a thick chaotic zone overlain by continuous parallel reflectors. This section closely correlates with the major marine regression and transgression that occurred during the Nebraskan (Valvulineria "H") and Aftonian (Lenticulina 1) glacial/interglacial periods respectively (table II). The base of the chaotic zone is interpreted to represent an erosional surface at the beginning of the Nebraskan Glacial Stage. There are many localities in the study area where Valvulineria "H" fossils are not found because of limited marine transgression or erosion. The lower Pleistocene cannot be seismically differentiated on the southern half of the study area and appears as an undifferentiated unit from Lenticulina (LPL-2) to Buliminella 1 (UP). During the Nebraskan low stand of sea level, most of the Pliocene sediments were exposed to subaerial erosion. Cross Section TLS-9 exhibits the profile of an entrenched valley. Coastal onlap of lower Pleistocene sediments is apparent on the western end of the section. A prograding fluvial-deltaic shoreline is observed on Cross Sections TLS-6, TLS-8, and TLS-12.

The middle Pleistocene section is divided into two units characterized by two occurrences of Angulogerina "B" (MPL-1 and MPL-2). The Upper Pleistocene Marker 1 (UPL-1) corresponds to the Hyalinea balthica "B" index fossil. The unit thins north of Cross Section TL-11, and the updip limit is difficult to determine. It thickens on a downdip direction attaining a maximum thickness along Cross Section TL-13. In this study the "climbing" Angulogerina "B" faunas in the High Island and Galveston Areas are considered to be the updip equivalent of the Hyalinea "B" zone and are included in the UPL-1 mapping unit.

Stratigraphic markers UPL-2 and UPL-3 are defined by the second and first occurrence of Trimosina "A". Both markers occur in wells in West and East Cameron along Cross Sections TL-9 and TL-11. The UPL-3 is present throughout most of the area and can be correlated across growth faults. The UPL-4 marker relates to the Sangamon (interglacial) period.

SUMMARY AND CONCLUSIONS

° A regional correlation grid of 26 horizons is established using electric well logs, seismic data, and paleontological information.

° Recent exploratory drilling has indicated that the Miocene in the High Island Area has prograded farther seaward than along other parts of the Texas/Louisiana shelf.

° The regional structural style is one of deep-seated anticlinal uplifts, salt and shale domes, and ridges. Numerous flexures and associated listric growth faults trend east-west.

° The High Island Ridge is an east-west-southwest trending anticline that began to form in middle Miocene time.

° The beginning of the Pleistocene age is marked by widespread fluvial-deltaic and associated prodelta facies characterized by chaotic seismic reflectors.

° The Pleistocene depocenter attains thickness in excess of 20,000 feet. Numerous regional listric growth faults contribute to the basinward movement of sediments along glide-plane fault systems at the top of the Miocene.

APPLICATION OF THE STUDY

The stratigraphic cross sections, which have been supported by a wealth of data and thoroughly documented, will provide a sound basis for a number of geological and engineering operations related to exploration and production, as well as reserve and resource estimates.

Recognizable benefits include

1. More accurate information for the correlation and identification of producing horizons and a more reliable basis for projecting trends and assigning geographically isolated producing horizons to the proper producing trends.

2. Provide a more accurate data base for evaluating tracts when pay, kinds of traps, thicknesses, etc. have to be projected in from other locations. It could also influence the assignment of risk values.

3. The process of prospect ranking will be enhanced by a more accurate identification of the correct stratigraphic horizon of prospective traps.

4. The study will provide a solid basis for determining the correct geological trend to be used in the calculation of reserves and in estimating undiscovered resources.

5. Exploration will benefit from the increased control provided by the basic framework and additionally from the structural and stratigraphic maps that will be generated and tied into the cross sectional framework. Sand-shale ratio and sand percentage maps can be extended through the use of information supplied by the study because the logs and the seismic sections have been reproduced at a scale that allows detailed analyses.

6. Research will be encouraged because of the establishment of the stratigraphically controlled cross-sectional grid. By utilizing this grid additional studies can be made to refine more localized and subtle structures and to determine how they relate to the regional structural framework.

7. In particular, this work will form a comprehensive basic data base permitting exploration groups, large and small, to consider a broader range of possible exploration prospects.

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Figures and Tables

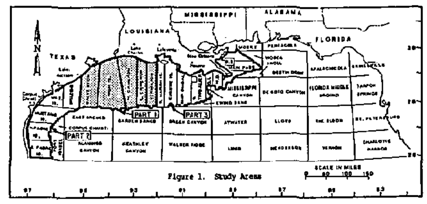


Figure 1. Study Areas

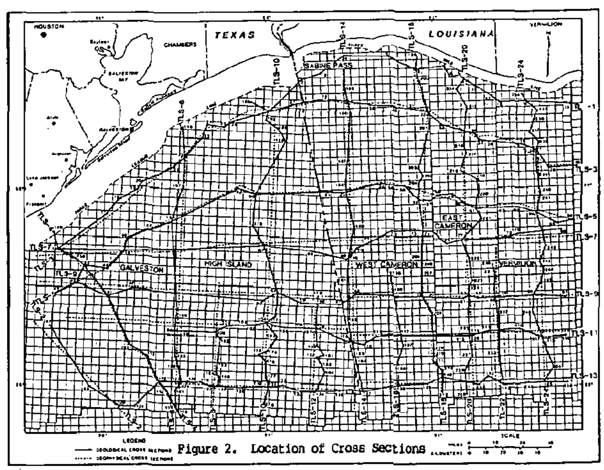


Figure 2. Location of Cross Sections

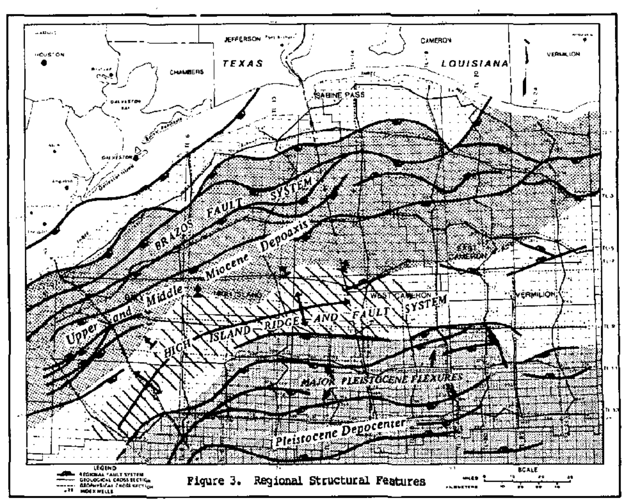


Figure 3. Regional Structural Features

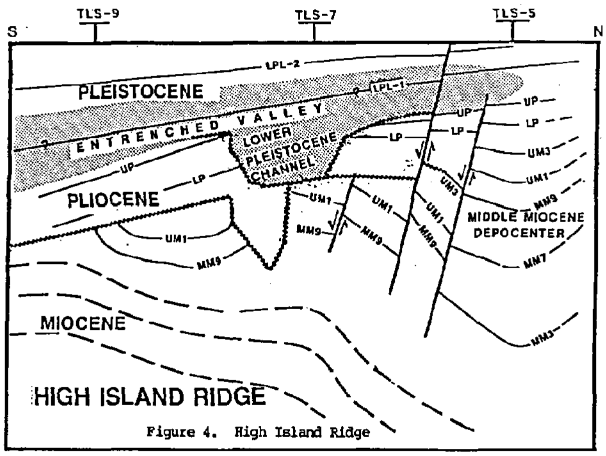


Figure 4. High Island Ridge

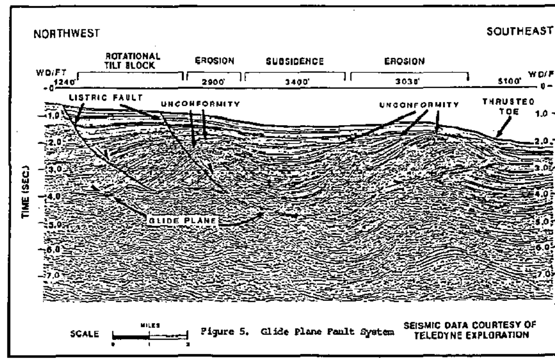


Figure 5. Glide Plane Fault System

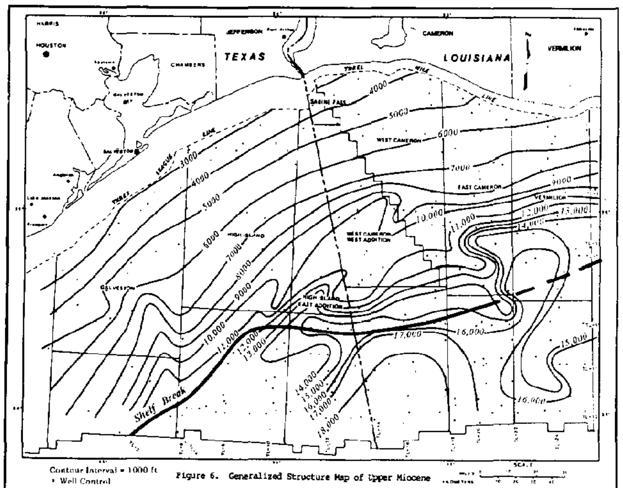


Figure 6. Generalized Structure Map of Upper Miocene

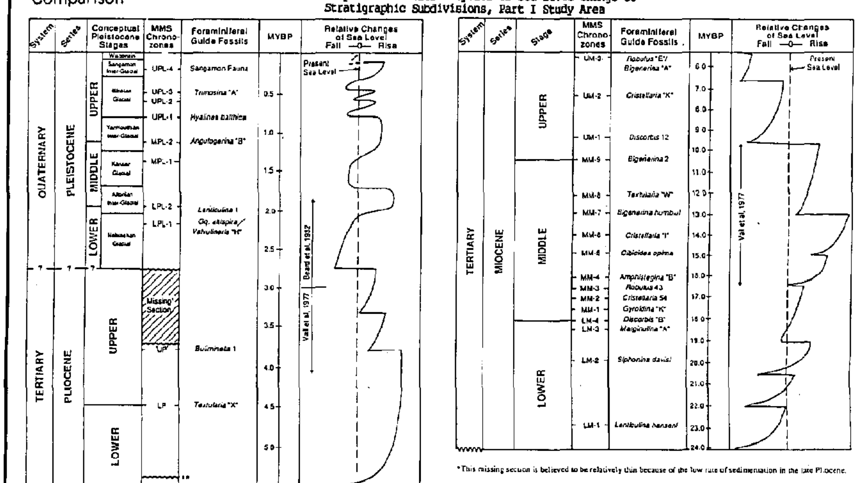
The following Regional Stratigraphic Markers and chronozones are determined by paleontological information, electrical log correlations, and seismic data.

Table I. Part I Study Area Stratigraphic Subdivisions

ERATHEM	SYSTEM	SERIES	STAGE	CHRONOZONES	BIOCHRONOZONES
CENOZOIC	QUATERNARY	PLEISTOCENE	UPPER	UPPER PLEISTOCENE MARKER 4	
				UPL-4	Sangamon Fauna
				UPPER PLEISTOCENE MARKER 3	
				UPL-3	*Trinosina* "A" 1st occurrence
				UPPER PLEISTOCENE MARKER 2	
				UPL-2	*Trinosina* "A" 2nd occurrence
				UPPER PLEISTOCENE MARKER 1	
				UPL-1	*Hyalinea* "B"/ *Trinosina* "B"
			MIDDLE	MIDDLE PLEISTOCENE MARKER 2	
				MPL-2	*Angulogerina* "B" 1st occurrence
				MIDDLE PLEISTOCENE MARKER 1	
				MPL-1	*Angulogerina* "B" 2nd occurrence
			LOWER	LOWER PLEISTOCENE MARKER 2	
				LPL-2	*Lenticulina* 1
				LOWER PLEISTOCENE MARKER 1	
				LPL-1	*Valvulineria* "H"
	?	?		UPPER PLIOCENE MARKER	
	TERTIARY / MIOCENE SUBSYSTEM	PLIOCENE	UPPER	UP	*Bulimina* 1
				LOWER PLIOCENE MARKER	
			LOWER	LP	*Textularia* "X"
		MIOCENE	UPPER	UPPER MIOCENE MARKER 3	
				UM-3	*Robulus* "E"/ *Bigenerina* "A"
				UPPER MIOCENE MARKER 2	
				UM-2	*Cristellaria* "K"
				UPPER MIOCENE MARKER 1	
				UM-1	*Discorbis* 12
			MIDDLE	MIDDLE MIOCENE MARKER 9	
				MM-9	*Bigenerina* 2
				MIDDLE MIOCENE MARKER 8	
				MM-8	*Textularia* "W"
				MIDDLE MIOCENE MARKER 7	
				MM-7	*Bigenerina humblei*
				MIDDLE MIOCENE MARKER 6	
				MM-6	*Cristellaria* "I"
				MIDDLE MIOCENE MARKER 5	
				MM-5	*Cibicides opima*
				MIDDLE MIOCENE MARKER 4	
				MM-4	*Amphistegina* "B"
				MIDDLE MIOCENE MARKER 3	
				MM-3	*Robulus* 43
				MIDDLE MIOCENE MARKER 2	
				MM-2	*Cristellaria* 54/*Eponides* 14
				MIDDLE MIOCENE MARKER 1	
				MM-1	*Gyroidina* "K"
			LOWER	LOWER MIOCENE MARKER 4	
				LM-4	*Discorbis* "B"
				LOWER MIOCENE MARKER 3	
				LM-3	*Marginulina* "A"
				LOWER MIOCENE MARKER 2	
				LM-2	*Siphonina davisi*
				LOWER MIOCENE MARKER 1	
				LM-1	*Lenticulina hanseni*

Comparison

Table II. Comparison of Global Cycles of Sea Level Change to Stratigraphic Subdivisions, Part I Study Area



*This missing section is believed to be relatively thin because of the low rate of sedimentation in the late Pliocene.

**This unconformity occurs near the Miocene-Pliocene boundary and marks the termination of a general lowering of sea level beginning in the late middle Miocene (*Textularia* "W"). The upper Miocene section contains many unconformities in the study area related to periodic low stands of sea level.

A QUALITATIVE ASSESSMENT OF THE HYDROCARBON POTENTIAL OF THE WASHINGTON AND OREGON CONTINENTAL SHELF

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ABSTRACT

The continental shelf off Washington and Oregon encompasses a large volume of subsurface strata that may contain appreciable accumulations of hydrocarbons. Regional analyses of exploratory well and seismic reflection data indicate the presence of a thick succession of Cenozoic marine sedimentary and igneous rocks, which exist within five shelf-wide, unconformity-bounded, stratigraphic sequences. The sequences comprise rocks from the early Paleogene, late Paleogene, early Neogene, late Neogene, and Quaternary periods. Oil- and gas-prone source rocks that have undergone thermal maturation and hydrocarbon generation exist within the sedimentary rocks of the sequences; also present are potential hydrocarbon reservoirs and traps. These factors suggest that geologic conditions that favor hydrocarbon generation, accumulation, and entrapment have existed along the Washington and Oregon continental shelf and that appreciable hydrocarbon resources may be present.

INTRODUCTION

The continental shelf off Washington and Oregon (Figure 1) encompasses a large volume of subsurface strata that may contain appreciable accumulations of hydrocarbons. Although economic hydrocarbon accumulations have not yet been discovered offshore Washington and Oregon, the area has been relatively unexplored compared with other regions of the petroliferous Pacific continental shelf. Regional analyses of exploratory well and seismic reflection data offshore Washington and Oregon provide insight to geologic conditions that have controlled hydrocarbon generation, accumulation, and entrapment along the shelf and permit a qualitative assessment of the hydrocarbon potential of the region.

STRATIGRAPHY

Exploratory well and seismic reflection data indicate the presence of a thick succession of Cenozoic marine sedimentary and igneous rocks

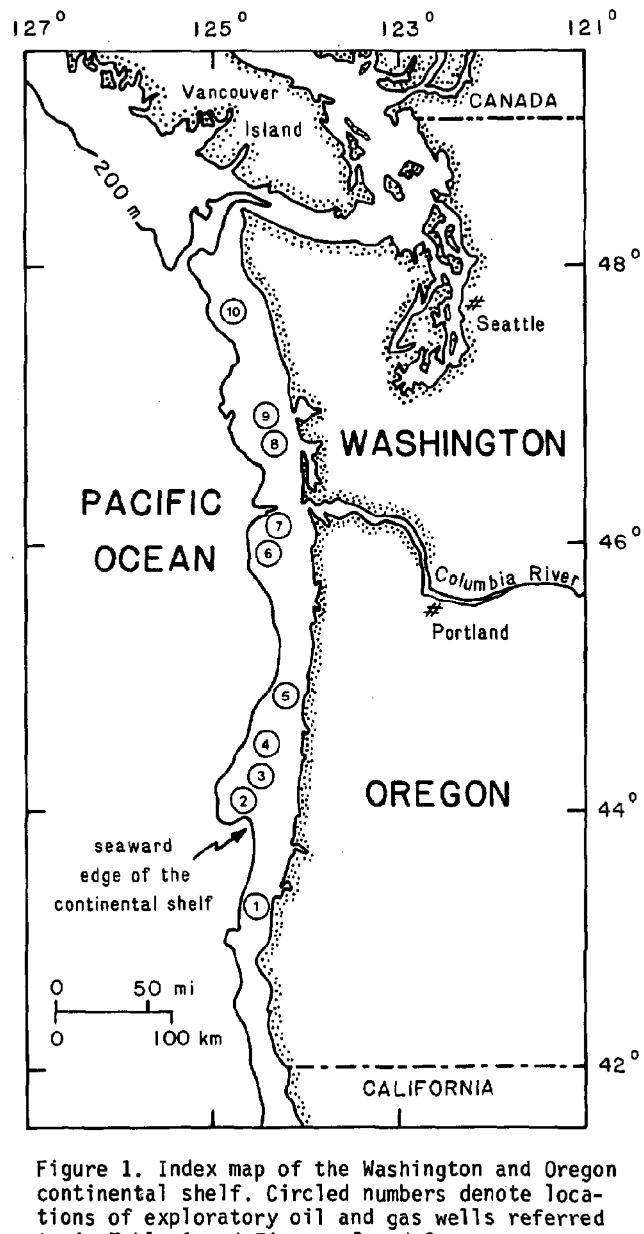

Figure 1. Index map of the Washington and Oregon continental shelf. Circled numbers denote locations of exploratory oil and gas wells referred to in Table 1 and Figures 2 and 3.

TABLE 1

REFERENCE NUMBER	COMPANY	WELL NAME and NUMBER
1	Pan Am	OCS P-0112 No.1
2	Union	OCS P-0130 Fulmar No.1
3	Shell	OCS P-087 No.2
4	Union	OCS P-093 Grebe No.1
5	Standard	OCS P-0103 Nautilus No.1
6	Shell	OCS P-072 No.1
7	Shell	OCS P-075 No.1
8	Shell & Pan Am	OCS P-0150 No.1 & 1A
9	Shell	OCS P-0155 No.1
10	Pan Am	OCS P-0141 No.1

Table 1. Exploratory oil and gas wells referred to in Figures 1 through 3.

along the continental shelf off Washington and Oregon. The strata exist within five shelf-wide, unconformity-bounded, stratigraphic sequences (Figures 2 and 3), which were produced by episodic marine sedimentation and volcanism during the early Paleogene, late Paleogene, early Neogene, late Neogene, and Quaternary periods. The sequences range in age from Paleocene (?) to middle Eocene (lower Paleogene sequence), late Eocene to Oligocene (upper Paleogene sequence), early to middle Miocene (lower Neogene sequence), late Miocene to Pliocene (upper Neogene sequence), and Pleistocene to Holocene (Quaternary sequence). Although Paleogene strata are widespread along the continental shelf, thick accumulations of Neogene and Quaternary strata are restricted to six depositional shelf basins. Maximum stratigraphic thickness occurs at the basinal depocenters where the Cenozoic section ranges from 10,000 feet (3050 meters) to more than 20,000 feet (6100 meters) thick.

SOURCE ROCKS

Sedimentary source rocks suitable for hydrocarbon generation exist within the subsurface strata of the continental shelf and the adjacent onshore area. It is likely that the hydrocarbon source-rock potential of offshore strata is more favorable than that of adjacent onshore source rocks, which are organically lean, gas prone, and of marginal thermal maturity. This supposition is based on the inference that potential offshore source rocks were deposited in deep-water, organically rich environments and have undergone greater burial and thermal maturation.

The occurrence of oil and gas ("shows") in rock samples from offshore exploratory wells (Figures 2 and 3) indicates that thermal maturation of hydrocarbon source material has occurred locally along the continental shelf. The probable existence of volcanically elevated regional geothermal gradients suggests that hydrocarbon maturation and generation may have occurred elsewhere along the shelf as well.

RESERVOIR ROCKS

Knowledge of the presence and quality of reservoir rocks along the continental shelf is limited to exploratory well locations where lithologic data have been collected. These data indicate that sedimentary rocks along the shelf are predominantly fine-grained sandstone and siltstone of relatively low porosity and permeability. However, the occurrence of hydrocarbon shows within each of the stratigraphic sequences indicates that some of the sedimentary rocks have sufficient porosity and permeability to permit migration and accumulation of oil and gas.

Although a greater number of hydrocarbon shows were encountered in Paleogene strata as compared with younger rocks, it is unlikely that potential reservoirs are more abundant within the Paleogene sequences. Most of the well locations are outside or along the periphery of the post-Paleogene basins; therefore, the well data do not provide meaningful lithologic insight to strata within the thickest and potentially most prospective portions of the Neogene and Quaternary sequences. The existence of coarse-grained clastic rocks within depositionally similar shelf basins suggests that the Neogene and Quaternary basinal sequences offshore Washington and Oregon contain some porous and permeable sedimentary rocks that may be potential hydrocarbon reservoirs.

TRAPS

Seismic reflection data along the continental shelf indicate the presence of numerous structural and stratigraphic features that have potential for entrapment of hydrocarbons. Although the quantity and areal extent of the seismic data are insufficient to permit trap-specific evaluation, the data provide insight to the geographic and stratigraphic distribution of potential traps along the shelf.

Potential structural traps include simple to complexly faulted anticlines, fault traps, and traps associated with shale diapirs, pillow structures, and igneous intrusions. A shelf-wide discontinuity in structural style exists in the vicinity of the Columbia River. Geologic structures north of the discontinuity generally consist of numerous northwest-trending, tightly folded anticlines and thrust faults, as well as shale diapirs; the structural

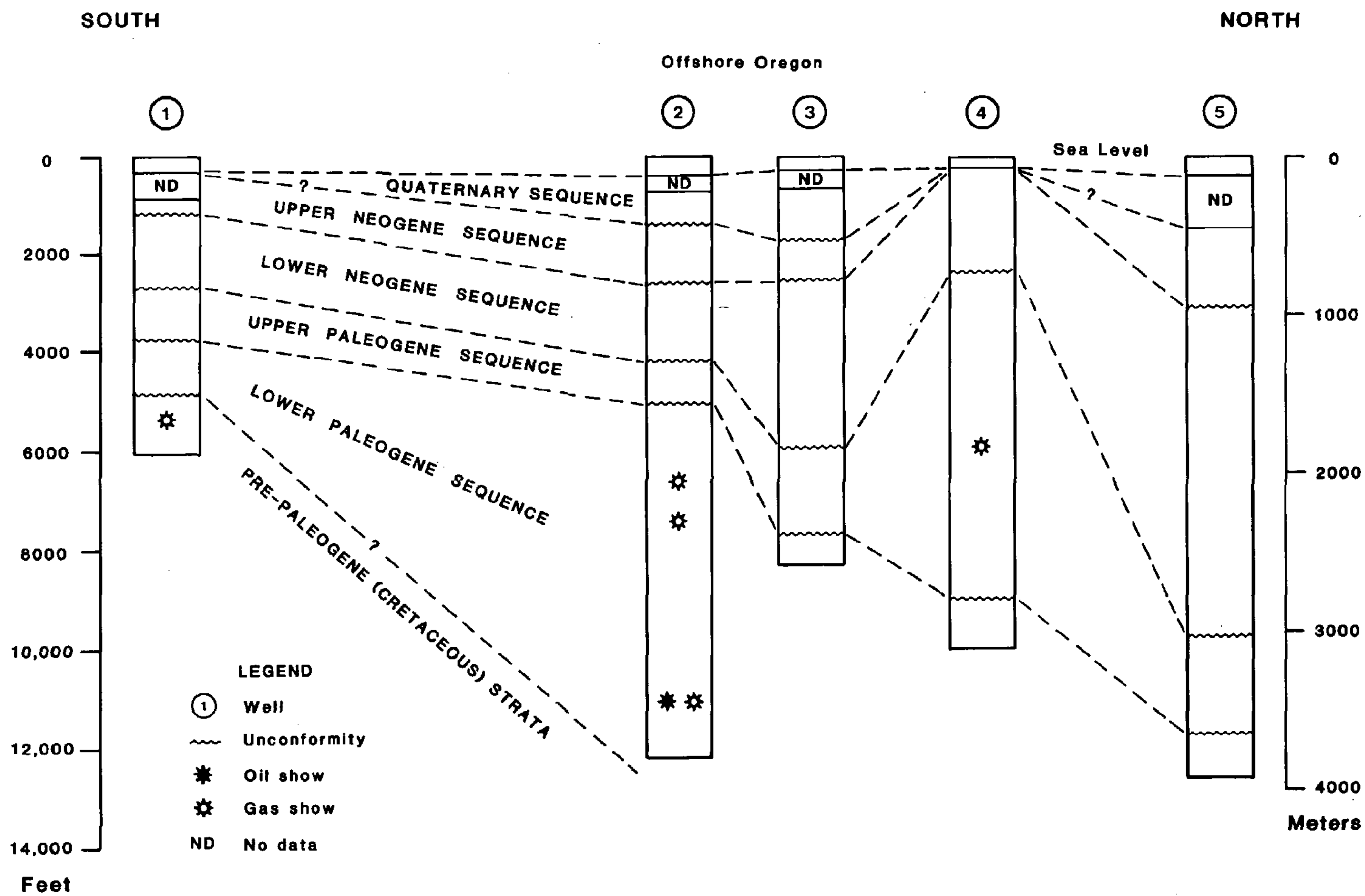

Figure 2. Stratigraphic correlation chart along the southern and central Oregon continental shelf, showing stratigraphic relations of unconformity-bounded sequences and hydrocarbon shows in exploratory wells. Locations and names of wells are shown in Figure 1 and Table 1.

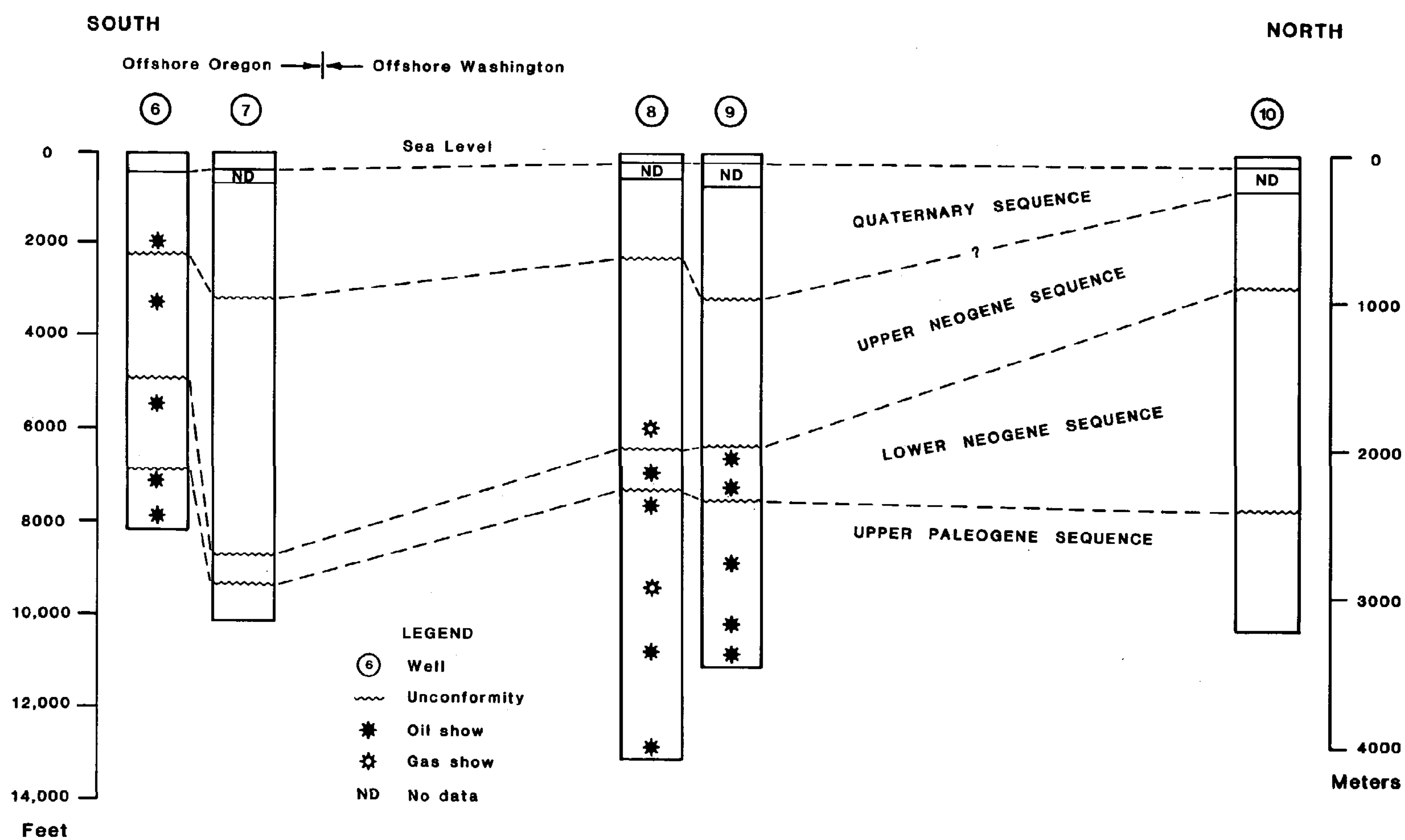

Figure 3. Stratigraphic correlation chart along the northern Oregon and Washington continental shelf, showing stratigraphic relations of unconformity-bounded sequences and hydrocarbon shows in exploratory wells. Locations and names of wells are shown in Figure 1 and Table 1.

style south of the discontinuity is characterized by relatively extensive, broad anticlines and thrust faults that trend northward. In general, older stratigraphic sequences along the shelf display greater structural complexity. These observations seemingly infer that numerous small, complex structural traps may exist within the older (e.g., Paleogene) sequences in offshore Washington and, conversely, that fewer and larger structural traps may exist within the younger (e.g., Neogene and Quaternary) sequences in offshore Oregon.

Potential stratigraphic traps are abundant along the continental shelf, and may exist along unconformities and within lithofacies pinch-outs.

CONCLUSIONS

Synthesis of geologic and geophysical information from the Washington and Oregon continental shelf indicates (1) the presence of a large volume of marine sedimentary rock, (2) the presence of oil- and gas-prone hydrocarbon source rocks, (3) the existence of geothermal gradients that have permitted hydrocarbon maturation and generation, (4) the presence of porous and permeable sedimentary rocks that are potential hydrocarbon reservoirs, and (5) the presence of abundant potential hydrocarbon traps.

These factors suggest that geologic conditions that favor hydrocarbon generation, accumulation, and entrapment have existed along the Washington and Oregon continental shelf and that appreciable hydrocarbon resources may be present.

ACKNOWLEDGMENTS

The ideas expressed here are based on collective analyses by the author and by Frank Webster and Tim Ingwell of the Minerals Management Service. Our analyses have been greatly aided and influenced by numerous geologic studies of the region; the primary of these are listed in the bibliography. I thank my colleagues for constructive reviews of the manuscript.

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IMPACT OF THE OIL-BEARING MONTEREY FORMATION ON UNDISCOVERED RESOURCES OF OFFSHORE CALIFORNIA

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ABSTRACT

About 1.4 billion barrels of oil equivalent reserves will be ultimately produced from fractured Monterey reservoir systems within identified fields in the southern California Outer Continental Shelf. Understanding Monterey fracture systems will help develop new potential discoveries within offshore central and northern California.

INTRODUCTION

The United States of America needs secure sources of domestic oil and gas. Recent published working papers by the U.S. Geological Survey personnel suggest that the nation's economically recoverable oil and gas maybe lower than previously estimated.[1] Lower resource estimates are the result of recent drilling disappointments (e.g., $150 million Mukluk dry hole) and lower oil prices that have precluded exploration or development of high-cost pools.[1] As a result of this postulated reduction of resources, additional attention is needed to augment these reserves.

The frontier basins of the California Outer Continental Shelf (OCS) are considered to be among the few remaining areas within the continental United States in which to find major undiscovered resources. Since OCS Lease Sale 53, May 5, 1981, 39 exploratory wells have been determined to have recoverable hydrocarbons that are producible in paying quantities in the southern California OCS. Twenty-one new oil fields have been identified within the Pacific Outer Continental Shelf Region (POCS) by these wells (fig. 1).

Total estimated ultimate production from discovered fields in the southern California OCS is 2.1 billion barrels of oil equivalent. This production is attributed to 22 oil and gas fields and 2 gas fields. Gas reserves are expressed in terms of oil on the basis of equivalent heating values (6,000 cubic feet of gas has approximately the same heating value of 1 barrel of oil). Approximately two-thirds of anticipated ultimate production, 1.4 billion barrels of oil, will be from the Monterey Formation.[2]

The Partington (northern Santa Maria basin), Ano Nuevo (Outer Santa Cruz), La Honda (Inner Santa Cruz), Bodega, and Point Arena basins have all experienced similar tectonics and sedimentation. Although the sediments (e.g., Monterey Formation) are not continuous laterally, they are correlatable (fig. 2).[3, 4] The Monterey Formation is organic rich with a total organic carbon (TOC) content of 3 to 18 percent.[5] Diagenetic alteration of sediments and tectonic overprinting have created massive fracture systems. Once formed, these fracture systems become excellent fluid migration paths/fracture reservoirs. Accordingly, a better comprehension of fracture reservoirs, such as the Monterey, can well enhance oil recoveries.

REGIONAL GEOLOGY

The regional geology for central and northern California is similar for the following four basins: (1) Santa Maria - Partington (northern Santa Maria), (2) Ano Nuevo (Outer Santa Cruz), (3) La Honda (Inner Santa Cruz) - Bodega, and (4) Point Arena (fig. 2). Three major depositional/orogenic cycles make up the tertiary stratigraphic section of coastal California (fig. 3). During the Paleogene, approximately 58 to 28 million years before present (mybp), sand, silt, and mud were deposited into deep ocean environment. At the beginning of the Neogene (26 mybp), the land was uplifted (Oligocene uplift) above the sea and eroded (fig. 3). During the early Miocene (26 to 16 mybp), the oceans started to transgress onto the land. During the Miocene (26 to 5 mybp), the present basins were formed as a consequence of right lateral movement along the San Andreas fault zone. In the middle Miocene (16 to 13 mybp), the Monterey Formation and its equivalent rocks were deposited into deepwater, oxygen-starved (anaerobic) basins during the maximum transgression of the sea. The depositional cycle was terminated with the Miocene-Pliocene uplift (approximately 13 mybp). Sea level rose again in late Miocene time (13 to 5 mybp), and initiated the late Neogene depositional cycle, which ended with the Pliocene-Pleistocene uplift (1 mybp).[4]

The Eel River basin is a forearc basin that follows a similar set of depositional cycles (fig. 3).

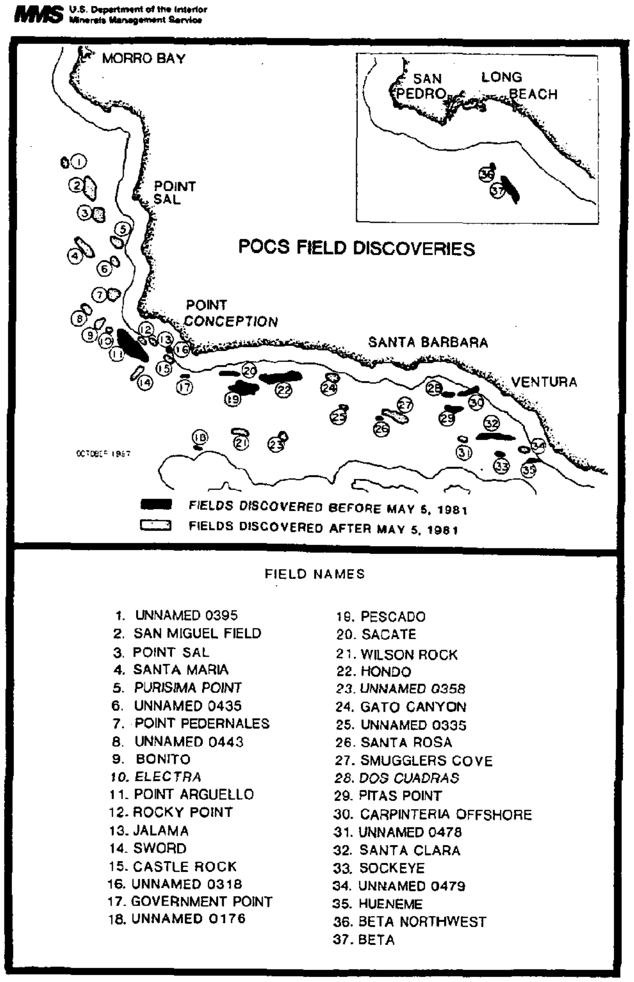

Figure 1. Oil and gas discoveries within the Pacific OCS Region since Sale 53.

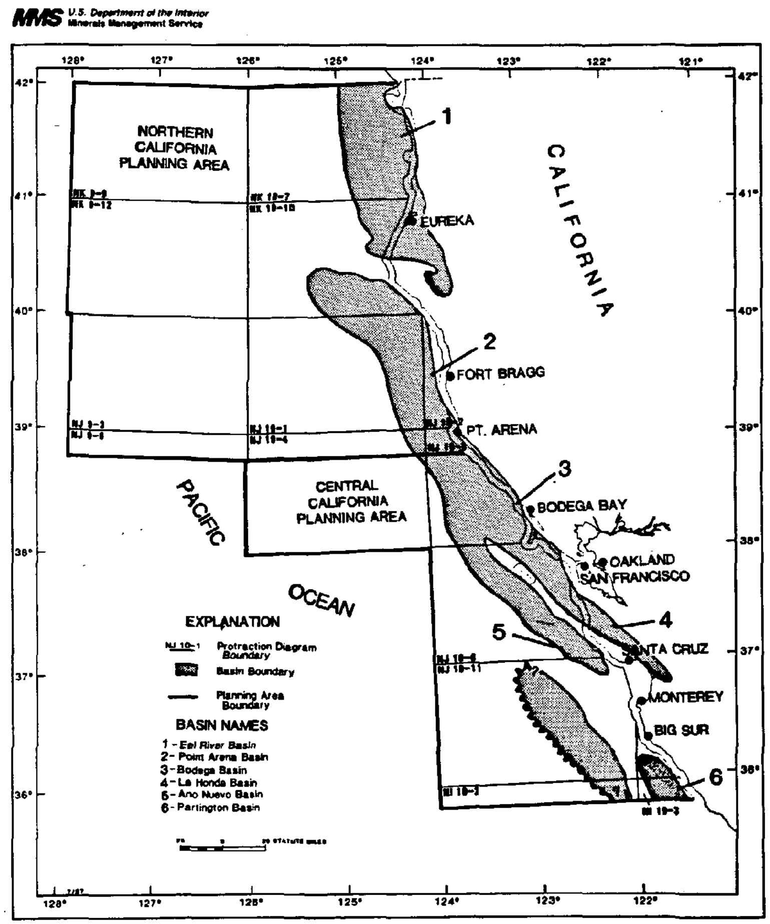

Figure 2. Geologic features of the Northern and Central California Planning Areas.[14] Basin numbers correspond to Figure 3.

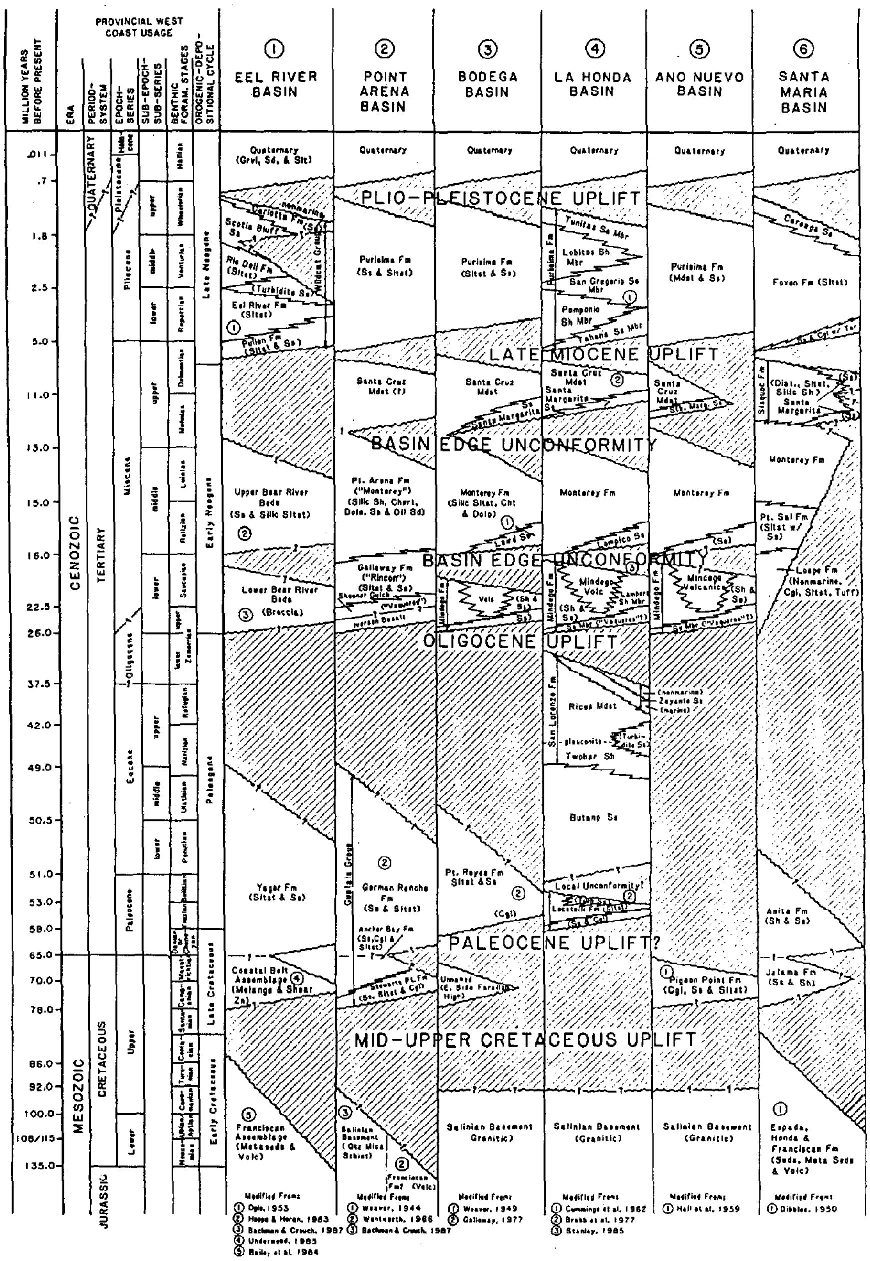

Figure 3. Stratigraphic chart of central and northern California.[4]

MONTEREY FORMATION

The middle Miocene Monterey Formation records the deposition of foraminiferal and diatomaceous oozes with various amounts of calcareous and phosphatic detritus in anaerobic, deepwater marine basins.[3,5] Widespread deposition of siliceous and calcareous lithofacies suggest that a rapid bloom of plankton occurred below or near the fluctuating boundary of an ocean oxygen minimum zone. Material deposited below this zone is well preserved as it is not destroyed by most microbiological and scavenger action. A source rock of 1 percent TOC is considered good; the Monterey has a TOC of 3 to 18 percent, which makes the Monterey a superb source rock.

With increasing pressure and temperature during burial, the organic finely laminated biogenetic deposits in time were converted into diatomites cherts, porcellanites, siliceous siltstones, mudstones, and dolostones. X-ray diffraction analysis has shown the diatomites convert from amorphous silica (Opal-A) to a more ordered crystalline phase of Cristobolite-Tridymite (Opal-CT), with increasing temperature from 40.6°C to 58.9°C (105°F to 138°F).[5,6] A final phase change occurs from Opal-CT to quartz at a temperature range between 65.6°C and 87.8°C (150°F and 190°F).[5,6] The silica phase changes will reduce porosity to 18-22 percent, which is typically found in Monterey reservoir rock. The amounts of clay material in the oozes may retard these phase changes.[7] With each phase change the rock becomes denser and water is expelled as the molecular volume decreases. Internal hydraulic fracturing of rock compensates for pressure changes.[8]

Fracture density is lowest in the siliceous mudstones, shales and dolostones and greatest in the brecciated cherts (quartz).[5] Fractures may be caused by (1) syneresis (a shrinkage crack formed by spontaneous expulsion of water), (2) diagenetic fractures, (3) tectonic fracturing (fold and fault related), (4) joints, and (5) fractures from weathering.[9] Within the Point Arquello Field, fracture permeability (1 to 2% of reservoir volume) appears to be the major factor in controlling initial production rates (6,000 barrels of oil per day) from the Monterey Formation.[5] Within the field, matrix permeability commonly averages 0.1 millidarcy or less [5, 10] suggesting that within the Monterey Formation fracture intensity is controlled more by lithology than by structural position or bed curvature.

MONTEREY RESERVOIR STUDIES

Review of individual well production histories for several fracture reservoir fields revealed that more than half of the production came from only a few wells. These wells were drilled on a 50- to 90-acre spacing. Initial production rates in some of these development wells ranged from 20 to 6,000 barrels of oil per day (BOPD). An apparent direct relationship exists between the location of the perforated interval for those wells with the highest production rates and the structural position. Highest production rates were associated with the crest of the structure and those wells that penetrated a fault zone (zone of high fracture potential). Those wells with the lowest production did not appear to penetrate a fault or fractured zone (matrix production only).

Plotting the following five pieces of information may aid in planning a field development: (1) plot perforation interval of all wells on Monterey structure map; (2) posting of production rates (per perforation foot per month); (3) identification and posting of lithofacies; (4) comparison of rock density to movement along faults or crestal flexture of beds to delineate the size of fracture zones or envelopes (area of fracturing); and (5) review of seismic interpretations to identify new fault zones. By understanding the fault patterns and mapping potential Opal-CT and quartz lithofacies the location of a development well can be optimized to intersect the maximum exposure of the fracture envelope. These wells should be able to produce for a longer period of time at a higher production rate. Infill drilling between fault zones may be necessary to recover all conventionally recoverable reserves before abandonment of the field.

MONTEREY PETROLEUM POTENTIAL IN THE CENTRAL CALIFORNIA PLANNING AREA

The Central California Planning Area includes the region between the offshore extension of the San Luis Obispo-Monterey County line and the offshore extension of Sonoma-Mendocino County line. Within this planning area are four sedimentary basins: Partington (northern Santa Maria basin), La Honda, Ano Nuevo, and Bodega basins (fig. 2). In this area, 12 wells were drilled from September 1963 to September 1967. These wells were drilled on leases issued from the May 1963 lease sale.[11]

Two wells were drilled in the Ano Nuevo basin. Shell Well OCS-P 036-1 found 530 m (1,760 ft) of Monterey Formation. Drill cuttings throughout the Monterey Formation were coated (up to 100%) with free tarry oil. Shell Well OCS-P 035-1, located 19.2 km (11.5 miles) southeast of OCS-P 036-1, drilled 451 m (1,480 ft) of Monterey Formation. Free tarry oil coated the drill cutting throughout this zone. The amount of free tarry oil was less than what was observed in OCS-P 036-1. No formation tests were run on either well.[11]

In the Bodega basin, 10 wells were drilled. The Monterey Formation ranged in thickness from 43 to 314 m (142 to 1,030 ft) within these wells. Shell Well OCS-P 055-2 and redrill 2A penetrated a thin section of Monterey sediments. Oil stains and traces of bleeding oil were noted from 1,976 to 1,979 m (6,480 to 6,490 ft) within the Monterey chert. Minor or no oil shows were observed in the other eight wells.[11]

No wells were drilled in Partington or offshore La Honda basins.

MONTEREY PETROLEUM POTENTIAL IN THE NORTHERN CALIFORNIA PLANNING AREA

The Northern California Planning Area includes the region between the offshore extension of the Sonoma-Mendocino County line and the offshore extension of the California-Oregon border. Within the planning area are two sedimentary basins: Point Arena and Eel River (fig. 2). In this area seven wells were drilled from blocks offered in the May 1963 lease sale. These wells were drilled from July 1964 to November 1966.

Three wells were drilled within the Point Arena basin by Shell Oil Company. Well OCS-P 030-1 was a vertical hole drilled on a faulted and tightly folded structure to a total depth of 3,243 m (10,636 ft). From the first recovered drill cuttings, 171 m (61 ft), to total depth, up to 90 percent of the cuttings were coated with free, tarry oil. A 1,494-m (4,900-ft) section of Point Arena Formation (Monterey equivalent) was penetrated. This well penetrated two reverse faults thus encountering repeated sections of Point Arena Formation. Six wire-line formation tests were made recovering mostly water and drilling fluids. Formation test No. 1 in the Point Arena Formation at 1,564 m (5,130 ft) recovered 50 cubic centimeters (cc) of 29 degree API gravity oil and 9,950 cc of water. This well has been considered to be a potential new discovery by private industry.[12] Weak oil shows were observed throughout the Miocene and pre-Miocene sections in the remaining two wells.[4]

Commercial gas has been produced from the Neogene (26.0-0.7 mybp) turbidite sandstone reservoirs in two onshore fields within Eel River basin. Oil seeps have been reported within the basin, and minor amounts of oil have been produced from Cretaceous (135 to 65 mybp) strata near Petrolia, 17 km (10 miles) south of Eel River basin. Monterey type deposits (Bear River Beds) exist on the flanks of the onshore Eel River basin and may exist offshore. Four offshore leases issued from the May 1963 lease sale were tested by drilling. These wells were drilled along the flanks and crest of a basement high. No oil or gas shows were reported and the Monterey Formation or its temporal equivalents, the "Bear River Beds", were not encountered.[11]

MONTEREY OIL, A NEW LOOK

Before 1969, the Monterey Formation and similar rocks were not considered to be economically capable of producing oil and gas offshore. In 1969, oil was discovered in the Monterey Formation at the Hondo structure in the Santa Ynez Unit within the Santa Barbara Channel, offshore California. Ultimate production from this field is estimated at 202 million barrels.[13] In May 1981, Chevron USA and partners bid $333,596,200 for OCS-P 0450 to delineate and confirm a giant Monterey oil field (Point Arquello) with estimated reserves between 300 and 500 million barrels of oil.[5] Within offshore Santa Maria, over 1 billion barrels of discovered oil is from the fractured strata of the Monterey Formation.[11]

The geology, oil shows, and well log characteristics found in wells of central and northern California are similar to those seen in the Santa Maria basin. These similarities suggest that several undiscovered giant oil fields may yet be found in central and northern California.[11]

SUMMARY

Due to increasing oil demands and shrinking national oil reserves, the United States needs to improve its methods of discovering new oil and gas fields and maximize recovery from those already producing. The Monterey Formation holds the most promise for containing new large oil and gas discoveries in central and northern California planning areas. As Monterey production depends heavily on fracture permeability, locating zones of optimum fracturing will play a major role in the discovery and development of California OCS resources.

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THE ANCIENT ATLANTIC REEF TREND

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ABSTRACT

In 1983 and 1984, Shell Offshore, Inc., drilled four petroleum exploration wells about 90 miles offshore from New Jersey, Delaware, and Maryland. This exploration program, at the time, established world deep-water drilling records; one drill hole was in 6,952 feet of water. Shell's main exploration targets were the limestones of an ancient, buried platform margin, reef, and other associated rock units. These limestones extend discontinuously from Canada to Florida beneath the edge of the continental shelf and slope. Petroleum accumulations occur in many parts of the world in deeply buried reefs of former geologic ages, but the Shell drill holes encountered no significant amounts of oil or gas. Nevertheless, this exploration effort provided considerable information about previously untested rocks. The platform-edge limestones and reef do have reservoir characteristics and may contain petroleum at other locations offshore from the Atlantic seaboard.

INTRODUCTION

In the 1960's, dredge hauls recovered Lower Cretaceous reefal and shallow-water platform limestone fragments from the base of Blake escarpment,[1] north of the Bahamas and Offshore from Florida. Relying on these discoveries and on seismic data, investigators speculated that an ancient reef or limestone bank system is buried in the North American Atlantic offshore subsurface.[2, 3] Continued seismic interpretation, together with information from United States Gulf Coast and Canadian Nova Scotia shelf exploration wells, provided additional evidence that a Jurassic-Lower Cretaceous reef-limestone platform system is buried under the continental slope and outer shelf. This platform system extends from the Grand Banks of Newfoundland, along the North American margin, around the tip of Florida, and into the Gulf of Mexico.[4, 5, 6, 7]

The Baltimore Canyon trough, offshore from the mid-Atlantic States, is the most thoroughly explored of the U.S. Atlantic sedimentary basins. Two stratigraphic test wells, COST (Continental Offshore Stratigraphic Test) B-2 and B-3, and 28 industry petroleum exploration wells were drilled shoreward of the limestone platform and reef trend between 1975 and 1981. In 1983 and 1984, Shell Offshore, Inc., conducted a four-well exploration program on the seaward margin of Baltimore Canyon trough, about 90 miles offshore from New Jersey, Delaware, and Maryland (Fig. 1). Three of these drill

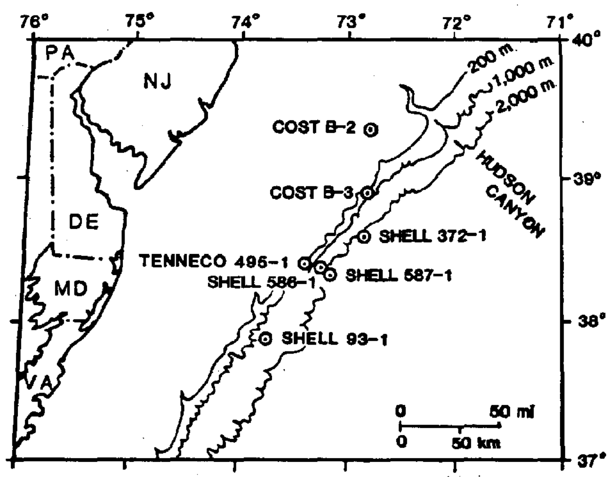

Figure 1. Map of a portion of the Baltimore Canyon trough area, showing locations of the Shell 372-1, 586-1, 587-1, and selected other wells. English equivalents of bathymetric contours are 565 ft (200 m), 3,281 ft (1,000 m), and 6,562 ft (2,000 m).

holes penetrated the limestone platform, reef, and associated other limestone units. Although no commercially significant hydrocarbon shows were encountered, these wells produced a wealth of geologic information, including the first rock samples from the ancient, buried reef. In addition, a world deep-water drilling record was set by the Shell Wilmington Canyon 372-1 well (water depth 6,952 feet); the record stood until 1987.

THE REEF TREND IN BALTIMORE CANYON TROUGH

The reef and limestone platform are in the seaward portion of the Baltimore Canyon trough (Fig. 2). Through Middle

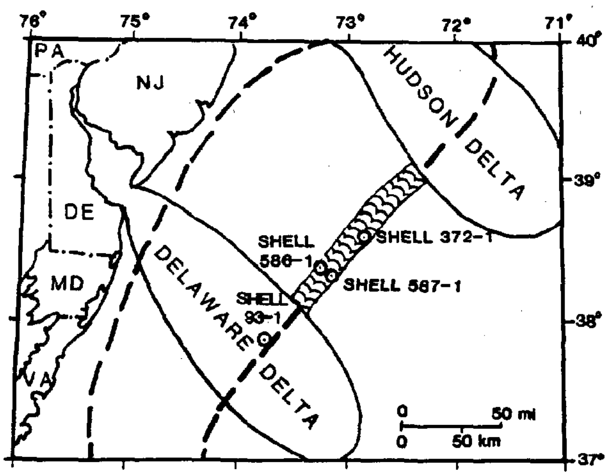

Figure 2. Schematic map showing the outline of Baltimore Canyon trough (heavy dashed) and the position in the subsurface of the limestone platform (shaded) between the ancient Hudson and Delaware submarine deltas.

and Late Jurassic and Early Cretaceous time, the trough was dominated by continental detrital sediments (sand, silt, clay), which were shed into the basin from the west. Therefore, the limestones, which require relatively clear water, were restricted to the outer part of the basin. In addition, major rivers built large deltas, and the submarine portions of the deltas extended seaward beyond the reef trend. As a consequence, the limestones occur as segments between delta systems, for example, between the ancient Hudson and Delaware deltas. Shell's exploration program investigated this segment of the reef trend, which is shown in cross section in Figure 3.

The Limestone Platform

The deepest rock unit tested by Shell is a platform limestone, which is flat topped and slopes landward. Correlation with adjacent basins indicates that the platform exists discontinuously all along the North American Atlantic margin. However, north of Cape Hatteras it is narrow, being flanked on its landward side by continental detrital rocks and terminating on its seaward side as the continental slope. In the vicinity of the Shell wells, the top of the platform is less than 10 miles wide. Thickness of the platform is difficult to determine because it has not been entirely penetrated by drilling and because seismic profiles show few interpretable reflections within or under the platform. However, the platform may be as much as 33,000 feet (10 km) thick.[8]

The platform is cut by normal faults, which trend northeast-southwest and mostly have down-to-the-basin throws toward the ocean. Major faults are generally growth structures, showing greater displacement with increasing depth, and appear to be lystric, having concave fault planes that merge with the bedding of rocks deep in the basin. The top of the platform slopes downward to the west, interpreted to be a consequence of rotation of platform segments, owing to downward movement along the curved faults.

Comparison of Baltimore Canyon drilling results documents the transition from shoreward, continentally derived detrital rocks to the platform limestones at the seaward edge of the basin (Fig. 3). The Tenneco 495-1 well is about 10 miles west of the seaward rim of the platform and penetrated interbedded sandstone, siltstone, shale, and minor limestone in that part of the stratigraphic section equivalent in age to the platform. The Shell 586-1 well, about 3 miles from the platform rim, encountered mostly limestone but with many interbeds of sandstone, siltstone, and shale. The platform-edge Shell 587-1 well penetrated limestone with numerous thin shale interbeds.

The Baltimore Canyon platform limestones are typically fine grained, having been lithified from carbonate mud sediments, and contain variable quantities of calcareous micro- and macrofossils. Abundant fossils include bryozoans, echinoderms, sponges, stromatoporoids, foraminifers, and blue-green algae. In moderate quantity are corals, bivalves, and rudists. Minor components include gastropods, ostracods, and green algae.

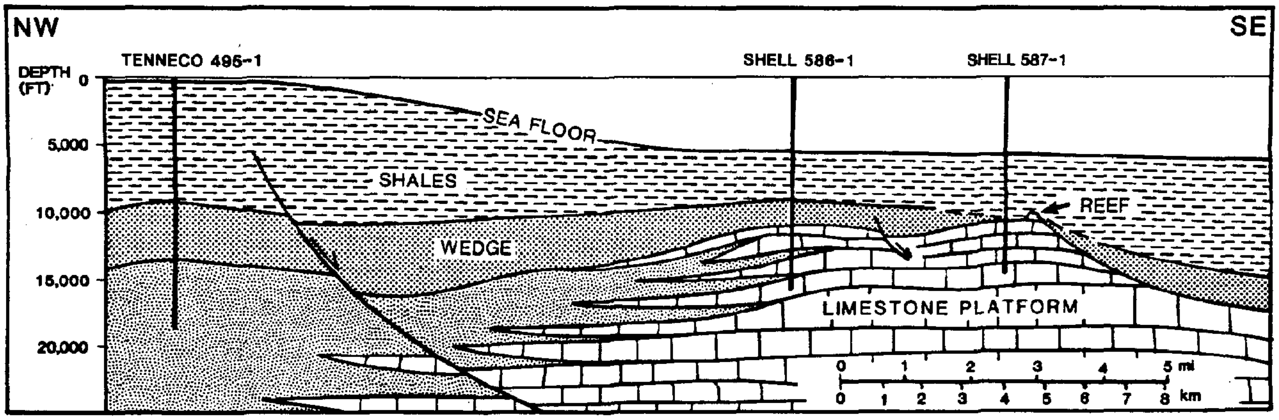

Figure 3. Schematic cross section through the ancient continental shelf margin in the vicinity of the Tenneco 495-1 and Shell 586-1 and 587-1 wells.

Geologic age ranges of diagnostic fossils indicate that almost all of the platform is Jurassic in age but that its uppermost portion persisted into the earliest part of the Early Cretaceous Epoch. Finally, deposition of platform sediments is inferred to have occurred in the generally quiet waters of a shallow marine environment protected from the open sea by the platform rim. The great thickness of shallow-water limestones is explained by basinal subsidence, which allowed accumulation of sediments for tens of millions of years.

The Reef

According to seismic analysis, the reef is discontinuous and variable in size and shape. Where present, it occurs as a raised rim along the seaward edge of the limestone platform (Fig. 3). In places, this ridgelike structure is rounded and mound shaped and in others it is flat topped. Its relief above the adjacent platform is as much as 500 to 600 feet.

Two Shell wells were drilled at the seaward edge of the platform, the 587-1 and 372-1. The latter penetrated a moundlike reef and the former encountered reeflike limestones and fossil reefbuilding biota within the platform margin. Limestone samples from the 587-1 well were also strongly weathered, having a chalky texture. In general, the reefal and shelf margin rocks appear to be largely carbonate detrital accumulations. That is, fossils, fossil fragments, and limestone clasts form a chaotic assemblage, which implies probable agitation and reworking by wave and storm action. Some limestone intervals contain carbonate mud matrix and some do not, indicating relatively lower and higher energy cycles of deposition. Calcareous fossils and clasts range from sand and gravel sizes to a few inches in diameter and probably much larger, but determination is limited by the drill hole diameter. Fossil biota include corals, stromatoporoids, sponges, echinoderms, bryozoans, pelecypods, gastropods, and blue-green algae. Within some intervals of the detrital assemblage are pods and crusts of corals and stromatoporoids that appear to be in growth positions.

Age-diagnostic fossils are rare in these limestones, but calpionellid species from the moundlike reef in the 372-1 well and the top of the platform margin in the 587-1 well are earliest Early Cretaceous. The data suggest that deposition of the limestone platform persisted into Early Cretaceous time and concluded with the rapid upward growth of reefs along the platform edge. This culmination appears to be related to a period of rapid worldwide rise in sea level.[9]

The Overlying Rock Units

Through most of the Early Cretaceous Epoch a wedge of continental detrital sediments prograded seaward, burying the continental shelf in Baltimore Canyon trough.[10] This wedge is readily apparent on seismic sections and is shown diagrammatically in Figure 3. This progradation is interpreted to have been caused by cycles of low sea level. When the wedge reached the edge of the carbonate platform, it spilled over the reef and onto the continental slope, creating a thick apron of Cretaceous sediments. In middle Cretaceous time the continental shelf-edge sediments appear to have become subaerially exposed during a period of low sea level. The ancient continental slope was then beveled by erosion to its present configuration in the subsurface. Finally, Late Cretaceous shales, associated with rising sea level, covered the underlying sedimentary units.

PETROLEUM POTENTIAL

Shell's exploration program found porous platform margin and reefal limestones. Platform-edge limestones in the 587-1 well had up to 25 percent porosity, based on petrophysical tests of plugs from drill core. Porosities were much poorer in the 372-1 well reefal core, having a maximum of only 6 percent. However, well log analysis and drilling rates suggest that porous intervals do occur in that well. The more shoreward 586-1 well showed no evidence of significant porosity in the platform.

The limestone platform margin and reef occupy a regional topographic high ground, and the weathered limestone in the 587-1 well suggests that the platform edge, or immediately overlying rocks, became subaerially emergent during periods of low sea level. Freshwater leaching of the limestones produced zones of good porosity. Reservoir top seals may be provided by the shales above the platform margin and reefal limestones. It was hoped that petroleum had migrated into the reservoirs from underlying organic-rich carbonate rocks or shales or from source beds on the continental slope, immediately to the east. However, no hydrocarbons were encountered other than trace quantities of natural gas, owing to apparent lack of organic-rich source beds in the vicinity.

With the reservoir potential of the limestone margin established, future drilling targets along this trend will probably be chosen only after considerable effort is expended in identifying likely source rocks. Source rocks may include limestones and shales of the underlying platform and shales on the continental slope. In addition, submarine portions of river deltas, where they are adjacent to the limestone trend, may contain pertinent source beds.

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THE EFFECT OF EXPLORATION ON RESOURCE ESTIMATES FOR THE ALASKA OUTER CONTINENTAL SHELF

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ABSTRACT

Resource estimates generated prior to exploration drilling of the Alaska Outer Continental Shelf (OCS) indicated the general optimism held for this vast frontier area. Drilling in six of the most promising planning areas indicates less potential than previously anticipated. Recent resource estimates reflect the fairly negative drilling results, showing a marked decline in resource potential for the drilled areas.

Numerous traps, plays, and structural provinces remain untested in each of the drilled areas. Though drilling results have tempered optimism, these untested features still provide hope for finding significant resources in the Alaska OCS.

INTRODUCTION

The Alaska Outer Continental Shelf (OCS) comprises 74 percent of the total OCS acreage of the entire United States. The Department of the Interior (DOI) has divided the Alaska OCS into fifteen "Planning Areas" for Federal OCS sales (Figure 1). Planning areas encompass one or more geologic provinces or sedimentary basins. To date, fourteen sales have been held by the Department of the Interior in seven different planning areas offshore of Alaska: the Gulf of Alaska, Lower Cook Inlet/Shelikof Strait, Beaufort Sea, Norton Basin, St. George Basin, Navarin Basin, and Chukchi Sea.

More than sixty exploration wells have tested structures in these planning areas, with the exception of the Chukchi Sea Planning Area, leased for the first time in May of 1988. Most of these exploration wells have been plugged and abandoned.

Drilling results and a better understanding of the petroleum geology of the tested planning areas have tempered the early general optimism of the 1970's for the Alaska OCS as a geologically prospective area for major hydrocarbon accumulations. The U.S. Geological Survey (USGS) developed resource estimates for the Alaska OCS in 1981. These early estimates were based primarily on reconnaissance mapping and analog basin studies. In 1984 and 1987, updated estimates were developed by the U.S. Minerals Management Service.

The USGS estimates are not directly comparable to MMS estimates due to the use of different methodologies. A gross comparison of the USGS 1981 and MMS 1984 estimates can, however, serve to show the change in perspective regarding the resource potential for the Alaska OCS (Table 1).

TABLE 1 -- Comparison of USGS 1981* and MMS 1984 estimates of undiscovered, economically recoverable resources (risked mean estimates), offshore Alaska. (1), (2)

Oil (BBO)			Gas (TCF)		
USGS 1981 Total	MMS 1984 Federal	Percent Diff. (+) (-)	USGS 1981 Total	MMS 1984 Federal	Percent Diff. (+) (-)
12.2	3.3	-73	64.6	13.9	-78

*USGS estimates include both State and Federal offshore lands, since in 1981 land ownership had not been completely determined.

BBO=billion barrels. TCF=trillion cubic feet.

TABLE 2 -- Comparison of MMS 1984 (1) and 1987* estimates of undiscovered, economically recoverable resources, Alaska OCS.

Drilled Planning Area	Conditional Oil-BBO Mean		Conditional Gas-TCF Mean		Marginal Probability Hydrocarbons	
	1984	1987	1984	1987	1984	1987
Gulf of Alaska	0.54	1.17	8.34	5.95	0.08	0.05
Lower Cook Inlet	0.21	0.17	0.35	0.25	0.03	0.02
Norton Basin	0.64	0.15	2.94	1.51	0.15	0.01
St. George Basin	1.69	0.41	15.76	4.55	0.22	0.05
Navarin Basin	4.80	1.19	5.84	3.50	0.27	0.04
Beaufort Sea	1.28	0.91	5.62	5.61	0.70	0.42

*1987 resource estimates are preliminary and subject to review.

BBO=billion barrels. TCF=trillion cubic feet.
The 1984 and 1987 estimates were generated using comparable price scenarios.

Comparison of resource estimates generated by the MMS in 1984 and 1987 shows an overall decline in potential resources (Table 2). The 1987 MMS estimates reflect a systematic reassessment based on detailed seismic mapping and well data.

To understand the basis for declining resource estimates, a basic understanding of the geology of the tested basins is necessary. A general overview and summary of the resource potential for the six tested planning areas follows.

GULF OF ALASKA PLANNING AREA

The Gulf of Alaska (GOA) Planning Area encompasses 30,000 square miles of OCS lands (Figure 1). Acreage in the central GOA was offered in 1976, in the first Federal OCS sale for Alaska. Industry leased over 400,000 acres at this time. Twelve exploration wells tested structures during the 1977 and 1978 drilling seasons. All wells were plugged and abandoned, with no commercial hydrocarbon accumulations encountered.

Two more sales held for the GOA Planning Area included acreage in both the central and eastern GOA. At these sales the DOI leased about 200,000 more acres, all in the eastern GOA. One well tested a structure in this area, but encountered no commercial hydrocarbon accumulations and was subsequently plugged and abandoned.

Figure 2 summarizes the stratigraphy present in the GOA. Ten of the thirteen wells encountered severe overpressuring in the Yakataga Formation. The Yakataga exhibits fair reservoir potential but very poor source rock potential. It is thermally immature and contains low amounts of total organic carbon (TOC).

The Kulthieth occurred in only two wells but had good reservoir potential and fair source rock potential. It contained over 1 percent TOC and had sufficient thermal maturity to produce hydrocarbons.

The Poul Creek Formation, an offshore equivalent of the Katalla Formation reservoir of the now abandoned onshore Katalla Field, becomes shalier offshore. Where penetrated by wells, the Poul Creek appears thermally immature. Maturity may increase with deeper burial in other parts of the GOA, enhancing its potential as a source rock.

Resource estimates for the GOA show an increase in mean conditional oil from 540 million barrels to 1.17 BBO (Table 2). This increase reflects the additional traps recognized as having oil potential as a result of detailed mapping in previously unmapped areas. Drilling results were also incorporated into the resource estimates, but did not negate the new data generated from detailed seismic mapping. Mean conditional gas declined from 8.34 TCF to 5.95 TCF. The marginal probability that economically recoverable hydrocarbons exist in the GOA dropped from 8 percent to 5 percent.

Though resource potential as measured by the marginal probability has diminished, structural regimes remain untested. A Tertiary basin in the far-eastern GOA contains sediments which range from 5,000 to 20,000 feet in thickness. Sediments of middle to late Tertiary age are postulated to rest unconformably on Jurassic and Cretaceous metasediments, volcanics, and intrusives of the basement complex (Figure 2).

In the west-central GOA, a large province with sediments up to 20,000 feet thick remains untested. Structurally, this area appears thrust faulted, with good potential for traps to exist. Farther west, sediment thickness decreases to 12,000 feet and less. This area is structurally complex and possibly thrust faulted. Numerous traps probably exist.

LOWER COOK INLET AND SHELIKOF STRAIT

The DOI held the first Lower Cook Inlet (LCI) sale in October 1977, leasing about 410,000 acres at this time (Figure 1). Ten exploration wells tested structures over the next three years. The DOI held two additional sales for the LCI, including the Shelikof Strait area to the south. An additional 75,000 acres were leased. Through 1985, industry drilled three more exploration wells. Speculation that the producing trend found in the Upper Cook Inlet petroleum province continued southward into the Lower Cook Inlet/Shelikof Strait area lessened as all the wells were plugged and abandoned.

In Upper Cook Inlet, the sequence of Tertiary reservoir rocks (Lower Tyonek, Hemlock, and West Foreland Formations) overlies Jurassic source rocks. Large-scale faulting and a major unconformity between the Tertiary and Mesozoic rocks act as migration routes for hydrocarbons. This same unconformable relationship apparently does not exist in the LCI (Figure 3). The Tertiary section, in general, appears thin and has poor reservoir rock potential. Localized nonmarine sandstone reservoirs do exist, however, in the west-central part of the LCI where two wells encountered noncommercial oil accumulations.

Resource estimates for the LCI/Shelikof area have declined since 1984 (Table 2). A decrease from 210 million barrels to 170 million barrels for mean conditional oil estimates reflects the most recent drilling results. Mean conditional gas estimates declined from 0.35 TCF to 0.25 TCF, while the marginal probability for economic hydrocarbon accumulations to exist in the planning area decreased slightly from 3 to 2 percent.

A number of untested structures remain within the LCI/Shelikof Strait area. In addition, localized marine sands may occur in the planning area. These sands could be thicker and have better reservoir quality than those encountered in the two exploration wells with hydrocarbon shows.

NORTON BASIN PLANNING AREA

In 1983, the DOI held the Norton Basin sale, the first sale to offer acreage in the Bering Sea (Figure 1). Industry leased some 330,000 acres at this sale. During the next two years, six exploration wells tested structures in the planning area. All wells were plugged and abandoned with no commercial accumulations of hydrocarbons found.

Figure 4 shows the stratigraphy present in the Norton Basin. Norton Basin encompasses two subbasins separated by the Yukon Horst. Up to 20,000 feet of Tertiary sediments overlie probable Paleozoic metamorphic basement. A sequence of mainly fluvial to shallow marine mudstone, siltstone, sandstone, and minor coals occurs. Deeper water clastics were deposited in the western subbasin during the lower Tertiary, when it was structurally isolated from the eastern subbasin by the Yukon Horst.

Reservoir quality rocks occur mainly in the Oligocene nonmarine and shallow-water deposits in the eastern subbasin. Thermal maturity sufficient to generate hydrocarbons exists below about 10,000 feet in both subbasins. However, source rocks appear to be scarce and mainly gas prone.

Resource estimates for the basin appear in Table 2. The estimate for mean conditional oil declined from 640 million barrels in 1984 to 150 million barrels in 1987. This large decline reflects the paucity of oil-prone source rock evident from well data. Mean conditional gas resources also declined, from 3 TCF to 1.5 TCF. In addition, the marginal probability dropped from a 15-percent chance of economic accumulations of hydrocarbons being present to a 1-percent chance.

Though interest in the hydrocarbon potential for Norton Basin has waned, many traps remain untested. Only one well has tested the western subbasin. This subbasin exhibits a more marine character in the deeper, older sediments which could provide a better potential for oil maturation and generation.

ST. GEORGE BASIN PLANNING AREA

In 1983, DOI leased over 540,000 acres in the St. George Basin (Figure 1). Nine exploration wells tested structures during the next two years. All wells were plugged and abandoned with no commercial accumulations of hydrocarbons encountered.

St. George Basin Planning Area contains two main depocenters, the St. George Basin graben, with up to 40,000 feet of sediment, and the Pribilof Basin half-graben, with about 20,000 feet of sediment. A Tertiary-age sequence dominated by fine-grained sandstones, siltstones, mudstones, and minor conglomerates overlies either Mesozoic sediments or basement igneous rocks (Figure 5).

The common occurrence of volcanic rock fragments limits the development of good reservoir rock. These generally alter to zeolites and clay minerals, and reduce porosity and permeability of the sediments. Source rock potential appears low in the Tertiary, with low TOC values and thermally immature sediments.

In 1984, MMS estimated the economically recoverable oil (mean value) at about 1.7 billion barrels (Table 2). Estimates for 1987 dropped to 410 million barrels, indicative of poorly developed reservoir and source rock in the wells. Gas resource estimates declined from 15.8 TCF to 4.6 TCF (mean values of economically recoverable gas). The marginal probability for the planning area also declined from 22 percent to 5 percent.

St. George Basin Planning Area still has potential for hydrocarbon accumulations. Plays within the graben and half-graben may be associated with rocks deposited in a restricted basin providing conditions more favorable for source rock preservation and maturation. Generation and entrapment of hydrocarbons, before adverse diagenetic changes occurred within the sands, could have preserved reservoir porosity and permeability.

NAVARIN BASIN PLANNING AREA

In 1984, DOI held the first lease sale for the Navarin Basin (Figure 1). Industry leased over 920,000 acres at this sale. During the next year, eight exploration wells tested structures within the basin. All wells were plugged and abandoned with no commercial accumulations of hydrocarbons found.

Navarin Basin encompasses three subbasins. A thick Tertiary section overlies Cretaceous and possibly older Mesozoic rocks (Figure 6). Maximum sediment thickness within the three subbasins ranges from about 26,000 feet to at least 36,000 feet. The wells did not reach basement rocks.

The Tertiary sediments lack good reservoir rocks. Sediments appear very shaly and silty. Mesozoic rocks, though sandier, exhibit little reservoir potential because of low porosities and permeabilities. Source rock potential is, in general, poor to marginal, owing to low TOC content and insufficient thermal maturity. The basin may, however, have source rock of limited geographic extent.

Based on seismic mapping and drilling results, resource estimates for Navarin declined substantially from 1984 to 1987 (Table 2). Mean conditional oil estimates dropped from almost 5 billion barrels to 1.20 billion barrels. In addition, the marginal probability for the basin declined from 27 percent to 3 percent. Estimates for gas declined from almost 6 TCF to 3.5 TCF.

Despite poor drilling results, the Navarin Basin still provides exploration opportunities. The potential for stratigraphic traps, such as turbidite sequences, exists within the basin. In addition, a number of structural provinces within the planning area remain untested.

BEAUFORT SEA PLANNING AREA

The Beaufort Sea Planning Area remains the premiere area for hydrocarbon potential offshore of Alaska (Figure 1). Four lease sales have taken place for the Beaufort Sea since leasing first began in 1979. To date, the DOI has leased almost four million acres.

Industry drilled nineteen wells in the planning area. MMS classifies eight of these wells as "producible." In this context, "producible" means a well is capable of producing oil or gas, or both, in quantities that will provide a monetary return in excess of cost, after completion, at the well head. The costs of the lease, building of ice or gravel islands, drilling, and other investments are not included in the determination.

The Beaufort Planning Area comprises several geologic provinces. It lies offshore of the largest oil field discovered in North America, the giant Prudhoe Bay field, with original reserves estimated at ten billion barrels of oil and 26 TCF of gas.

Figure 7 shows the stratigraphy of the Beaufort Planning Area (3). All commercial hydrocarbon accumulations, both onshore and offshore, occur within the Ellesmerian sequence. The Ivishak Formation remains the most prolific reservoir of the North Slope, with the Lisburne and the Endicott Groups subsidiary reservoirs in the Ellesmerian sequence.

The Ellesmerian sequence represents sediments deposited in a stable shelf environment which onlapped an ancient landmass situated north of the present-day Beaufort continental margin. Ellesmerian sedimentation ended during the Late Triassic when rifting began.

The Beaufortian sequence represents sediments deposited during a failed rifting episode of the Jurassic and the successful rifting event which opened the Canada Basin during the Early Cretaceous. The Barrow Sandstone, Kuparuk River, and Point Thomson reservoirs formed during the rifting events.

Rifting ended by mid-Cretaceous time. The Brooks Range to the south provided the sediment for the deltaic deposits prograding into and filling the newly formed Canada Basin.

Though reservoir rocks occur in the Brookian sequence, the discontinuous nature of deltaic sedimentation limits their extent. Reduction of the permeability and porosity of sediments due to diagenetic alteration upon burial also commonly occurs.

The Ellesmerian and the Beaufortian sequences have good hydrocarbon source rocks. Source rock potential for Brookian sediments offshore is not well documented as data are scarce. Brookian shales encountered in the Canadian Beaufort, possibly equivalent to distal shales present in the Beaufort Sea, are considered probable source rock for hydrocarbons encountered during drilling.

Resource estimates for 1984 show mean conditional oil resources of about 1.3 billion barrels and mean conditional gas resources of over 5.6 TCF (Table 2). Resource estimates for 1987 show a 400 million barrel decrease in mean conditional oil to about 900 million barrels. This decrease follows the unsuccessful drilling of a number of traps in the oil-prone Ellesmerian sequence.

Estimates for conditional gas resources remain virtually unchanged, reflecting the greater number of traps identified through detailed seismic mapping in the Brookian sequence. The marginal probability dropped, however, from 70 percent to 42 percent, as a number of wells tested dry structures.

The Beaufort Sea Planning Area maintains high exploration interest and resource potential. Numerous traps remain untested within the planning area, as do several structural provinces. The chance of hydrocarbon discoveries appears quite good for the area.

CONCLUSIONS

Over six million acres in seven Alaska OCS planning areas have been leased since 1976. More than sixty exploration wells have tested structures in six of the leased areas. The majority of these wells have been plugged and abandoned.

Recent Federal Government estimates show a marked decline in resource potential for the leased areas from estimates generated early in the exploration history of the basins. The lower estimates reflect not only the number of dry holes drilled, but also the more pessimistic view of basin geology obtained from the wells. But the drilling results do not tell the whole story. Numerous traps, plays, and structural provinces remain untested in the six planning areas. These still provide hope for finding significant resources in the Alaska OCS.

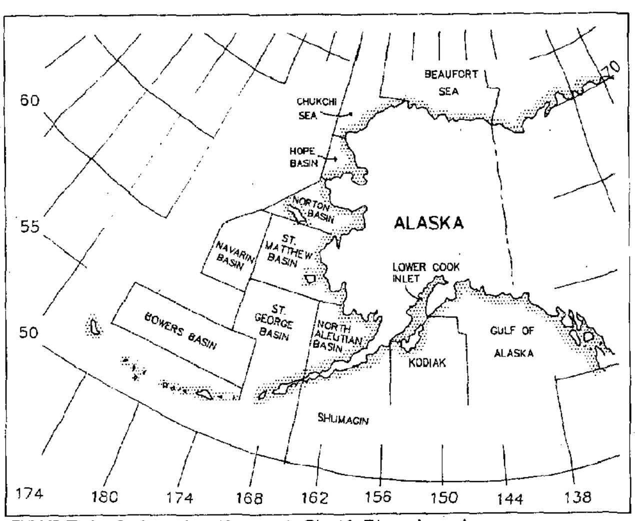

FIGURE 1. Outer Continental Shelf Planning Areas

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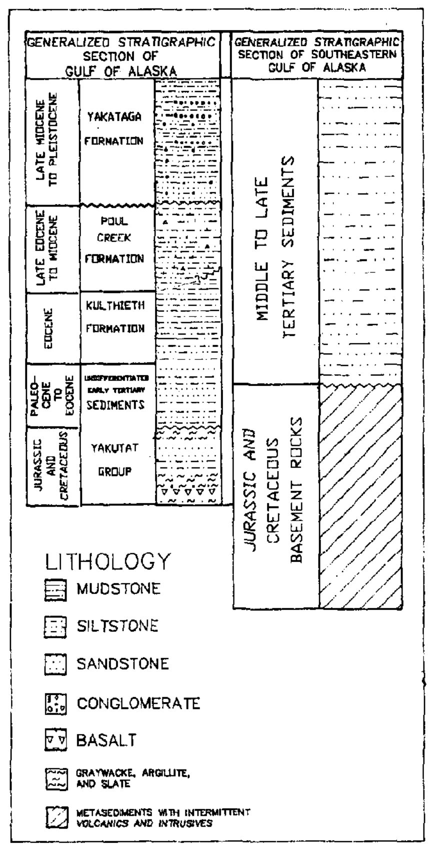

FIGURE 2. Generalized stratigraphic column of the Gulf of Alaska

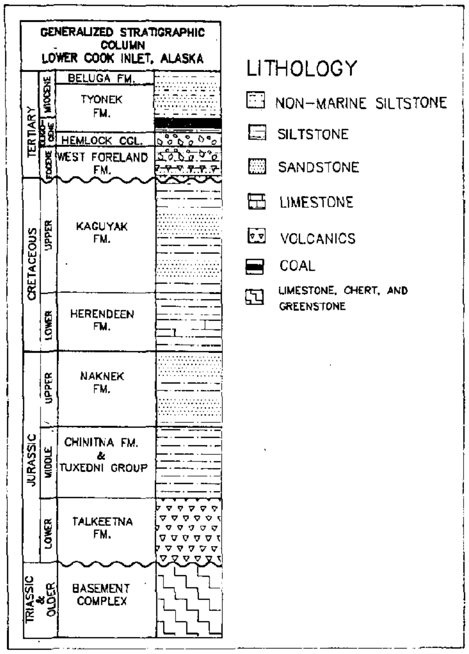

FIGURE 3. Generalized stratigraphic column of Lower Cook Inlet

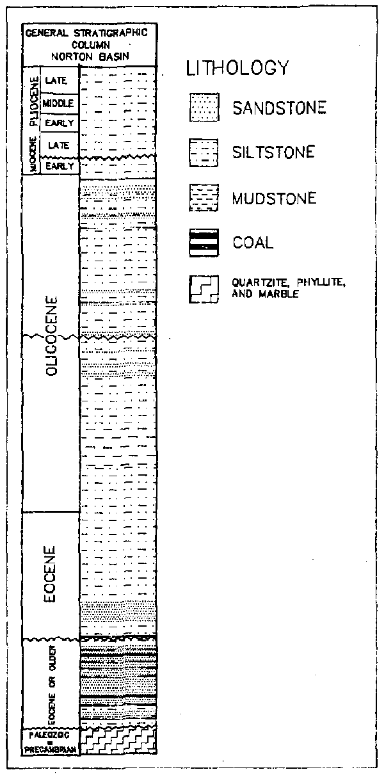

FIGURE 4. Generalized stratigraphic column of Norton Basin

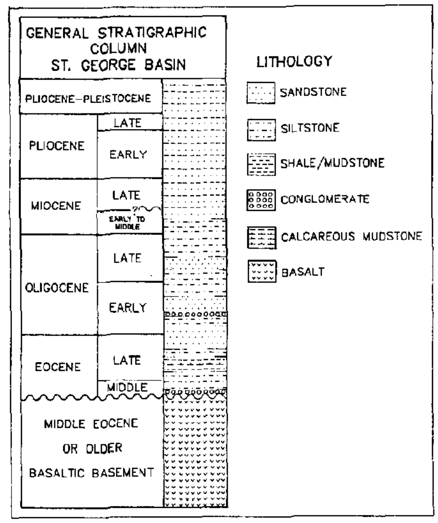

FIGURE 5. Generalized stratigraphic column of St. George Basin

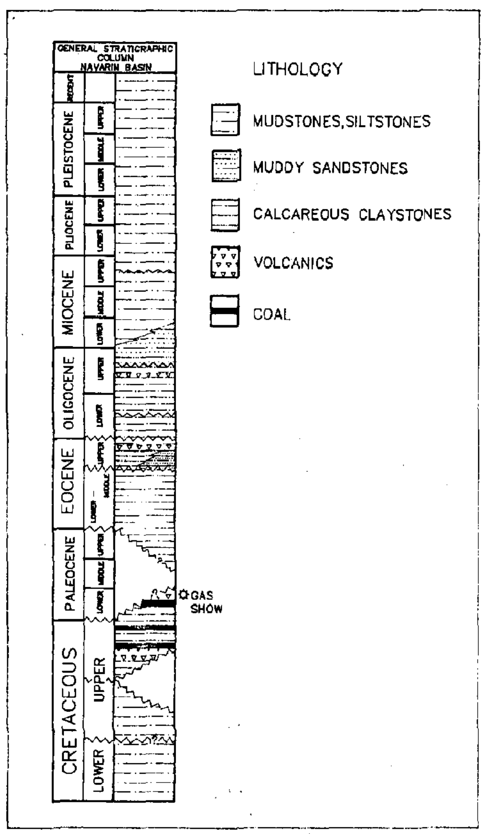

FIGURE 6. Generalized stratigraphic column of Navarin Basin

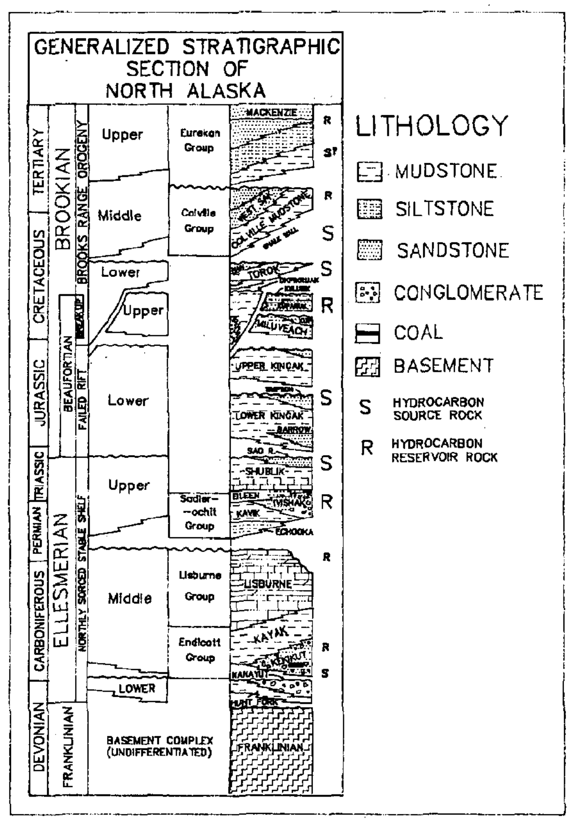

FIGURE 7. Generalized stratigraphic column of northern Alaska

PRE-LEASE GEOPHYSICAL PERMITTING FOR THE PACIFIC OCS; PROCEDURES, PROBLEMS, AND SOLUTIONS

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ABSTRACT

Geophysical surveys, using nondynamite energy sources, in Federal waters off the Pacific coast have traditionally been treated as relatively innocuous operations with little impact on the marine environment or other users of the Outer Continental Shelf (OCS). However, the increasing use of three-dimensional seismic survey techniques, combined with the inconclusive results from recent studies dealing with the effects of geophysical surveys on the marine environment, has increased public and media awareness of geophysical surveying. This has, in turn, affected the process by which permits for that activity are approved by the Minerals Management Service. Additionally, strong local opposition to OCS Lease Sale No. 91 for northern California has focused attention on all mineral exploration activity along that stretch of coastline. Within the last 3 years the geophysical permitting process has shifted from a low-profile formality to an event with high visibility in environmental and political groups. Consequently, other OCS users, namely the fishing industry, have seized the opportunity to unify and publicly voice their concerns to environmental and political groups that had previously taken little notice. This ability to jointly voice their concerns has enabled the fishing industry to change the permit process and force the seismic industry to listen to their complaints. Throughout these changes, the MMS has remained flexible and supportive so that a balance between the oil industry and other OCS users can be maintained. To facilitate this balance, the Pacific OCS (POCS) Region has incorporated its own procedures into the geological and geophysical permit process that benefit all POCS users by attempting to minimize or eliminate operational conflicts prior to the issuance of the permit.

INTRODUCTION

Complaints from the fishing industry and environmental groups regarding seismic survey activity along the Pacific coast, especially off California, have risen dramatically since 1986. This paper examines the procedures the Minerals Management Service Pacific Outer Continental Shelf (POCS) Region uses to issue permits, the types of geophysical surveys conducted in the POCS Region, and the operational and environmental problems encountered during the permit process. This paper also reviews some of the solutions that have been tried to eliminate or minimize Outer Continental Shelf (OCS) conflicts.

PROCEDURES

General

The Minerals Management Service (MMS) is authorized under title 30, section 251 of the Code of Federal Regulations to issue a geophysical permit to any applicant wishing to conduct geophysical activities on Federal OCS waters not already authorized under a lease. A permit is also required if these activities will occur on leased lands under lease to a third party. These permits are issued by the MMS Regional Office of Resource Evaluation (ORE).

There are two types of geophysical permits: (1) Geophysical Permit for Mineral Resources (generally sought by companies wishing to sell data or exploit the hydrocarbon resources of an area) and (2) Geophysical Permit for Scientific Research, which involves the use of solid or liquid explosives (usually sought by universities or public utilities). Data and information gathered under the latter permit must be made available to the public for inspection and reproduction at the earliest practicable time. Data acquired under the former permit is proprietary and not releasable to the public for a period of 50 years. Information derived from the data (eg., processed seismic sections) are not releasable to the public for a period of 25 years from the date on which the information is submitted to the MMS. The majority of applicants for geophysical permits in the POCS Region request that their permit be for mineral resources.

Additionally, every geological and geophysical (G&G) permit is subjected to a categorical exclusion review (CER) by the MMS Office of Leasing and Environment. This review determines whether or not the proposed survey may be excluded from further environmental review, or whether further review such as an Environmental Assessment or an Environmental Impact Statement is required pursuant the National Environmental Policy Act.

Specific POCS Region Procedures (California)

All applicants for G&G permits on the OCS off California are required to distribute survey notifications (by return-receipt mail) prior to permit issuance. The notices are sent to fishing organizations, fuel docks, fish markets, harbormasters, State and local government agencies, Federal agencies with regulatory authority offshore, and the military. These notifications are intended to identify other OCS users who might foresee a potential operational conflict with the proposed survey. All notifications are clearly marked "SURVEY NOTICE" and give detailed information on the timing and nature of the proposed survey. The recipient is requested to post the notice in a prominent place so that the survey information reaches the greatest number of other OCS users. All recipients are provided with the name, phone number, and address of the applicant, State of California geophysical coordinator, and the ORE Regional Supervisor. Recipients are encouraged to alert MMS and the permit applicant of a potential conflict at the earliest practicable time so that negotiations can begin promptly and a speedy resolution can be obtained. See Figure 1.

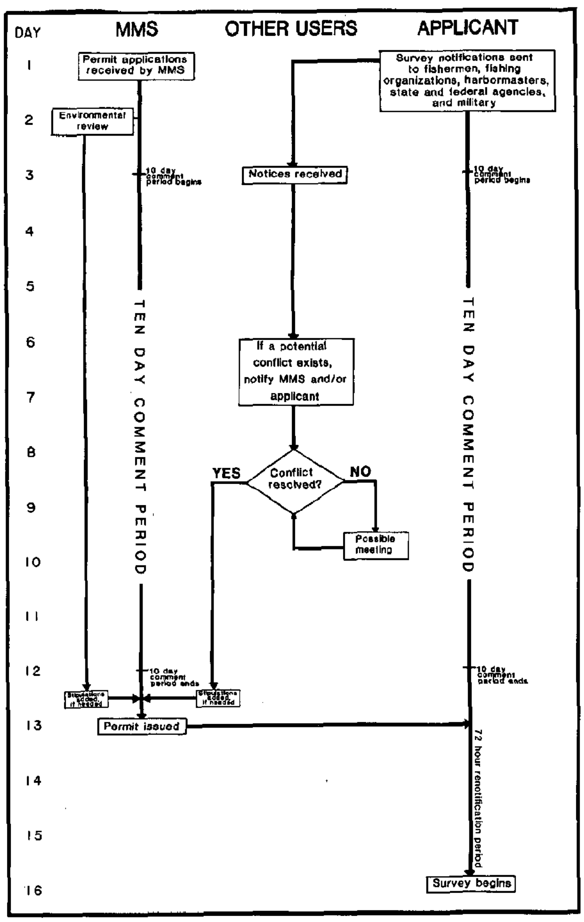

Figure 1. Flow diagram showing the procedures used and the idealized timing of the Pacific OCS Region's G&G permit process.

The POCS Region also incorporates a set of stipulations into the permit that (1) recommend the use of a scout boat for surveys shallower than 120 fathoms to guard against accidental gear entanglements, (2) encourage two-way radio communication between the fishermen and the seismic vessel, and (3) require permittees to renotify other users who are identified as having possible operational conflicts with the survey, 72 hours in advance of the survey. This renotification need not be a written one. Additionally, the permit allows for special stipulations to be included, if it is deemed necessary from the responses to the notifications, to minimize at-sea conflicts.

Specific POCS Region Procedures (Washington and Oregon)

In 1982 the MMS and the State of Washington entered into a Memorandum of Agreement to facilitate coordination and scheduling of seismic activities off the coast of that State. When MMS determines a permit application is complete, a copy is forwarded to the Washington State Departments of Ecology and Fisheries. Initial notifications are handled by the State and 72-hour renotification is handled by the permittee. Within 14 days, the aforementioned departments provide MMS with recommendations they feel are necessary to avoid or minimize potential conflicts between the survey and State resources. They also provide a listing of Washington State fishermen identified as having an interest in the survey. This list is included in the permit. If MMS does not incorporate one or all of the State's suggestions into the permit, MMS provides the State with written justification for its actions.

A similar agreement was reached between the MMS and the State of Oregon in 1983. The two Oregon agencies responsible for application review and notification are the Oregon Department of Land Conservation and Development and the Oregon Department of Fish and Wildlife. Except for the response period (Oregon returns its suggestions within 10 days) all other procedures are essentially the same as that of Washington.

TYPES OF GEOPHYSICAL SURVEYS

There are two geophysical survey methods that are routinely used on the Pacific OCS. The first is a high-resolution survey, the second is a deep penetration common-depth-point survey.

High-Resolution Surveys

High-resolution surveys are generally conducted over areas that have already been leased. As part of the lease agreements, the MMS requires that these surveys be performed in order to evaluate geologic hazards and shallow structural detail in the leased block prior to drilling or along proposed pipeline routes leading to and from the block.

Most high-resolution systems consist of bottom profiling instruments that give a cross-sectional depiction of the seafloor and the uppermost underlying rock layers. Seismic signals generated by the seismic source are reflected back to the source or to pressure sensitive hydrophones towed in a cable behind the survey vessel. The length of the cable tow varies but is generally less than 1 mile long. The depth of the towed cable varies from 0 to 40 feet below the surface.

Deep Seismic Surveys

If a company is searching for new hydrocarbon reserves or wishes to delineate the deeper structures in a known field, then high-resolution seismic techniques are inadequate. Seismic equipment that generates signals capable of penetration into the deeper layers of the earth's crust use various technologies developed by a multitude of manufacturers. By far, the most common deep penetration marine seismic source in the world is the airgun. It operates by rapidly venting highly compressed air into the water column. Usually, airguns are towed in an array behind the survey vessel. By varying the size, spacing, and timing of the airgun array, the operator can "tune" the array so that the signals merge and the reverberations from the bubbles, produced by the venting of air, partially cancel each other. This helps to produce a single, large detonation.

Two types of deep seismic surveys are conducted in the POCS Region. The first, known as a two-dimensional (2D) survey, is usually conducted for regional, reconnaissance work. The trackline spacing varies, but is generally on the order of a 1- to 2-mile separation. Surveys in frontier areas can have a trackline spacing greater than 20 miles. Most 2D surveys along the west coast are run in a grid pattern, over a relatively large area (200 to 1000 square miles) and over a period of about 3 to 5 weeks. The mileage shot averages about 500 to 1000 miles per survey. The second type of deep penetration survey, known as a three-dimensional (3D) survey, is generally used for postlease operations. It is useful for giving a detailed representation of the structure on a lease or block of leases. It can be used for reconnaissance work, but the large size and long duration of the survey traditionally makes it economically impractical to do so. As opposed to 2D surveys, 3D surveys on the west coast can be up to 3500 line miles on hundreds of parallel seismic lines, spaced approximately 150 to 300 feet apart. They are ordinarily run over a small area (10 to 100 square miles) and can extend over a time period of up to 4 months. Figure 2 contrasts the two types of surveys.

PROBLEMS

There are two types of problems associated with the application for a geophysical permit. First, there are the operational conflicts between the survey vessel and other legitimate users of the OCS such as fishermen or the military. Military space-use problems occur occasionally, but they are generally short lived and easily solved by rescheduling. Conversely, fishing conflicts are not short lived, and scheduling around an all-year activity can be complicated and often times impracticable. Secondly, there are environmental conflicts between the permit applicant and environmentally conscious organizations and general public. The MMS is responsible for minimizing or eliminating conflicts between all of the parties and tries to balance operational conflicts and environmental concerns against the country's growing need for greater energy autonomy.

Operational Conflicts

Operational conflicts occur when two or more OCS users want to be in the same place at the same time.

With the military, operational conflicts usually amount to scheduling problems with underwater noise measurement tests or missile/shell firing practice. With the former, the survey vessel will shut down operations for a brief period. With the latter, the survey vessel wisely stays out of the area until the firing is over. The key to preventing mishaps with the military is communication. The military is included on the survey notification lists, and the contractor is directed, when the permit is granted, to contact the U.S. Navy scheduling officer prior to commencement of seismic operations. If these guidelines are followed, there is usually no conflict.

Fishermen along the west coast have a more complicated situation. Many oil company representatives initially assume that since oil exploration and fishing coexist somewhat peacefully along the Gulf coast, that west coast operational conflicts between the two industries have little merit. This is an erroneous assumption. Aside from oil being a high-profile, large employer for Gulf coast citizens, the Gulf has a continental shelf (where most fishing and hydrocarbon exploration occur) approximately 10 to 15 times larger than the Pacific shelf. The narrow Pacific shelf means greater opportunity for space-use conflicts to occur and greater opportunity for mistakes to be made.

Generally, fishing is seasonal. However, most fishermen fish for more than one species, and if the season for one species ends or wanes, they switch to another fishery. Since they operate during the day and sometimes the night, at all locations along the coast, they cannot always be accommodated by scheduling the survey when the fishermen are not around. Sometimes a permit applicant will schedule operations to avoid a particular fishing season, only to be confronted by another group of fishermen seeking a different type of fish at the rescheduled time.

Historically, permit applicants have found that during the pre-survey negotiation process, fishermen from some areas are more difficult to deal with than fishermen from others. The main reason for this is not that some fishermen do not like "Big Oil." In fact, most fishermen fully acknowledge their dependence on petroleum to run their boats. However, many fishermen have had negative experiences with the oil industry. Conflicts with a negligent seismic operator, or supply boat captain, all can contribute to skepticism and, in some

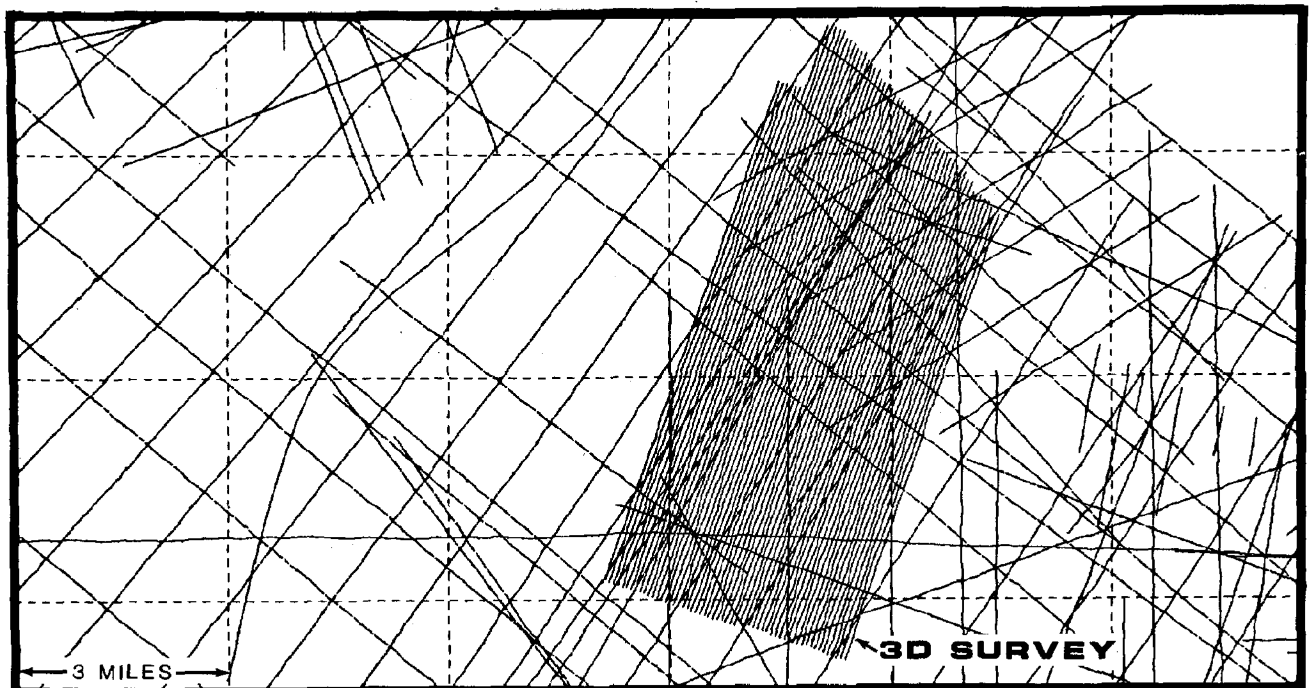

Figure 2. Contrast between 2D and 3D geophysical surveys. 2D surveys acquired over 5 year period (1983-1987). 3D survey acquired in less than 4 months (Note: Every other line in the 3D survey shown above has been removed for clarification during reproduction). The tremendous amount of 3D survey seismic lines compressed into a small area has led to increased allegations from the commercial fishing industry in southern California that 3D surveys can have a negative impact on the amount of fish they catch in and around the survey area. Also, fishermen feel that the long duration of the survey, usually during the peak fishing months, precludes them from fishing in that area. They have asked for compensation for lost catch and preclusion.

cases, hostility toward marine hydrocarbon exploration as a whole. Oil companies work very hard to project a good image. Cooperation and communication are their forte, and sometimes their personnel seem astounded when fishermen complain about negative experiences with their company. All it takes to upset a year's worth of good relations with a fisherman is a minute of carelessness from a seismic vessel captain or the quarrelsome attitude of a seismic party chief who wants to finish the survey.

One group of commercial hook and line fishermen from southern California feel that the oil industry is ruining their fishing grounds in the Santa Maria basin area. They maintain that they have only a limited area to fish and that every platform and pipeline built in that area impacts their ability to catch fish; they want to be compensated. Compensation has been paid to certain fishermen by the oil industry for various projects that impact their fishing grounds.

The same group of fishermen, along with a growing number of others in southern California, believe that the 3D surveys, conducted over leased blocks, also have a detrimental effect on their fishery. In 1986, the POCS Region permitted lessees to conduct 3D surveys over their lease or lease block unit in lieu of drilling to extend the term of the lease. From the operational standpoint of the oil companies this is more cost effective since delineation of a field can be accomplished without drilling as many delineation wells. Nevertheless, many of these surveys shoot 2 to 3 times more seismic line-miles than a conventional survey in an area 10 times smaller and over a period 4 times longer than a 2D survey (see Figure 2). These conditions make space-use conflicts commonplace and have led to increased allegations that seismic surveys, particularly 3D surveys, can impact the fishing in an area for months after the survey is completed. This situation has caused some fishermen to ask for compensation for lost catch, not just during the survey period, but for up to 8 months after the survey ends. The oil companies and seismic contractors view such compensation as a dangerous precedent, especially when the allegations appear to have minimal, if any, evidential support.

In two cases during the summer of 1987, two disgruntled fishermen placed their fishing gear in the middle of the survey area and refused to move it. They insisted on compensation and the oil companies involved refused to pay it, although attempts were made to negotiate an equitable settlement. The end result was that both companies could not acquire all the data they had originally wanted and the survey eventually took 20 to 30 percent more time than it would have under normal circumstances.

Recognizing that the OCS is a multiple-use resource and that the MMS has no regulatory authority over the fishing industry, the MMS POCS Region has remained neutral on the compensation issue and maintains that both parties should negotiate their differences on their own. However, before a permit is issued, the ORE Regional Supervisor must be assured that either their differences have been resolved or a good faith attempt has been made to reach an agreement.

Environmental Conflicts

In the last 3 years, the POCS Region has experienced a surge in the amount of complaints from fishermen regarding offshore exploration activities. Many of the complaints are easily solved by putting the fishermen in contact with the permittee's representative or the contractor. However, in the State of California, vocal opposition to Lease Sale No. 91 and increased newspaper and television coverage of the events leading up to the sale have put offshore oil exploration in the public eye. It has become a cause celebre with environmentalists and politicians. The increased attention to the offshore has helped fishermen to consolidate, focus, and showcase their grievances so as to gain greater support from State and local legislators.

Four years ago, the POCS Region rarely heard from political or environmental groups when a permit application was received. Now, comments from State and local governments and environmental groups are routine. Three recent permit applications for seismic surveying in northern California received comments from approximately 100 citizens, State and local politicians, and environmental groups from northern California. In fact, for the first time, the California Coastal Commission (CCC) requested that the Department of Commerce (DOC) permit the CCC to review these permits for consistency with the California Coastal Management Program. Though CCC later withdrew their request, the DOC Office of Ocean and Coastal Resource Management decided that the permitted activities would not affect the coastal zone and that the CCC has "no authority under the CCMP to review the G&G permits."

Two recent studies regarding the effects of seismic survey activity on (1) the catchability of rockfish[1] and (2) the survivability of anchovy eggs and larvae[2] have helped support some California fishermen's contention that seismic surveys impact their fishing.

The authors of the rockfish study noted a substantial reduction (52.4%) in the amount of rockfish caught when an airgun was in operation. However, the experiment was not at all similar to a typical marine seismic survey. A typical survey is conducted in straight line segments at speeds of 4-5 knots, thus passing over (in a few minutes) a given fish aggregation only once. The experiment was designed to show a worst case effect and therefore required the survey vessel to circle the fish aggregation for a period 15-20 times longer than normal and at a distance of about 500 feet. The study did not address the duration of the effect or the distance at which the effect can be felt.

The eggs and larvae study revealed no dramatic changes in the survivability of anchovy eggs and larvae that could clearly be attributable to airgun signal exposure. Although there was some mortality to very young stages (2-3 day old), it only occurred within 10 feet of the airguns and was relatively small when compared with natural mortality. Nevertheless, the State of California, through the California State Lands Commission, seized on the negative effects of these experiments and, in conjunction with other uncertainties, banned all high-energy geophysical surveying in California State waters until an Environmental Impact Report is completed and evaluated. The MMS feels the State's action is premature, given the equivocal results of the rockfish experiment and the lack of negative effects for the eggs and larvae experiment. A second catchability study, using a more realistic seismic regime and designed to address distance and duration of effects, is in progress, as is a second study using crab eggs and larvae as opposed to anchovy.

SOLUTIONS

The POCS Region has always maintained that communication is the key to conflict resolution. Communication is the framework for the permit procedures, and a number of steps are taken to insure that the communication lines are as clear as possible.

If MMS receives a complaint from a fisherman or fishermen, the POCS Region's first step is to notify the permit applicant of the problem and request that they contact the person(s) with the complaint and try to reach a solution. Usually there is a simple misunderstanding, which is easily remedied. Sometimes there is no easily identifiable solution and further clarification and negotiations are needed. The POCS Region stresses that permit applicants should work out their problems on their own, and in fact, most prefer to do that. The permit applicant is encouraged to do everything possible to maintain a meaningful dialogue, including sending a representative to the town(s) where most of the fishermen are located and, if necessary, hold a meeting(s) with the fishermen who foresee a conflict. Meetings are generally informal and cordial, and even if no solution is reached, both parties part with a greater understanding of one another's concerns. Whatever the outcome, the stage is set for further negotiations until a resolution is found. There are times when neither party is willing to compromise and it becomes necessary for MMS, as the permitting agency, to step in and try to effect a solution. Sometimes, additional permit stipulations are added that restrict operating times or areas of operations. At other times, ORE might request that the permit applicant convene a meeting with all parties present and try to negotiate a settlement. But frequent meetings can be an irritation, especially for the fishermen since they do not receive a paycheck for attending them. This has led to a call from fishermen for a solution that is more permanent.

One option that the POCS Region examined and rejected was the possibility of permanent seismic operation "windows" based on low fishing activity levels. During the summer of 1987, personnel from the POCS Region, together with personnel from the State of California, attended a series of meetings at various locations along the California coast. The purpose of the meetings was to solicit comments from the fishing industry regarding impacts of seismic surveys to their operations, what times of the year would be best for seismic activity, and what times are best for fishing. The outcome was that although there might be times when fishing activity wanes, a window does not exist when there is no commercial fishing activity. Some fisheries are year round. Generally, the slowest time of year are the winter months when frequent storms often keep fishermen onshore and short daylight hours keep fishermen close to port. However, these months are also the worst times for seismic surveying since high seas can deteriorate data quality. Also, the commencement and completion dates of fishing seasons are set by the appropriate regulatory agencies and are therefore subject to change from year to year, or even closure.

Certainly better scheduling by the companies that intend to collect seismic data could help minimize or eliminate some of the problems. This aspect is encouraged by MMS, and some companies have taken the lead and applied for permits well ahead of the minimum time period set by the procedures. Also, greater coordination between the agencies that set fishing seasons and the MMS would alert both organizations to potential problems before can to become major issues. In Santa Barbara and San Luis Obispo Counties, a committee composed of representatives from the oil industry and commercial fishing industry has hired a neutral liaison officer to help answer fishery questions, expedite claims for lost or damaged fishing gear, and facilitate communications between both industries. This solution has worked quite well and should be examined for use in other areas as offshore oil production grows. Newsletters published by local marine advisors also help aid communication among OCS users.

Communication and continuing dialogue are the foundation upon which greater cooperation and fewer misunderstandings are built. In every equitable solution these have been the underlying principles that have enabled the conflicts to be resolved. These should be maintained.

CONCLUSIONS

As publicity and controversy surrounding POCS Region lease sales increase, it is likely that the conflicts surrounding geophysical permit applications will increase. Whether this is due to a legitimate problem or an alleged problem perceived by those who would like halt OCS leasing is becoming harder to discern. Whatever the problem, it is up to MMS to sift through the extraneous rhetoric and grasp the facts. This enables MMS to make informed decisions and incorporate stipulations into the permit so that an equitable solution can be reached. The OCS is a multiple use resource. Fishermen and oil companies have a legitimate right to conduct their business on the OCS. The POCS Region strives to maintain a balance between the two industries and remains committed to a flexible permit process that emphasizes cooperation and, just as importantly, communication.

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POST-LEASE SALE EXPLORATION OF THE NAVARIN BASIN, BERING SEA, ALASKA

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ABSTRACT

Although the basin had optimistic beginnings, interest in further exploration of the Navarin Basin is waning because of disappointing drilling results. Eight exploratory wells were drilled in the Navarin Basin in the year following Lease Sale 83 in 1984. All of these wells tested Tertiary fill that drapes or folds over simple, broad basement highs. Significant reservoir rocks were absent in all of these wells. Immature to mature Eocene kerogen with possible hydrocarbon-generating characteristics was found in a stratigraphic test well and two exploratory wells located on the flanks of the Pervenets subbasin. However, no signs of oil or oil migration were evident. A third exploratory well drilled on the southeast flank of the Pinnacle Island subbasin encountered thermogenic gas from a thin, probably lenticular Paleocene sandstone. The gas was probably sourced from interbedded, resinous coal. The geologic information collected from seven of the eight exploratory wells has now been released to the public. Of the leases acquired in Sale 83, 74 percent have been relinquished as of January 1988.

1. INTRODUCTION

The Bering Sea lies between western Alaska, eastern Siberia, and north of the Aleutian Arc (fig. 1). This region is truly a frontier area with a remote and hostile subarctic marine environment that long discouraged exploration. The northern Bering Sea includes a broad, shallow epicontinental shelf covering an area of approximately 275,000 square miles, where water depths range between 100 and 600 feet.

Soviet and American explorations of the adjacent onshore areas since the early 1900's were initially prompted by the presence of oil seeps. Government and university reconnaissance surveys of the Bering continental shelf revealed large Tertiary sedimentary basins with features associated with hydrocarbon generation and entrapment. Subsequent investigation by private industry of the Navarin Basin included the collection of over 84,000 line-miles of seismic-reflection data and the drilling of a stratigraphic test (COST) well in 1983. Navarin Basin Lease Sale 83, held in 1984, received approximately $631 million in high bids. This sale opened up exploration in the Navarin Basin and resulted in 8 exploratory wells being drilled on leased acreage.

Overall, drilling results from the eight exploratory wells were disappointing, with all wells being plugged and abandoned. These negative drilling results eventually led to the relinquishment of 120 of the 163 leased tracts in the Navarin Basin by January 1988.

2. REGIONAL EXPLORATION HISTORY

The earliest petroleum exploration in the shelf basins of the western Bering Sea was initiated by the Soviet Union in 1959 in the onshore portions of the Anadyr and Khatyrka Basins [1] (fig. 1). Between 1963 and 1978 the Soviet Union drilled over 30 onshore exploratory and stratigraphic test wells, most of them in the larger Anadyr Basin. Exploratory results were discouraging, and both reservoir rock distribution and timing of trap formation appeared to be major problems. Gas shows were reported in Miocene sandstones, and oil and gas shows were reported in Eocene and Oligocene strata. One well produced excellent initial gas shows from at least 10 middle to upper Miocene sandstones with an aggregate thickness of 260 feet. Reservoir pressures declined rapidly with further testing, which suggests that the sandstones were small-volume, lenticular bodies.[1] The most prospective reservoir rocks were encountered in Cretaceous and upper to middle Miocene sandstones; the interbedded source shales contained mostly gas-prone humic organic matter. Exploratory drilling since 1978 has yielded more encouraging results. In 1981, an oil discovery was reported.[2] This discovery, although not a commercial find, stimulated further drilling. More recently, commercial accumulations of both oil and gas condensate have been reported from the Anadyr lowlands of the Anadyr Basin.[2] Specific data on reservoir horizons or flow volumes were not disclosed.

Exploration in the Khatyrka Basin has been spurred on by the discovery of oil seeps and over 200 hydrogen sulfide springs where Miocene rocks are present.[1] The upper Senonian, Paleogene, and lower Miocene sections contain source rocks capable of generating hydrocarbons. Upper Senonian marine shales have measured total organic carbon contents of up to 0.81 percent and contain dominantly humic kerogen. The Eocene and Oligocene section contains mudstone with an average total organic carbon content of 1.05 percent, and the lower Miocene section contains shale beds with a total organic carbon content (dominantly sapropelic kerogen) ranging from 0.38 percent to 1.79 percent. McLean [1] states that there appears to be major problems with reservoir-rock distribution and the timing of trap formation.

Petroleum exploration in the Alaska Peninsula, north of the Aleutian volcanic arc, has occurred since the early 1900's. A description of oil seeps reported by the Russians in 1869 "near Katmi" probably referred to the Kanatak district near Lake Becharof on the Alaska Peninsula.[3] Between 1903 and 1959 there were 11 wells drilled in the Kanatak district. Since 1959, another 16 wells have been drilled west and south of the Kanatak district along the Alaska Peninsula. None of these wells discovered any producible hydrocarbons.

Seismic exploration of the continental shelf began in the mid-1960's. Government and university research surveys of the northern Bering Sea have been generally uncoordinated, reconnaissance seismic surveys investigating the regional geologic framework and shallow geology. Seismic surveys by private industry have been ongoing since the 1970's. These surveys have established a high-density, seismic grid over the prospective areas of the individual sedimentary basins.

3. REGIONAL GEOLOGY

The Bering Sea continental shelf contains five large Tertiary basins (Navarin, Pribilof, St. George, Amak, North Aleutian) (fig. 1). These basins were formed as rifts in the Mesozoic basement rocks. The

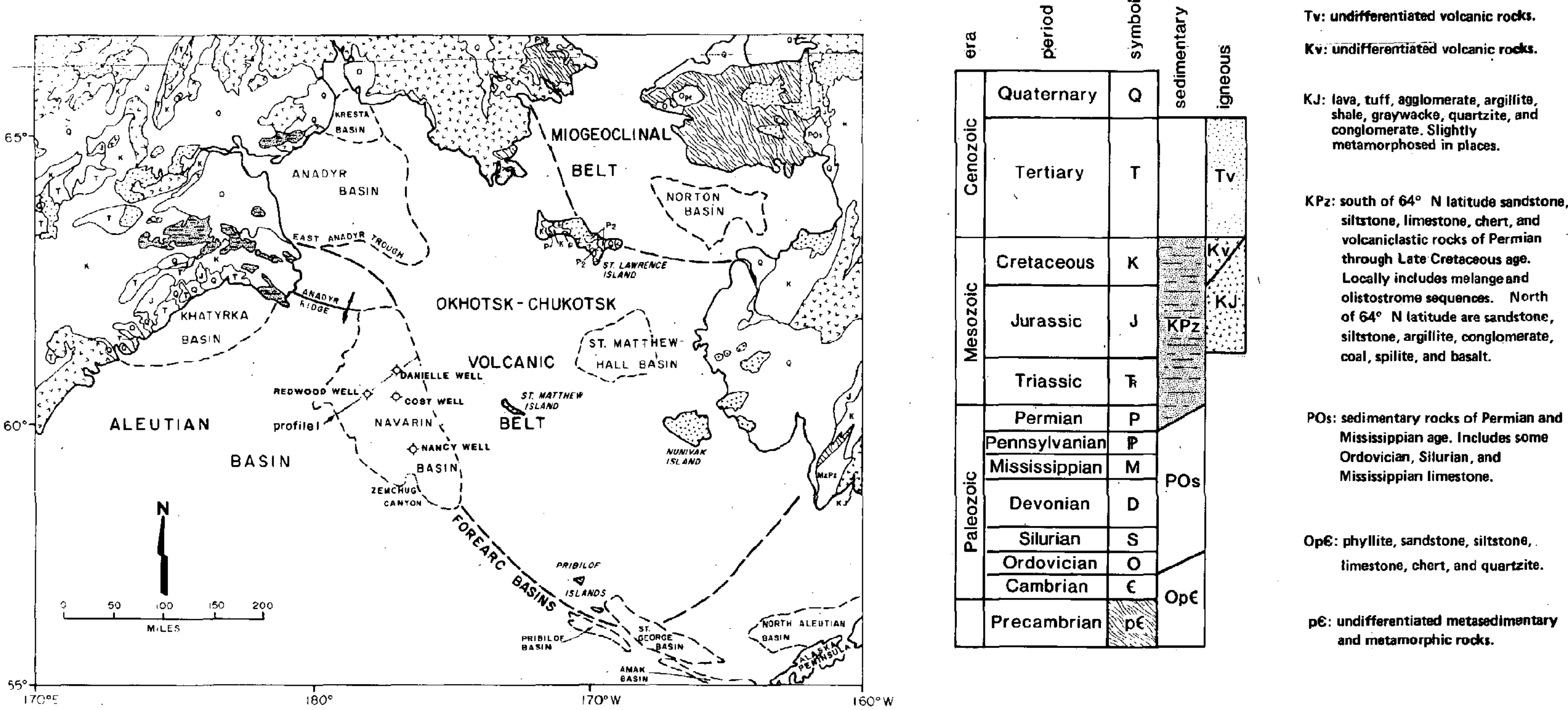

FIGURE 1. General geologic map of eastern Siberia, Bering Sea, and western Alaska. Major Tertiary basins and pre-Tertiary geologic provinces of Fisher and others (4) are indicated.

pre-Tertiary basement complex of the Bering Sea outer continental shelf, parts of northeastern Siberia, and the Alaska Peninsula is part of the forearc basin belt of Fisher and others.[4]

The forearc basin belt consists of Paleozoic and Mesozoic rocks composed of deep-water olistostromes, mafic volcanics, and nonmarine and marine sediments. The belt may extend beneath the Tertiary forearc basins. The northern portion of the Koryak Range of eastern Siberia contains complexly juxtaposed slabs of Mesozoic olistostrome and melange sequences and ultramafic masses. These possibly allochthonous blocks are unconformably overlain by Paleozoic and Mesozoic volcanics or terrigenous deposits. Devonian through Permian limestones are also present.[5,6] The Anadyr Ridge is probably an offshore extension of the Koryak Range and defines the northern boundary of the Navarin Basin (fig. 1). South of the Bering Sea, Mesozoic rocks of the Alaska Peninsula include the Late Jurassic to Early Cretaceous siltstones and sandstones of the Naknek Formation, which may be correlative with the Late to Middle Jurassic rock in dredge samples from Zemchug Canyon and the Navarin continental slope.[6,7] The composition of the basement rock sampled by exploratory wells and dredge hauls in the Bering Sea tends to support the contention of Marlow and others [6] that the basement rock along the modern Beringian margin is a northern extension of the Mesozoic Peninsular Terrane.

4. NAVARIN BASIN GEOLOGY

The Navarin Basin consists of three en echelon subbasins (Navarinsky, Pervenets, Pinnacle Island), each filled with more than 34,000 feet of layered Tertiary sedimentary rocks (figs. 2 and 3). The subbasins started to form in response to extensional subsidence associated with strike-slip motion or oblique subduction of the Kula Plate beneath the North American Plate in the early to middle Eocene time. Basin paleobathymetry deepened rapidly from continental to middle bathyal by early Oligocene. Basin axes trend northwestward and parallel the modern continental shelf break. Fault-bounded ridges and compressional folds segregated the subbasins and isolated their depositional systems.

By the late Eocene, movement of the Kula Plate was isolated by the onset of intraoceanic subduction at the modern Aleutian Arc. Subbasin subsidence remained active until the late Oligocene, resulting in the continuous deposition of marine mudstones and siltstones throughout most of the Paleogene. Sea-level lowerings in the middle and late Oligocene, however, exposed older Tertiary and Mesozoic basement highs to wave-base erosion which resulted in the deposition of coarser-grained material along the subbasin flanks. Cessation of Kula Plate motion by the early Neogene was followed by crustal cooling which allowed regional subsidence of the shelf beyond the fault-bounded subbasins. Middle and outer neritic mudstones and sandy mudstones were deposited throughout the Neogene. Coarser-grained deposits may have formed on the flanks of basement highs exposed to wave-base erosion during a sea-level lowering in the late Miocene.

5. PRELIMINARY OBSERVATIONS OF THE EXPLORATION WELLS

Geochemical studies were conducted in each of the eight exploratory wells and the COST well. In three wells (Amoco Danielle No. 1 well, ARCO COST No. 1 well, Exxon Redwood No. 1 well) that are located on the basement ridges that delimit the Pervenets subbasin, potential source beds were encountered in Eocene to early Oligocene sequences (fig. 1). Interpretation of seismic-reflection data from the Pervenets subbasin area indicates that the Eocene to early Oligocene(?) section is mappable as a discrete seismic sequence between the wells and throughout the subbasin (figs. 2 and 3). This correlation is further supported by paleontological data.

Turner and others [8] rated the Eocene to early Oligocene(?) section as the most favorable for source potential in the ARCO COST No. 1 well (fig. 2). This section was found between 11,700 and 12,780 feet and consisted of gray claystones and organic-rich claystones with local limestone lenses. The section was deposited in outer neritic to middle bathyal environments, and rests unconformably upon coal-bearing, nonmarine sediments of Cretaceous age. Total organic carbon content (TOC) in this section ranged from 1.0 to 2.0 percent from a mixture of types II and III kerogen. The sum of amorphous plus exinitic kerogens is generally greater than 65 percent,[8] suggesting a liquid-prone source. In the COST No. 1 well, the random vitrinite reflectance (R_o) reaches 0.6 percent at 9,400 feet and 1.3 percent by about 15,000 feet; therefore, the Eocene to early Oligocene section falls within the catagenic zone (oil window).

Approximately 22 miles west-northwest of the ARCO COST No. 1 well lies the Exxon Redwood No. 1 well (figs. 1 and 3). Both wells were drilled on a northwest-trending basement ridge which defines the southwest border of the Pervenets subbasin. The Redwood well was drilled to a total depth of 11,536 feet and bottomed in a 536-foot interval of probable Late Cretaceous marine shales and mudstones deposited in an outer neritic to upper bathyal environment.[9] Geochem Laboratories, Inc.,[10] conducted a geochemical survey of the Redwood No. 1 well. Minerals Management Service (MMS) interpretation of this survey evaluates the interval between the depths of 5,650 and 8,800 feet as containing sediments with good potential to produce hydrocarbons. Micropaleo Consultants, Inc.,[9] reported the presence of probable late Eocene to Oligocene (possibly late Eocene) strata between the depths of 5,650 and 8,800 feet. Side-wall cores between 5,650 and 8,800 feet had TOC contents that ranged between 0.89 and 2.95 percent. Hydrogen indices measured from side-wall cores for the same interval are between 65 and 408 milligrams of hydrocarbons per gram of organic carbon, which when plotted versus oxygen indices on a modified Van Krevelen diagram indicate the presence of some type II kerogen. For this same interval of rock, the sum of amorphous plus exinitic kerogens is generally greater than 60 percent. MMS interpretations of data collected by Geochem Laboratories, Inc.,[10] indicates that the kerogen are largely immature and may just be approaching catagenesis at the bottom of the well. For combined side-wall cores from 8,623 and 8,640 feet the R_o value is 0.56 percent and Tmax values are 434 and 435 °C. The transformation ratio ($S_1/(S_1+S_2)$) remains quite low in the interval of interest from 5,650 to 8,800 feet. In addition, gas chromatograms of $C_{15}+$ hydrocarbons from as deep as 6,300 feet appear to be very immature.

The Amoco Danielle No. 1 well lies on the northern flank of the Pervenets subbasin, approximately 25 miles north-northeast of the Exxon Redwood No. 1 well (figs. 1 and 3). The Danielle No. 1 well was drilled on the southern flank of a west-trending basement ridge that plunges westward and separates the Navarinsky subbasin to the north from the Pervenets subbasin to the south. Micropaleo Consultants, Inc.,[11] reports that the well bottomed at 10,045 feet in a 2,755-foot sequence of probable Late Cretaceous age. Core Laboratories, Inc.,[12] geochemical investigation of the well classified the section which lies between 6,600 and 7,140 feet as having good gas- and oil-generating potential. This section consists of a brown siltstone with minor amounts of limestone, sandstone, and claystone of late Eocene age.[11] Traces of oil staining were reported common throughout this 540-foot section. This interval has a reported TOC content ranging between 1.12 and 2.15 percent. Hydrogen indices measured from cuttings and sidewall cores ranged from 208 to 415, which when plotted versus oxygen indices on a modified Van Krevelen diagram suggest mixed type II and III kerogen. This mixture is confirmed by Core Laboratories, Inc.,[12] visual descriptions of significant amounts of amorphous, herbaceous and woody macerals. Thermal maturity of this 540-foot interval is rated by Core Laboratories, Inc.,[12] to be very marginally mature based on a Tmax of 426 to 432 °C, a TAI of +1 to +2, and a R_o ranging between 0.33 and 0.43 percent.

Sparse beds of coal and claystone in the Paleogene sequence were found to be marginally mature in a few of the other exploratory wells drilled in the Navarin Basin (fig. 2). Oxidation of the coaly organic material limits the present potential for hydrocarbon generation. However, a sidetrack

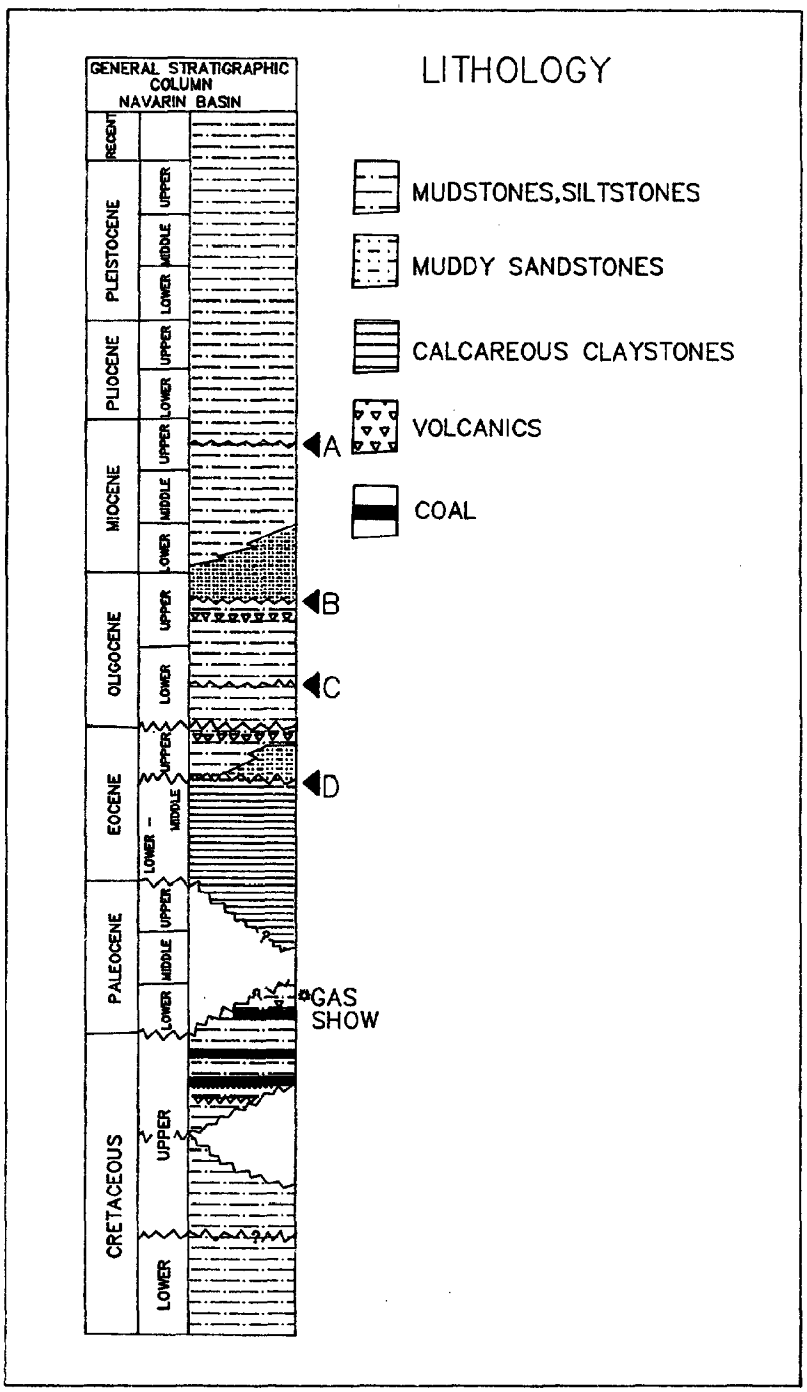

Figure 2. General stratigraphic column for the Navarin Basin.

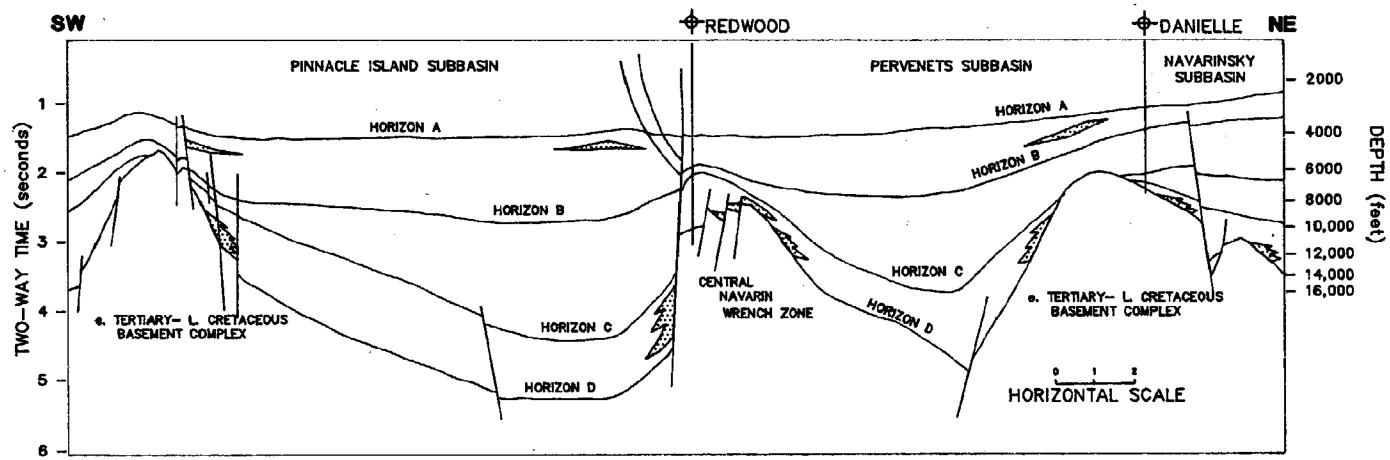

Figure 3. Profile of the Navarin Basin.

of the Amoco Nancy No. 1 well (located in the southeastern flank of the Pinnacle Island subbasin (fig. 1)) encountered thermogenic gas from this interval. This gas show occurred in thin coal seams interbedded with claystone and sandstone between 7,470 and 7,830 feet in this well. Core Laboratories, Inc.,[13] has rated this section as having good to excellent potential for generating hydrocarbons, due, in part, to a high-resin component of the coals which is very localized in occurrence. Micropaleo Consultants, Inc.,[14] classified the sidetrack between the depths of 7,380 and 7,920 feet as being nonmarine and having a probable Paleocene age based on palynology. A similar type and age section was found in the initial hole between the depths of 7,380 and 7,920 feet. TOC values from the sidetrack through the coal-bearing material ranged from 6.77 to 57.20 percent and averaged 19.48 percent.[13] Hydrogen indices measured from cuttings and sidewall cores ranged from 250 to 429, which when plotted on a modified Van Krevelen diagram indicate the presence of type II kerogen within the Paleogene section. The visual description by Core Laboratories, Inc.,[13] of the kerogen from this section was mostly woody macerals with only minor amounts of herbaceous (exinitic) material. These results led Core Laboratories, Inc., to suggest that the coals "have good to excellent hydrocarbon source potential for both gas and liquid generation." Thermal maturity of this 540-foot interval is rated by Core Laboratories, Inc.,[13] to be immature based on pyrolysis Tmax of 422 to 433 °C and R_o values between 0.40 and 0.48 percent.

No attractive reservoir sequence has been identified anywhere in the Navarin Basin. Neither the Miocene sands nor the basal Tertiary sands, though present, showed favorable reservoir characteristics. The concept of coarse-grained deposits flanking basement highs has not been fully evaluated by the present drilling program. The early Tertiary-Cretaceous basement complex sampled by the wells includes: Early Cretaceous marginal marine fine-grained clastics, Late Cretaceous coal-bearing nonmarine lithologies, Late Cretaceous bathyal fine-grained clastics, and Paleogene deep-water marine facies. Well tests showed no favorable reservoir characteristics for this section, but it is highly variable and should not be discounted as a potential play.

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ENVIRONMENTAL STUDIES AND IMPACT ASSESSEMENT ON THE ATLANTIC OUTER CONTINENTAL SHELF

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ABSTRACT

In 1973, the Department of the Interior, Bureau of Land Management established the Environmental Studies Program (ESP) to conduct studies with the purpose of building a reliable database to help predict, assess, and manage potential impacts from oil and gas development. The ESP, now under the direction of the Minerals Management Service (MMS), includes a major oceanographic research effort that has resulted in an improvement in the understanding of ocean resources through the development of concurrent and parallel programs of scientific research. Between Fiscal Year (FY) 1973 and FY 1987, nearly $100 million were spent on studies of the Atlantic Outer Continental Shelf (OCS) environment through this program.

Much of the research conducted under the auspices of the ESP has emphasized the collection of data on the environmental conditions of the Atlantic OCS. The ESP-funded research has also been an important source of information regarding sensitive OCS resources that could be affected by oil spills. These include archaeological resources, fish, benthic organisms, marine mammal and coastal birds and their habitats, the migration routes and calving areas for endangered or threatened species, and estuaries and wetlands. The benefits of this research on the oil spill risk analysis and impact assessment processes are examined in this paper.

INTRODUCTION

The Outer Continental Shelf Lands Act as amended authorizes the Department of the Interior (DOI) to make Outer Continental Shelf (OCS) lands available for ". . . expeditious and orderly development, subject to environmental safeguards . . . ." To accomplish this objective the MMS has been directed by the DOI to conduct lease sales on the OCS for the purpose of oil and gas exploration and development. The MMS prepares an Environmental Impact Statement (EIS) for each lease sale. Under the requirements of the National Environmental Policy Act, the EIS's assess the potential impact that an oil and gas lease sale could have on the human, marine, and coastal environment of the affected area.

A critical concern in the preparation of an EIS in the MMS leasing program is the risk of an accidental oil spill and the extent of environmental damage that may result. To assess the risk of spilled oil contacting OCS and coastal resources, the DOI developed the Oil Spill Risk

Analysis (OSRA) model in the early 1970's. This is a probabilistic model representing hypothetical spills. Individual trajectories are derived from ocean circulation models. There have been many improvements of the model throughout the last decade, and the results have been used for impact analysis in every lease sale conducted on the Atlantic OCS. The OSRA model deals with three factors that essentially define the total oil spill risk to OCS resources:

1) Probability of contact to sensitive resources derived from statistics of numerous simulated trajectories.

2) The probability of spill occurrence as a function of the amount of oil that is produced from individual production sites or is transported to shore.

3) The location in space and time of sensitive resources defined according to the same coordinate system used in the spill trajectory simulation.

The first factor relies on the environmental conditions and the spatial relationship between resources and areas of hypothetical development in the region where a lease sale is to occur. The second factor is based on historical records, updated and where appropriate, subjected to statistical analysis to account for recent experience. The probability of spill occurrence is assessed for each potential spill source (tankers, pipelines, and platforms). The third factor is dependent on an inventory of sensitive resources in the sale area.

The primary source of data for factors one and three is the ESP. The ESP began in 1973 under the Bureau of Land Management (BLM), and in May 1982 it was placed under the jurisdiction of the MMS. The purpose of the ESP is to conduct studies to build the reliable database that is needed to help predict, assess, and manage the potential impacts of OCS development on the human and marine environment of the U.S. Atlantic coast, shelf, slope, and rise regions. On the Atlantic OCS, it has spent nearly $100 million on studies of the environmental conditions between Fiscal Year (FY) 1973 and FY 1987.

Approved studies are funded in the form of contracts awarded to a variety of qualified research groups in addition to Interagency Agreements, Memorandums of Understanding, and Cooperative Agreements with other Federal Agencies. Past and ongoing contracts have produced numerous technical reports, maps, databases, and other products for use in the planning and management of OCS activities. This paper provides a description of the principles behind OSRA and the program of field measurement funded by the MMS through the ESP that has improved the reliability of the oil spill impact assessment process.

HISTORICAL PHYSICAL OCEANOGRAPHIC AND METEOROLOGICAL DATABASE

Data on ocean currents can be obtained from field measurements or numerical models. Information available at the beginning of the OCS oil and gas leasing program was obtained from drift bottle and card studies, historical current charts, the known geostrophy of the region, and oceanographic observations. Given the complicated nature of

Atlantic circulation, it was clear that the oceanographic and meteorological database of the early 1970's provided an inadequate description of the OCS circulation regime and its variability at appropriate time scales.

The initial response of the ESP to the inadequacy of the database was to propose and fund a series of environmental inventories and assessments for all Atlantic OCS planning areas. One of the primary objectives of these studies was to develop a comprehensive inventory of marine environmental data for use in preparing impact assessments for the development of offshore energy sources. This inventory enabled the ESP to define areas where information was sparse and determine what types of studies were needed to augment and enlarge the existing data base. Physical oceanographic data on the water masses and current systems on the Atlantic OCS including regional and local circulation systems were assembled. Additionally, meteorological information concerning atmospheric conditions in the study areas as well as air-sea interactions was collected.

Information on the continental shelf of the North and Mid-Atlantic Planning Areas between Sandy Hook, New Jersey, and the Bay of Fundy was compiled in a report by The Research Institute of the Gulf of Maine (TRIGOM) and the Public Affairs Research Center (PARC) of Bowdoin College. The continental slope of the North and Mid-Atlantic Planning Areas was similarly described in a second survey by TRIGOM that was completed in 1976 (see fig. 1). TRIGOM assembled information that was generated before 1975. In 1977, the ESP authorized The Center for Natural Areas (CNA) to prepare a report, which provided an updated analysis of published, unpublished, and raw data from 1972 to 1977 on the OCS from the Bay of Fundy to Cape Hatteras (see fig. 1). The Department of Commerce through the Environmental Data Service of the National Oceanic and Atmospheric Administration (NOAA) also completed a study in 1977 of the environment of the mid-Atlantic region.

An inventory of information for the continental shelf of the South Atlantic Planning Area between Cape Hatteras, North Carolina, and Cape Canaveral, Florida, was prepared by the Virginia Institute of Marine Science (VIMS) (see fig. 1). In 1979, another literature survey for the South Atlantic Planning Area that included information on the Blake Plateau was completed by Environmental Research & Technology Inc. In 1980, a report on the Georges Bank area was prepared under an interagency agreement between the DOI and NOAA (see fig. 1). A literature survey concerning the Atlantic Slope and Rise between 28^{o} and 42^{o}N. was completed by Marine Geoscience Applications Inc. (MGA) in 1984 in response to a need for information on deepwater environments (see fig. 1).

The analyses and conclusions of these inventories/assessments illustrated the need for an ongoing program of physical oceanographic and meteorologic data collection and analysis on the Atlantic OCS. Consequently, several data gathering programs were planned by the ESP.

NORTH ATLANTIC PLANNING AREA MEASUREMENT PROGRAMS

In 1976 in the North Atlantic Planning Area, the New England Outer Continental Shelf Physical Oceanography (NEOCSPO) program was initiated. The purpose of the NEOCSPO program was to describe the transport and dispersion processes in the region. In addition, information on the general temperature, salinity, and current patterns of the area was collected. This database was used to determine the rate of dispersion of materials released into the Georges Bank environment, and their travel patterns and residence times. Identification of nutrient sources and regions of high biological productivity were also objectives of the program which continued through 1979[1].

Several field measurement studies in addition to the NEOCSPO program were initiated in the New England region. Some of these were U.S. Geological Survey (USGS) environmental geology studies whose primary objective was to determine the areal extent of geologic hazards and constraints and evaluate the geotechnical properties of bottom and subbottom sediments on the shelf and slope. A determination of the areal extent of some geologic hazards and constraints (e.g., scour, sand waves, and mass sediment movement) necessitated an assessment of the seasonal and spatial variability of the major sediment transport mechanisms and a characterization of the regional bottom circulation patterns.

Other major studies in the area were the Nantucket Shoals Flux Experiment, the Larval Patch Study, and the National Marine Fisheries Services study of currents in the Northeast Channel. Archived National Oceanic Data Center data for the period 1975 through 1979 were also used. The NEOCSPO program relied on these sources in addition to its own field program in producing a final report[1].

In addition to the NEOCSPO program between 1980 and 1984, another field program called the North Atlantic Slope and Canyon Study was conducted. The objective of this study was to investigate the currents and sediment transport along the outer shelf and upper slope along the southern flank of Georges Bank[2]. Figure 2 shows the location of the current meter and meteorological stations used in the NEOCSPO and North Atlantic Geological and Slope and Canyon studies.

MID-ATLANTIC PLANNING AREA MEASUREMENT PROGRAMS

As in the North Atlantic Planning Area, environmental geologic studies were conducted by the USGS in the Mid-Atlantic Planning Area. Concurrently with the North Atlantic Slope and Canyon Study, Lamont-Doherty Geological Observatory investigated the physical and biological processes of the Baltimore Canyon and adjacent mid-Atlantic slope areas[3].

In 1983, Science Applications International Corporation (SAIC) began a 2-year field program known as the Mid-Atlantic Slope and Rise (MASAR) study. The objectives of the study were to determine the broad scale, general circulation features on the continental slope and rise on a seasonal basis and to quantify the variability of these features in the vertical and horizontal planes. Also, SAIC was to determine the degree to which slope/rise circulation features influence the physical oceanography of the shelf region.

A system for exchanging data with other field programs in the region was instituted to assure creation of the most comprehensive database possible. The principal contemporary programs with which MASAR was affiliated included:

> Shelf Edge Exchange Processes (SEEP), a program located off the New England slope to describe cross-shelf transport and deposition of organic carbon.
>
> The Microbial Exchange and Coupling in Coastal Atlantic Systems (MECCAS) program existing off Virginia Beach, Virginia. This program was designed to describe the dynamics of estuarine plumes formed by the outflow of low salinity water onto the shelf.
>
> The Warm Core Rings (WCR) Experiment off the U.S. East Coast was designed to determine the statistical properties of WCR motion, size, shape, and location based on a 10-year sample set of 87 rings.

The Gulf Stream Meander Dynamics program off Cape Hatteras, North Carolina was designed to study the meandering processes of the Gulf Stream.

The program of study for MASAR emphasized the Gulf Stream and associated elements (Gulf Stream rings, filaments, and similar near-surface events). Other study elements were the Western Boundary Undercurrent, circulation in the surface layer above the main thermocline (< 200 m), the shelf/slope front, and the potential transfer of wastes at the Environmental Protection Agency (EPA) 3,800-m dumpsite[4]. Figure 3 shows the arrays used in MASAR and affiliated programs.

A 10-year history of statistics (mean loci, lifetime and size, and movement in the slope-water region off the U.S. Northeast coast) on Gulf Stream warm core rings was generated by this study.

SOUTH ATLANTIC PLANNING AREA MEASUREMENT PROGRAMS

Between 1977 and 1984, SAIC conducted a multiyear program of field measurement and data interpretation and synthesis in an area extending along the shore from Cape Hatteras to Cape Canaveral and offshore across the shelf and Blake Plateau. This program was called the South Atlantic physical oceanography study (SAPOS). The objectives of the program were three-fold. First, a better understanding and description of the conditions and processes (i.e., tide, wind, density, and the Gulf Stream) governing South Atlantic Bight circulation was desired. A second objective was to document and explain the spatial and temporal variability of South Atlantic Bight hydrographic conditions (i.e., temperature, salinty, density, dissolved oxygen, and selected nutrients). Additionally, data gathering efforts were designed to define the initial and boundary conditions needed for a numerical circulation modeling program[5]. These objectives determined the type and amount of data gathered during each year of the program.

The objectives of the SAPOS were aided by several other data gathering programs in the South Atlantic Bight region. The efforts of the SAPOS were coordinated with a Department of Energy (DOE) current monitoring study, a BLM-funded USGS environmental geologic study, a BLM-funded National Aeronautics and Space Administration (NASA) study of sea surface transport and wave climatology, and the deployment of three offshore meteorological buoys by the National Data Buoy Office[5]. Additionally, the results of a joint DOE/MMS study of oceanographic processes in the area during the winter/spring of 1980 and summer/fall of 1981 (Georgia Bight experiments I and II) were incorporated into the SAPOS. The Georgia Bight experiment focused on the shelf's response to the wind and Gulf Stream forcing and the coupling of flow regimes. Near the end of the South Atlantic physical oceanography study, a current measuring program was instituted on the Blake Plateau. The results of the first year of this study were incorporated into SAPOS[5].

Current measurements made as part of the South Atlantic Bight study were supplemented by the Blake Plateau bottom and mid-water current study (see fig. 4). This program was designed to study mid-water and near-bottom current and temperature variations in the vicinity of the Gulf Stream axis simultaneously with near-bottom, shelf edge, and Blake Plateau currents at 30°N.[6]. Data were collected for a year to investigate seasonal changes in Blake Plateau current patterns and to overlap with the Georgia Bight I and II experiments[5]. The Georgia Bight I and II experiments were designed to study the circulation and exchange patterns occurring throughout the shelf area during the winter to summer transition (see fig. 4). The Blake Plateau current study was extended for a second year to include measurements along latitude 36°N. with the additional objective of producing data to determine boundary conditions for a numerical circulation model[6]. The study of the current regime and Gulf Stream dynamics in the Blake Plateau region culminated in a third field program whose study area extended from 30° to 36°N. in the South Atlantic Bight and the Blake Plateau[7]. The objective of this study was to determine the location of the Gulf Stream front on a daily basis and over longer time periods.

Several other programs that were ongoing during the Blake Plateau field program enhanced the study effort (see fig. 5). The Subtropical Atlantic Climate Study, which was jointly funded by NOAA and the Office of Naval Research studied the dynamics of the Florida current and its relation to north Atlantic circulation and global climate. The Spring Removal Experiment, an extension of the Georgia Bight program, primarily funded by the DOE studied the cause and effect of the hypothesized removal route of low salinity coastal water in the vicinity of the Charleston Bump. The Florida Atlantic Coast Transport Study (FACTS) funded by the MMS studied the frequency of filament structures on the western edge of the Gulf Stream and volume transport between latitude 27° and 30°N.[7]. Information from these programs and from other background sources (i.e., National Weather Service, National Climatic Center, National Ocean Survey) supplemented the database generated by the Blake Plateau program itself[7].

MODELING

As stated before, one of the objectives of the physical oceanography field programs in the South Atlantic region was to develop boundary and initial value conditions for input into a numerical modeling program. The ESP contracted with Dynalysis of Princeton (Dynalysis) to develop a numerical modeling program for the South Atlantic Bight. The MMS's reasoning was that data gathering programs on Atlantic OCS are best suited for observing and analyzing particular dynamic phenomena rather than determining the circulation of an entire region[8].

The focus of the Dynalysis project was the area between 27° and 37°N. and bounded by 73°W. (see fig. 1). Dynalysis was asked to develop a working descriptive and predictive model that would generate reasonably accurate predictions of surface current velocities for input into trajectory models for use in the MMS's oil spill risk analysis process. Dynalysis was also required to develop a capability for determining mid-water circulation to predict dissolved and suspended matter transport and near-bottom currents to predict sediment transport.

A time-dependent, three-dimensional general circulation model that Dynalysis had developed and used with success in the Gulf of Mexico, Mid-Atlantic Bight, and Chesapeake Bay was used for the project. Density fields from the most current database possible were used to establish the initial conditions for the model. The general circulation model was then run in several modes. These included a diagnostic mode where the density field is prescribed and held fixed in time, a prognostic (forecast) mode in which the density field is allowed to evolve dynamically under prescribed surface winds and other forcing mechanisms, and a truly predictive mode with forecast synoptic winds as input[8]. The general circulation model accurately simulates the evolution of the upper oceanic layer through an incorporation of realistic vertical mixing via a second-order turbulence closure model. It also incorporates wind and density forcing and can simulate tidal and storm surge processes.

The open boundary conditions for the general circulation model are generated by another model that uses geostrophic/Ekman equations of motion including the surface shear stress terms and is essentially a diagnostic technique. This Characteristic Tracing Model was developed under this contract and deduces the transports and currents not only on the open boundaries for the general circulation model, but also in the entire region from prescribed density and wind stress fields. The two models operating together describe current patterns in the South Atlantic Bight and throughout the entire water column. The resulting circulation model agrees well with available observations. The background diagnostic currents produced can also be used in trajectory models such as the OSRA model[8].

The ESP authorized Dynalysis to expand the area of coverage for its modeling efforts to the entire east coast in a later phase of the modeling program. This change was made because the earlier boundary (36°N.) cut across the most dynamically active and interesting features of the eastern continental shelf. The area for which data has been analyzed covers the coastal waters of the east coast from 65° to 82°W. and 23° to 46°N., excluding an area south of 30°N. and east of 70°W. where data coverage remains sparse. The Characteristic Tracing Model was modified to include the effect of bottom stresses in the planetary potential vorticity balance. The increased volume of physical oceanographic observations produced by the field program in the South Atlantic Bight were incorporated into the general circulation model and the Characteristic Tracing Model. The results of these refinements show that the circulation features of the east coast deduced by the modified Characteristic Tracing Model are in agreement with the first Characteristic Tracing Model and compare well with field observations. However, the modified Characteristic Tracing Model produces a more accurate picture of the currents on the shelf.

Another objective in the expansion of the modeling effort was to demonstrate the ability of the circulation models to predict event features of the Gulf Stream such as meanders, filaments, and eddy formation. Earlier calculations did not produce the observed Gulf Stream frontal variability. A series of numerical experiments using the general circulation model were conducted to study the initiation and evolution of these features. These experiments focused on three modes of external forcing for generating frontal activity. These forcing mechanisms are 1) surface forcing by a propagating wind stress curl, 2) changes in the intensity of the Gulf Stream, and 3) changes in the lateral position of the Gulf Stream[9].

The general circulation model used in the Atlantic is an orthogonal curvilinear coordinate system model that was previously used in the Pacific Region to model circulation patterns on the California shelf[9]. Both the California and Atlantic models use the coordinate system that can be modified to conform to coastal features, and a variable grid spacing is used to obtain high resolution in areas of interest.

The results of these models produce surface velocities on seasonal time scales. Oil spill transport occurs on the order of days, weeks, and months, rather than seasons. To account for this difference in time scales, a second method must be used to produce surface velocities for use in the oil spill risk analysis process. A wind drift model is used to aid in the determination of trajectories. The velocity component derived from the Ekman spiral is removed to prevent a duplication of the resultant wind-forcing. Winds from the historical database are sampled at 3-hour intervals. The results of this wind model are based on the assumption that the wind in one time-step is a random function of the wind in the previous time-step, a first order Markov process[10]. The wind induced current is determined to be a constant percentage of the surface wind speed. An empirically derived wind drift factor of 3.5 percent of the wind speed is used, along with a variable deflection angle that compensates for the effects of the Coriolis force[11].

Therefore, the OSRA model, as it is presently used on the Atlantic OCS, is based on a principle that can be expressed through the following relationship:

$$U_{oil} = U_{residual\ current} + 3.5(\text{def. angle})U_{wind}$$

Where U is a velocity vector. The effects represented by the first term are obtained through the Characteristic Tracing Model and the effects represented by the second term are obtained through the statistical wind model. The timing of an oil spill is selected at random, and trajectories are started from points on the OCS where oil is most likely to be found and developed, including transportation routes.

DEFINITION OF AREAS OF SENSITIVE HABITAT

If oil is spilled on the OCS, the process of determining the environmental impacts is dependent on the location and residence time of sensitive OCS and coastal resources. The ESP was designed not only to enlarge the database of oceanographic information, but also to aid in the definition and delineation of these areas of sensitive OCS and coastal habitat. Baseline/benchmark studies described the status of the biological, socioeconomic, and physical environment of the Atlantic OCS in the early and mid-1970's. Thereafter, numerous research projects were initiated with the objective of increasing the understanding of the resources that may be affected by oil and gas development. The following section gives two examples of these data gathering and assessment programs.

In the South Atlantic region, the ESP sponsored a program of study on hard-bottom habitats. The South Atlantic Hard-Bottom Study determined the ability of geophysical prospecting methods to identify hard-bottom habitats. Then the Ocean Bottom Survey, a part of the Atlantic Geological Studies program, determined the occurrence and distribution of hard-bottoms in the region.

The South Atlantic OCS Area Living Marine Resources Study, conducted by the Marine Resources Research Institute (MRRI) of the South Carolina State government, used the information gathered by previous studies to conduct a three-phase study of hard-bottom habitats. The first two phases generated a comprehensive characterization of the benthic invertebrate and demersal fish communities associated with nine representative hard-bottom areas located between 30°N and 33°N[12].

Phase III of the project was designed to gain a better understanding of the relationship between development activity and the recruitment and development of invertebrate communities. Also desired was information on the importance of the health of the invertebrate community to the development of fish species in the region.

In the North and Mid-Atlantic regions, the ESP contracted with the University of Rhode Island (URI) to conduct a Cetacean and Turtle Assessment Program (CETAP). This program gathered data over a 39-month period beginning in November 1978 and continuing until January 1982. Information was gathered from aerial surveys, aircrafts and ships of opportunity, opportunistic data from individuals and other researchers in the area, and special surveys. Special surveys were usually species-specific. They were organized when certain species were not adequately sampled, or certain areas or events were unique or of short duration and therefore would not be sampled by other survey methods.

Once the results of an OSRA model run are presented to the MMS analysts, these biological studies provide some of the detailed information needed for impact analysis. Seasonal location of endangered species and other marine mammals, as well as estimates of their populations, help to determine the likelihood and potential severity of impact. Information on the feeding and breeding patterns of different species is especially important in determining recovery times. The same is true for the location of hard-bottom areas and the sensitivity of resident species of invertebrate and demersal fish to contact with spilled oil.

SUMMARY

In the North Atlantic Planning Area, the NEOCSPO developed quantitative estimates of the amount of recirculation of the Georges

Bank Gyre, showing it to be a more intense and closed pattern in the summer than in winter. The conceptual model for the general seasonal circulation of the Gulf of Maine and Georges Bank region was verified by the NEOCSPO. Drifter observations provided the capability of determining the dynamics and structure of the wind-driven current fields that fluctuate with periods of between 2 and 30 days. Research on submarine canyons in the North and Mid-Atlantic identified them as regions of increased biological productivity in relation to adjacent shelf and slope areas. The active current regimes in these canyons promote sediment transport.

The MASAR study provides a long-term view of shelf-break exchange processes, which again includes estimates of seasonal variations. The effects of submesoscale and mesoscale eddies as well as wind-driven currents on these exchange processes have been documented. Additionally, other research programs that were associated with the Mid-Atlantic Slope and Rise program (e.g., MECCA, SEEP, Gulf Stream Variability) have benefitted immensely from the data generated by this ESP-sponsored study.

The SAPOS investigated the circulation pattern in the South Atlantic Bight. Forcing by the Gulf Stream and winds are most important on the outer shelf. Periodic migrating meanders and associated filaments are Gulf Stream events that affect this region. The filaments are the primary flushing mechanism for the South Atlantic Bight. At mid-shelf, tides and local winds have the greatest effect on current patterns. On the inner shelf, the density structure acts in concert with tides, in addition to buoyancy flux from fresh water input and surface wind stress to determine the current regime. Gulf Stream variability on the Blake Plateau was analyzed by the Blake Plateau current measurement study. The role of the Charleston Bump in the displacement of the Gulf Stream and the creation of meanders and eddies was outlined. The effect of these Gulf Stream disturbances on the exchange processes of the region was investigated, and the viability of the use of satellite imagery to document changes in Gulf Stream position and the effect of the Gulf Stream on regional circulation and water mass distribution was demonstrated. Comparisons between wind data gathered at coastal stations and offshore buoys were made to determine if there is a pattern to the differences between them. FACTS extended the study of the Gulf Stream southward to the Florida coastal regions. The periodicity of eddy events was determined, although the data were not sufficient to draw conclusions regarding the role of changes in Gulf Stream transport in eddy formation. Data from FACTS were also used to determine that nearshore small cyclonic circulation provided a possible mechanism for onshore transport of materials from OCS activities.

The oceanographic field program of the MMS has enlarged the existing database. Data from the field programs in the south Atlantic have been used by Dynalysis in conjunction with a general circulation model to describe south Atlantic circulation. It was demonstrated that a general circulation model using the appropriate boundary conditions could produce a realistic pattern of Gulf Stream intrusions along the western Gulf Stream boundary. The diagnostic currents produced by the Characteristic Tracing Model are used for input to the OSRA model with trajectory results being used in the oil spill risk and impact analysis processes.

The analysis of impacts on coastal or OCS resources produced by oil spills or the release of other pollutants is dependent, in part, on accurate resource definition. Therefore, another objective of the ESP is to determine the spatial and temporal variability of OCS resources. Representative of these efforts are the CETAP and South Atlantic hard-bottom studies. In the case of CETAP, the delineation of feeding and calving areas, as well as migration routes, serve to better pinpoint areas at risk from an oil spill. Information on population distributions of different species helps to determine which ones are most at risk and to identify their ability to recover from an exposure. The hard-bottom study defined the occurrence and areal extent of hard-bottoms in the South Atlantic Bight. It also determined the number of species associated with hard-bottoms and the extent of their dependency on this type of habitat. Again, this information is important in determining where an impact would occur, which species would be impacted, and what are likely time- frames for recovery.

CONCLUSION

The uncertainty involved in determining the risk to OCS resources is difficult to assess. The fate of oil, should a spill occur, will be a function of many environmental factors, of which, wind and current conditions are the major ones. The mean current database for the Atlantic Region prior to 1979 was inadequate for use in numerical modeling efforts. The forcing mechanisms in the area were not clearly understood, and they were poorly modeled. The efforts of the ESP have resulted in an improvement in the understanding of ocean resources through the development of concurrent and parallel programs of scientific research. They have provided direct, long-term current and hydrographic observations in the Atlantic Region. The modeling component of this program makes use of this database to model the circulation over the entire region and provides the MMS with a predictive capability. Other information-gathering programs have enabled the MMS to identify species that may be at risk from OCS development. The location of their habitats and temporal variations in habitat use have been described. Additionally, their dependency on the existence of other associated species is determined.

The ESP, through ongoing studies, is continuing to provide important information on the physical and biological oceanography of the Atlantic OCS. The ESP also is continuing to collect information on the impacts of OCS development on coastal and OCS resources. Additionally, the proposed "Long-Range Studies Plan" ensures that the ESP will continue to be a major contributor to our knowledge of the marine environment and the effects of OCS activities on our offshore resources.

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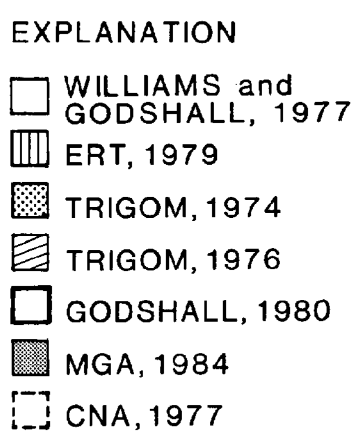

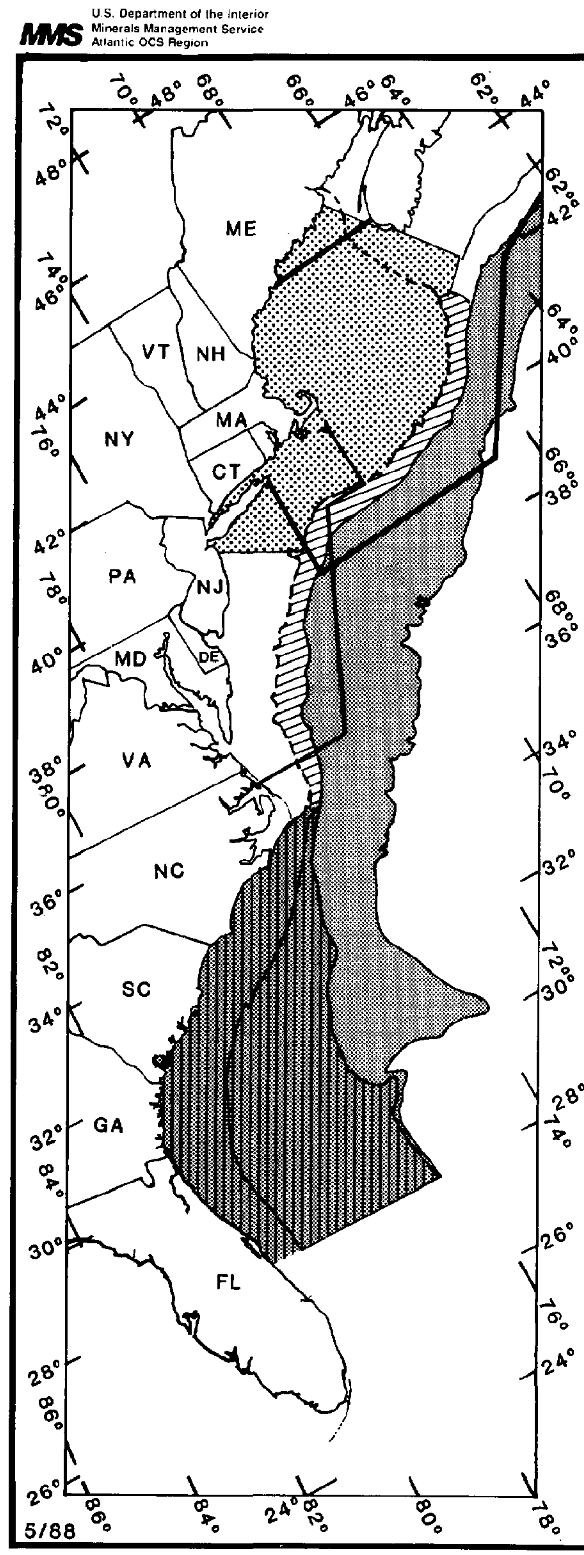

Figure 1. Study areas for the series of data inventory/assessments on the Atlantic OCS

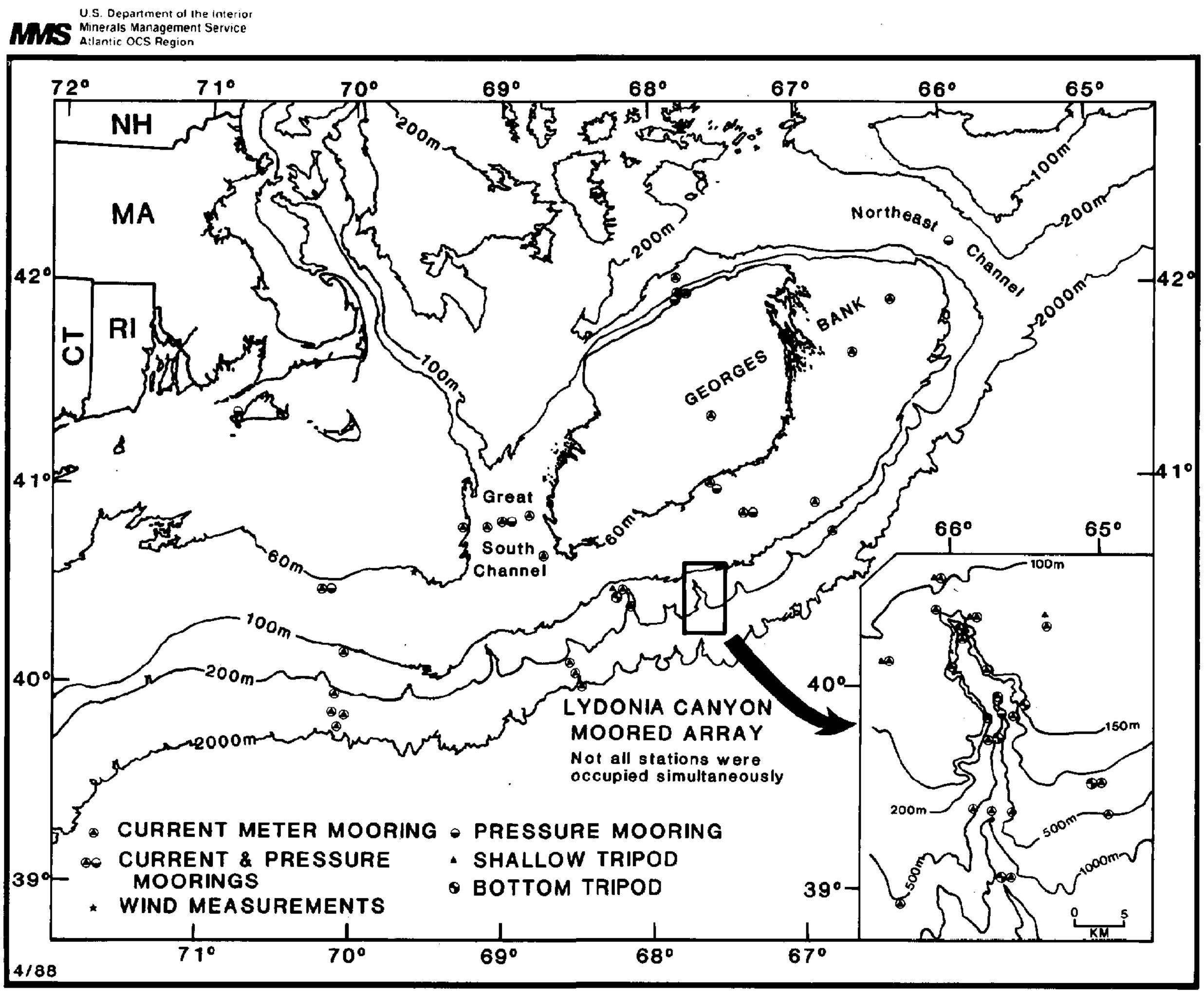

Figure 2. Current meter and meteorological stations used in NEOCSPO and the North Atlantic Geological and Canyon and Slope studies (Adapted from Flagg et al., 1982, and Butman, 1986).

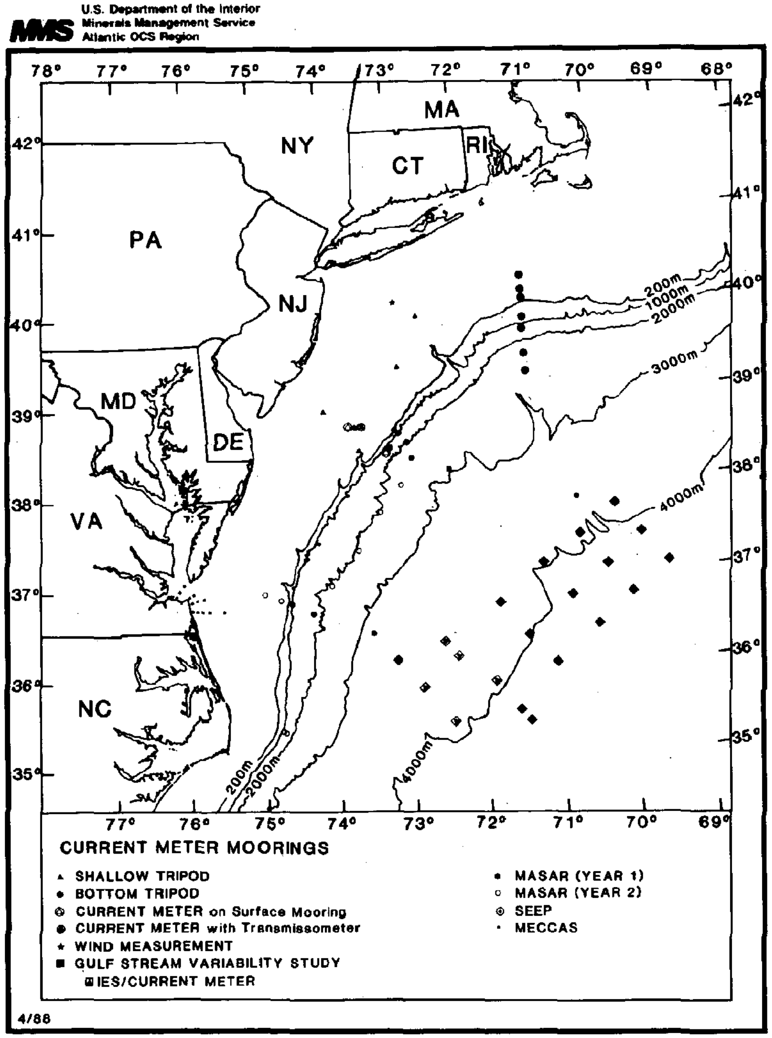

Figure 3. Current meter and meteorological stations used in Mid-Atlantic geological studies and the MASAR field program also shown are the current meter arrays of associated studies (i.e. SEEP, MECCAS, and Gulf Stream Variability) (Adapted from SAIC, 1986).

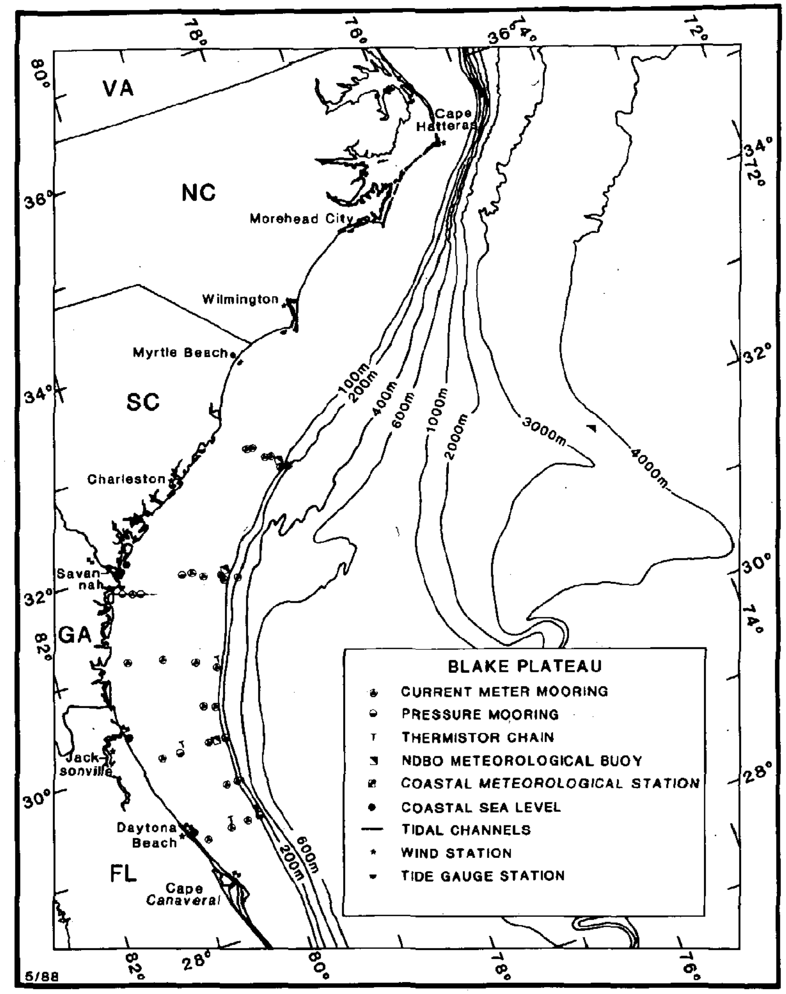

Figure 4. Current meter array for the SAPOS and meteorological stations used in National Data Buoy Office research projects. Also shown are the Georgia Bight Experiment I and II arrays and the locations for National Ocean Survey coastal tidal stations (Adapted from SAIC, 1984).

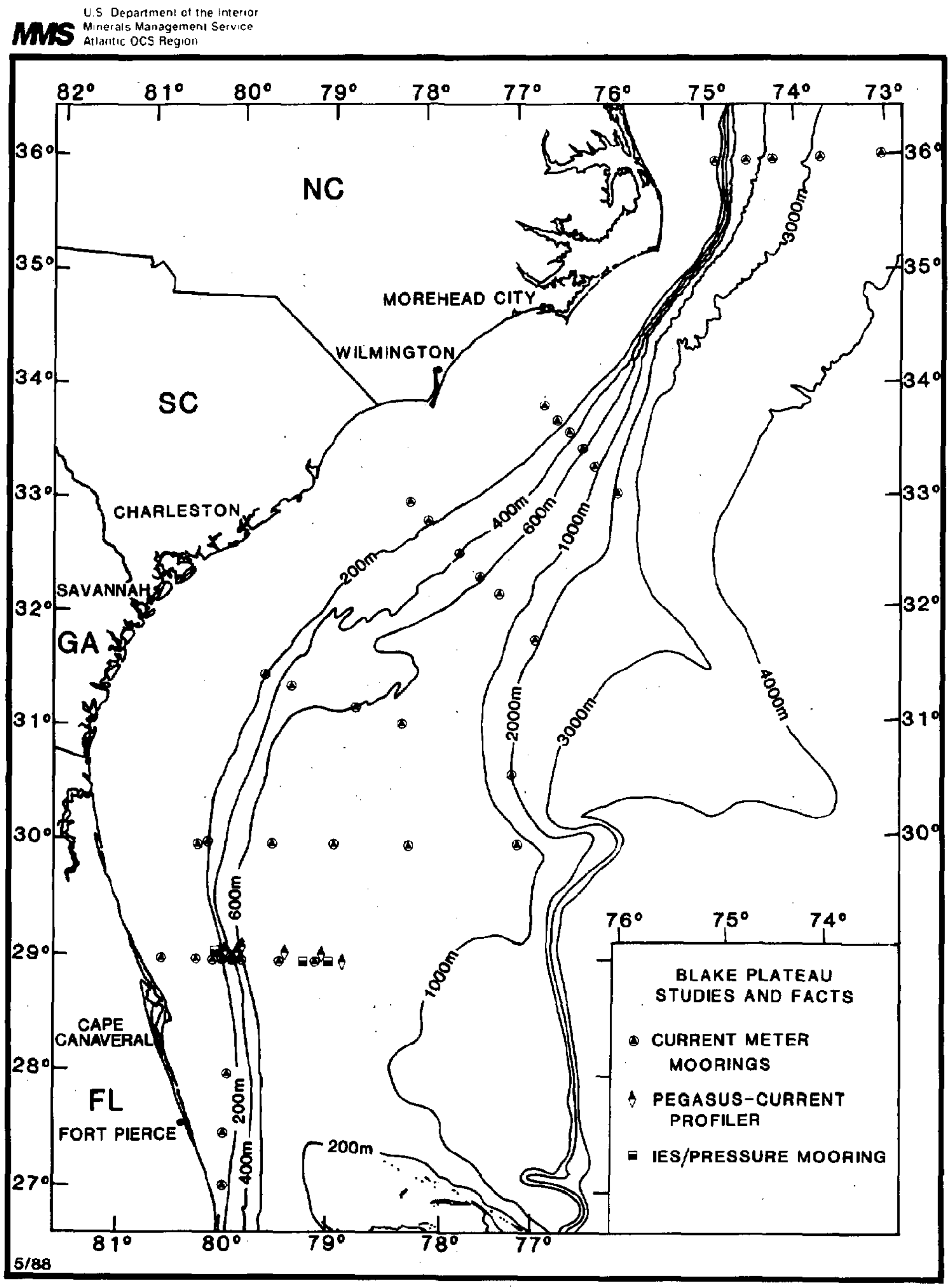

Figure 5. Current meter arrays for Blake Plateau and FACTS studies and current meter stations from concurrent research projects (i.e. STACS, and SPREX) (Adapted from General Oceanics Inc., 1982,1983,1986, and FIO, 1986).

DEVELOPING TECHNOLOGIES FOR OFFSHORE OIL AND GAS STRUCTURES IN FRONTIER AND HAZARDOUS AREAS

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ABSTRACT

Much of the United States' future domestic petroleum supply is expected to come from the areas offshore Alaska and the lower 48 states. Areas of highest potential are in the deep waters of the Gulf of Mexico (GOM), seismically active areas off southern California, and the ice-infested waters of the Arctic. Operations under any of these conditions are severe, with high development costs, and immense financial risks. Expansion into these areas requires extensive research studies and complex engineering solutions. Industry has historically demonstrated the ability to develop required technologies to meet new challenges and advances in the above areas are no exception. This paper addresses some of the technological breakthroughs proposed to develop oil and gas operations in these frontier areas, and the concerns expressed for the installation of platforms in seismically active areas. Recent activities relating to the U.S. Research Commission are covered as well.

INTRODUCTION

As the pace of exploration increases in the frontier areas of the Outer Continental Shelf (OCS), questions arise continually about technologies needed to safely and efficiently develop oil and gas operations in such severe environments. The engineering categories listed in Figure 1 entail some of the items requiring special attention. Each of these categories has its unique problems and constraints which must be addressed. Experience derived from numerous installations in nonfrontier areas coupled with extensive research sponsored by both industry and Government provides a solid basis to move operations into the less benign regions.

Technologies that will be used to develop, produce, and transport oil and gas in the Arctic are constantly being updated, and although some systems are well proven, others are not. Design criteria must include provisions for very low temperatures, sea ice, permafrost, seismicity, waves, and bottom scouring by ice ridges. Environmental issues which must be addressed are impacts from a major oil spill, effects due to marine structures as well as shore-based facilities, and the consequences of dredging, ice breakers, excess noise, and other possible hazards. Industry, however, has demonstrated its capability to use new technologies for exploration in the Arctic, and this insight will prove of great benefit for developing future production facilities.

Engineering Categories

- Well Control
- Structural Dynamics
- Structural Inspection and Monitoring
- Geotechnical
- Ice Mechanics
- Materials
- Risk Assessment
- Oil Spill Containment and Cleanup

Figure 1. *Engineering categories requiring special attention for the development of oil and gas operations in frontier areas.*

Industry is of the opinion that the technology exists for developing and producing oil and gas in water depths out to at least 3,000 feet. This does not imply that all potential engineering and operational problems have been solved. Uncertainties still exist and will continue to exist until facilities in these water depths become operational. Areas of concern for deepwater operations relate to well-control procedures, laying and operating pipelines, strumming of risers because of high ocean currents, inspection techniques, and the use of novel structures. All of these areas must be addressed from a technological standpoint to bring deepwater operations into the same realm of reliability as current operations.

Over the last several years, millions of dollars have been invested in designing equipment, developing analytical tools, and conducting model and full-scale field tests in preparation for frontier operations.

To illustrate the technological developments that have occurred or are anticipated for operations in the deep ocean, seismically active regions, and the Arctic, the following information is provided.

Deepwater Technology

Ten years ago the term deepwater referred to water depths greater than 600 feet; now this has been extended to water depths greater than 1,000 feet. In two recent lease sales in the Gulf of Mexico, 33 percent of the tracts leased were in water depths greater than 3,000 feet, and four tracts were leased in water depths of 10,000 feet. While it is unlikely that a significant number of projects will be carried out in these water depths over the next few years, the industry has retained a strong interest in continuing to acquire deepwater tracts for future development. Deepwater exploration has not been limited only to the Gulf of Mexico. Brazil is currently conducting exploratory drilling at two sites, one in 3,660 feet of water and the other at a depth of 3,690 feet. Other countries with deepwater activity are Norway, Australia, Indonesia, Italy, Spain, Thailand, and the U.S.S.R. Table 1 shows the total number of deepwater wells drilled worldwide during each of the past 10 years.[1]

A variety of structural concepts are available for deepwater development as shown in Figure 2. These include conventional fixed jackets, compliant towers, tension leg platforms, and floating production platforms. Many complex technical problems have been solved in developing workable systems, and each system has its own unique advantages and limitations. However, what may prove to be technically feasible may not be economical, that is, the size of the recoverable resource is a key component for the economic feasibility of deepwater development.

Table 1. *Chronology of Deepwater Drilling*
(Taken from Reference 1)

	600-1,000 ft.	1,001-2,000 ft.	2,001-3,000 ft.	Over 3,000 ft.	Total
1978	21	13	7	3	44
1979	39	35	3	10	87
1980	40	32	8	6	86
1981	31	44	4	0	79
1982	58	37	1	5	101
1983	64	36	2	3	105
1984	64	63	13	8	148
1985	66	74	12	10	162
1986	46	42	16	12	116
1987	33	41	16	11	101

The previous record for a fixed platform, is held by Shell's Cognac Platform located in 1,025 feet of water, has recently been surpassed by Shell's new platform, Bullwinkle, that is the world's tallest deepwater fixed platform. It is located in 1,350 feet of water and stands 1,615 feet tall from the ocean floor to the top of the drilling rig. The platform consists of a single-piece steel jacket with a weight of approximately 50,000 tons. The massive structure, too large for conventional launching equipment, required construction of a specially designed 853-foot by 253-foot launch barge that is being built in Korea.[2]

Recent studies indicate that steel-jacket platforms could be technically feasible up to a water depth of approximately 1,600 feet. However, these giant structures are subject to motions and stresses amplified by resonant vibration, which results in an unacceptable fatigue life. New designs are being developed to eliminate this problem, but it is reasonable to state that conventional jacket structures are not feasible beyond this depth.[3]

A new type of structure is being developed to extend platform depth capabilities significantly. Known as compliant platforms, these structures are allowed to move in response to waves and currents, thus reducing the magnitude of the load to be resisted. Figure 3 indicates the relative sway periods of fixed and compliant platforms and how each compares with typical wave-energy spectra.

Compliant platforms may be classified in two ways. The first is designated as bottom-founded. This would be typical of guyed towers and compliant towers. Exxon has installed a guyed tower, Lena, in 1,000 feet of water in the GOM, and the technology is such that guyed towers may be an efficient system down to a water depth of

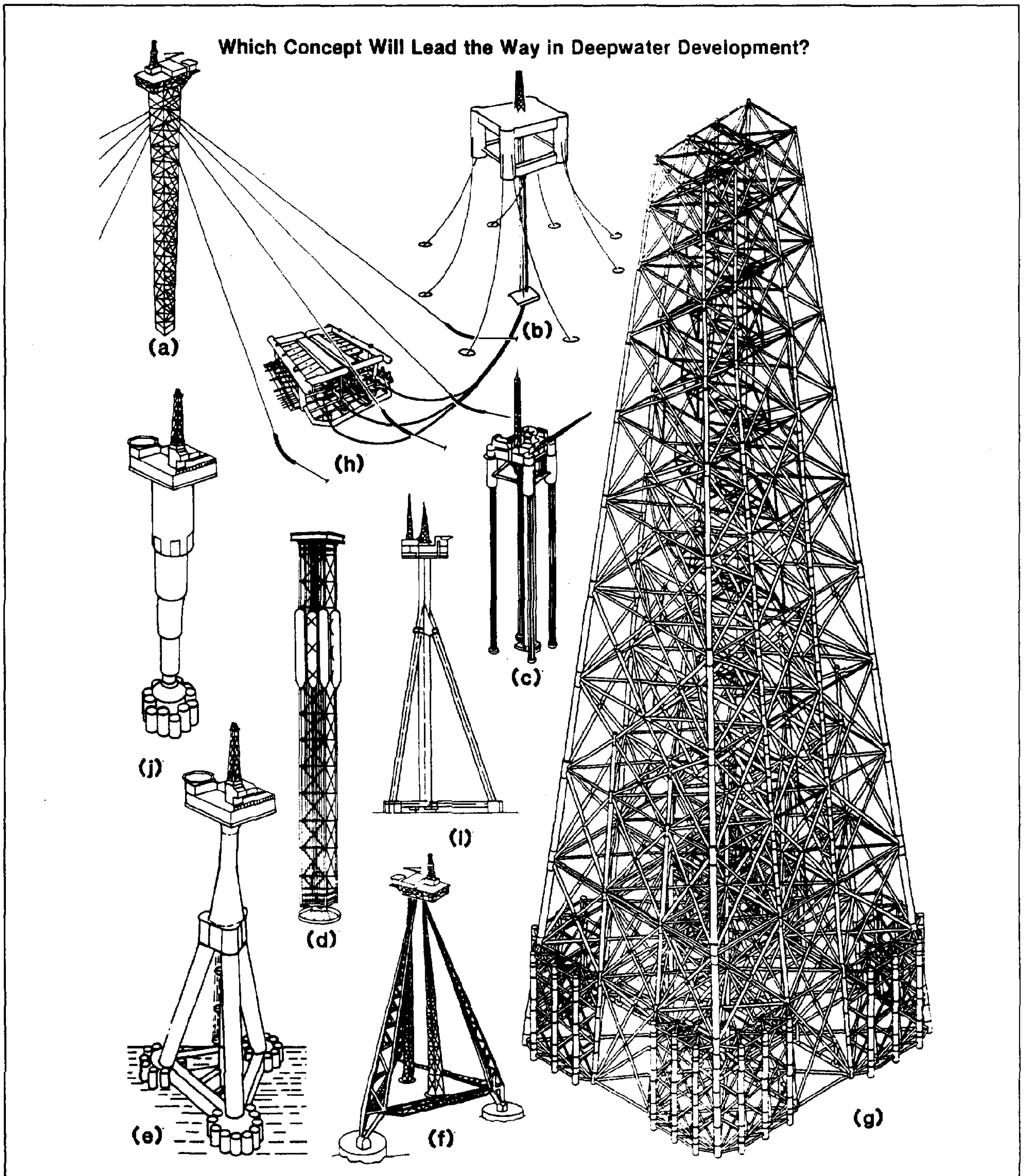

Figure 2. *Structural concepts for deepwater platforms: (a) Guyed Tower, (b) Floating Production System, (c) Tension Leg Platform, (d) Articulated Compliant Tower, (e) Rigid Concrete Tripod Structure, (f) Steel Tripod Structure, (g) Rigid Steel Jacket, (h) Subsea Production System, (i) Steel Box Tripod Structure, (j) Solid Compliant Tower (figure courtesy of McDermott International).*

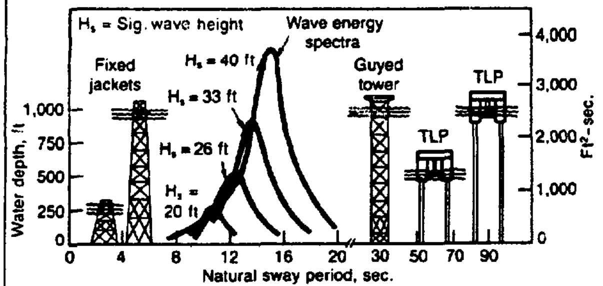

Figure 3. *Comparison of the natural sway period between a fixed jacket platform and a compliant platform and their relationship to the wave energy spectra for different significant wave heights.*

2,000 feet. The compliant tower differs from the guyed tower in that it eliminates the cable system that serves as the support for the tower. Stability is maintained by the flexibility of the frame as well as buoyant chambers built into the frame. These types of structures could be economical down to 3,000-foot water depths. Both of these compliant platforms are rigidly attached to the seafloor with piles and are designed with relatively slender flexible steel frames that have a natural period significantly higher than the high-energy wave periods.

The second class of compliant platform is basically floating structures. The tension leg platform (TLP) is typical of this type of structure for which the technology has been developed. The TLP makes use of excess buoyancy, which places the mooring legs or tendons under a very high tensile load. This in turn restricts the motions of the platform such as heave, pitch, and roll, while it allows movement in the horizontal direction. The first commercial application of a TLP was the Hutton Platform in the North Sea in 485 feet of water. The first deepwater application in the U.S. OCS will be in 1,760 feet of water on a Conoco tract in the GOM. This will be a lightweight version of the TLP and will be known as a tension leg well platform. It will have a displacement of only 18,000 tons, will not support a drilling rig, will have limited processing capabilities, and thus will serve primarily as the support for the well heads. Production will take place on a remote platform location in relatively shallow water.[4]

The TLP concept does suffer from a payload limitation. The larger the deckload, the larger the hull required to provide necessary buoyancy, and the larger the moorings and foundation requirements. With increased water depth, longer tendons and risers are required which add substantially to the deckload, and in turn increases the hull displacement.[3] It is this weight interaction that increases the cost of TLP's and keeps them from being the most economical choice for the deeper tracks. They are expected to be economical down to a water depth of approximately 4,000 feet.

To overcome the disadvantage of the TLP's, Floating Production Systems (FPS) technology is receiving increased attention as an option for deepwater oil and gas operations. An FPS facility is a floating platform held in place by catenary mooring lines. In a typical FPS, the production facility is coupled with a subsea completion system where well control is provided on the seafloor. Wells are usually predrilled through templates, and production is brought to the surface through a compliant riser system connected to the floating vessel. Satellite well production units may be placed at different locations with manifolds located on the template. Currently, some 22 FPS installations are operating worldwide involving converted or purposely built semisubmersible drilling rigs.[3] Placid Oil Company's FPS, being installed in the GOM, will be the world's deepest facility in 1,500 feet of water. This unit is designed to support a total of 24 template and satellite wells with the satellite wells located in water depths varying between 1,500 to 2,000 feet. Since other systems become economically unattractive with increased water depths, FPS's are considered to be the choice for future deepwater developments beyond 4,000 feet.

Whereas the Placid FPS utilizes a converted semisubmersible drilling unit as the production platform, Ocean Drilling and Exploration Company engineers have designed a purpose built semisubmersible platform which is touted to be a considerable improvement over converted drilling units. Shown in Figure 4, the "Ocean El Dorado" is a symmetrically shaped, six column semisubmersible designed to economically operate in water depths ranging from 1,000 to 8,000 feet. The unit operates at a deep draft of 180 ft. with a displacement of 112,558 L.T. and has a top deck elevation which is 262 ft. above the bottom of the pontoons. The deck shape is a 12 sided polygon measuring approximately 340 ft. across the flats. Depending on site specific design considerations, the mooring system will consist of 24 to 36 chain/wire mooring lines and will use anchors varing from 65 to 35 tons. With an air gap of 60 ft., the Ocean El Dorado is designed to safely withstand the passage of a 90 ft. high wave in conjuction with a 162 knot wind and 2 knot current. Further, given that the unit has been designed specifically for the purpose of oil and gas production, its deck load capacity, floating stability, and motion characteristics are far superior to those of semisubmersible drilling units. Having been provided with full drilling capability, simultaneous drilling and production operations are possible on the Ocean El Dorado. Typically, drilling would be done using a conventional subsea stack lowered through the moonpool. The vessel would first position itself vertically over the well location using the mooring system and set a permanent guidebase on the seabed.

It would then drill the well using a subsea stack and a drilling riser. After setting the 7 inch production casing, the stack and drilling riser would be removed and the well tied back to the vessel's tensioning system using a 9 5/8 inch riser enclosing the 7 inch protective casing. Approximately 30 wells could be individually drilled and tied back in this manner, thus eliminating the need for a massive seabed template. All completion and workover operations would be at deck level using conventional surface controls.

The compliancy of the production platform resolves the problem of resisting large loads due to the action of waves and currents, but complicates the design and operation of marine riser systems. This is the area of most need for future technological developments. The complications arise from the fact that marine risers are a critical and delicate component of a floating production system and must be designed and analyzed with the hull as a unified system. Regardless of the type of platform deployed or riser configuration used, the array of risers has distinctly different physical properties and tension requirements, and the platform will move relative to the various components. Therefore, interference between risers, risers and platform, and risers and mooring lines becomes of paramount importance in the design and operation of floating platforms.

Arctic Technology

The technology for Arctic oil and gas development is still in its infancy, even though great strides have been made since the Prudhoe Bay oil discovery in 1969. The capability to conduct exploration operations in this area has been demonstrated, and the first offshore oil production from the American Arctic, the Endicott Oil Field, has begun. However, year-round operations in other than nearshore areas are still a few years in the future. The industry's technical capability to explore and produce in the Arctic varies with a number of factors, but mainly with water depth.[5] Figure 5 indicates some of the numerous structural

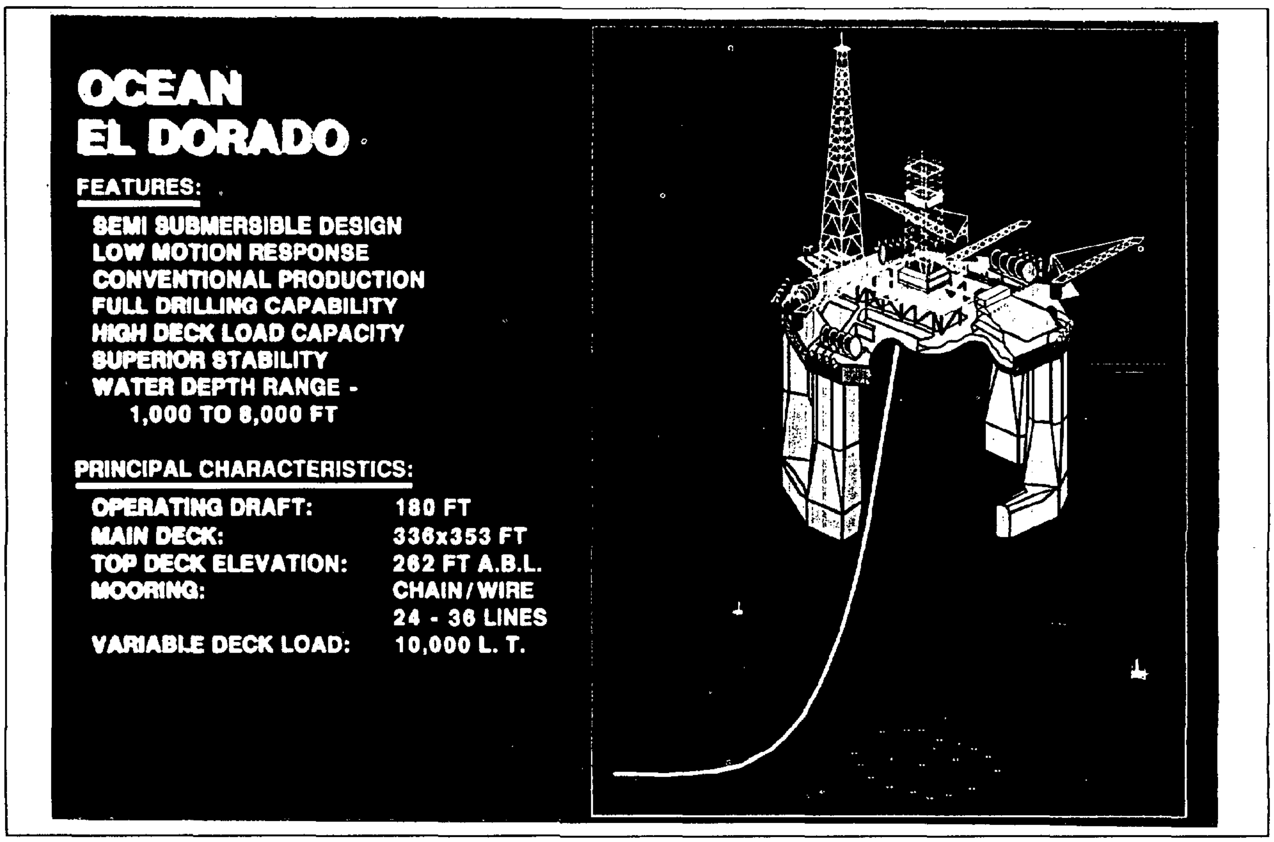

Figure 4. *ODECO El Dorado Platform.*

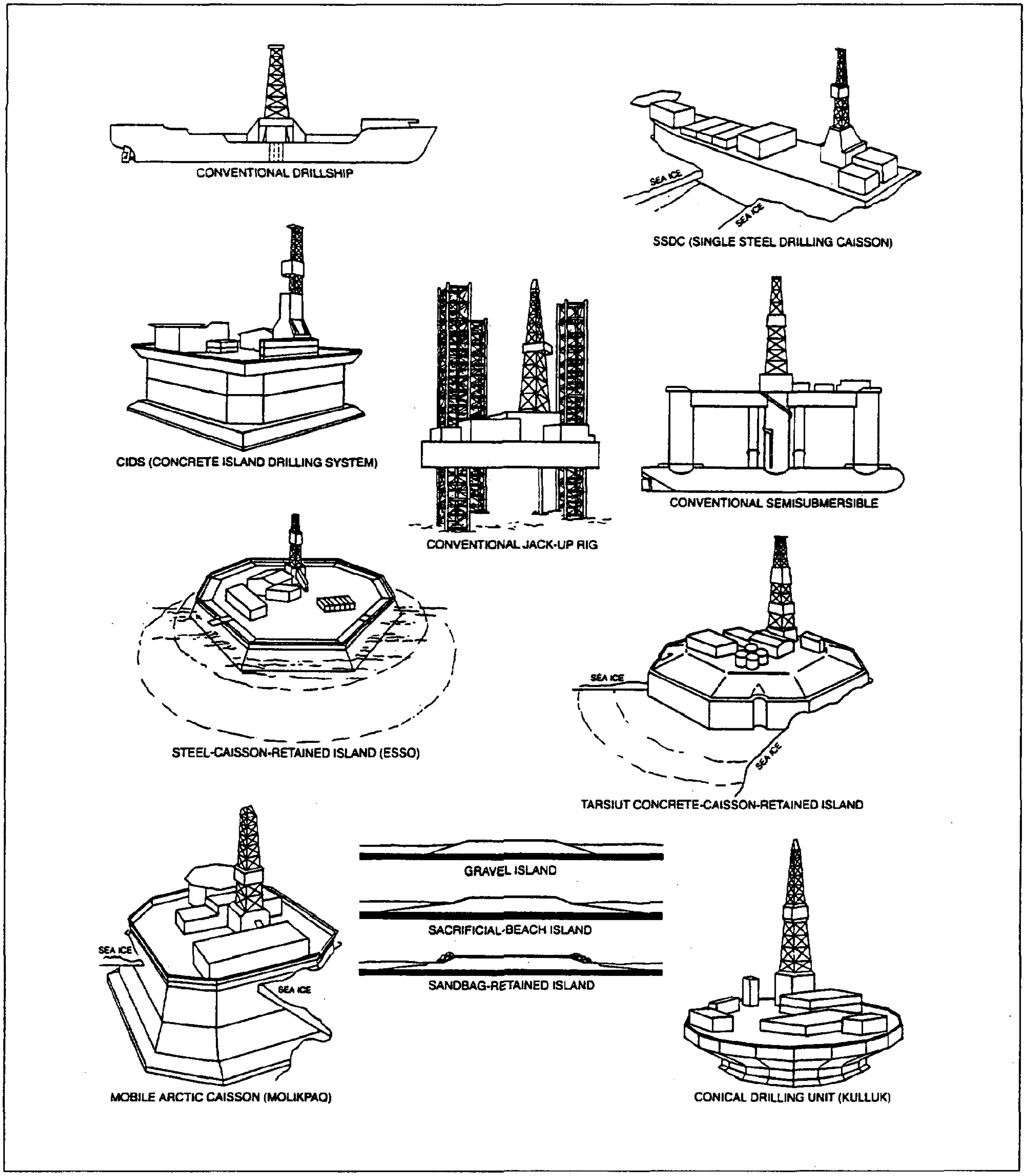

Figure 5. *Offshore exploratory drilling structures used in the Arctic.*

concepts that have been used, to date, for exploration. By using water depth as the limiting factor, current and future technological developments are more easily related.

For water depths between 0 to 100 feet, the current technology is adequate for both exploration and production. The basic types of systems used include earth-filled islands, caisson-retained islands, and submersible drilling vessels. Submersible drilling vessels, such as the Concrete Island Drilling System (CIDS), are typical of structures developed for these depths. The same three basic structural types may be used as well for production.

The technology for water depths between 100 to 200 feet is less defined and is currently being developed. Two types of drilling concepts are possible for this water depth depending on the ice thickness to be encountered. The first type would be a large conical gravity structure, such as the Arctic Cone Exploratory Structure (ACES), and the second type would be a floating drilling vessel, such as the Gulf Canada's Kulluk.[5] For production, a large fixed structure will be required, but towing it to the site and installation may present a new set of problems.

For depths greater than 200 feet the only currently available technology would be a floating drilling system, and because of large ice forces possible at these depths, this system may not be feasible. If it is possible to use a floating system for exploration, then a subsea production system would be an option for producing the field. The industry is gaining experience with subsea production systems, but a significant amount of work and field use outside the Arctic will be required before deploying such a system in the Beaufort Sea.

Arctic subsea soils present yet another environmental problem for both structures and pipelines. Structures and pipelines that rest on the sea bottom must have a firm foundation, and because of the presence of permafrost in the Arctic, the soils are much more difficult to work with. New technologies are being developed to keep the soil frozen to maintain a firm base for the massive structures necessary to withstand the large ice forces and to protect pipelines required to transport the product from offshore sites to shore facilities by encasing them in a protective frame.

U.S. Arctic Research Commission

Because of the vast potential for mineral recovery in the Arctic Region, the Congress of the United States created the Arctic Research Commission (ARC) under the Arctic Research and Policy Act of 1984. This Act assigned a number of responsibilities to the Commission. These include (1) recommending an Arctic research policy and priorities, (2) cooperating with the Interagency Arctic Research Policy Committee (IARPC) on development of an integrated 5-year plan for Arctic research, (3) recommending ways to improve logistic support of Arctic research, (4) handling of the information and data resulting from Arctic research, and (5) coordinating U.S. Agency programs on Arctic research.[6]

In the 4 years since passage of the Act, considerable progress has been achieved in meeting the Commission's goals. A comprehensive 5-year Arctic research plan has been prepared by the IARPC and steps are currently being taken to implement the plan and the priority research it recommends.[7] By autumn 1988, a document, "Five-Year Implementation Plan," is to be published. This document will further discuss and amplify the recommendations and will describe the efforts of the Government to carry them out. The IARPC Plan consists of three major technical sections. The Atmospheric and Oceans section emphasizes initiatives on sea ice and biological productivity. The Land section focuses on natural resources, engineering challenges, and research to improve understanding of how land environments respond to natural variation and human-induced changes. The section on People relates to their health, economics, and social environment and history.[8]

The IARPC, in consultation with the ARC, has developed and adopted a U.S. Arctic Research Policy, which includes an identification of U.S. interests and a statement of goals to carry out these interests. This research direction was used to put forth the 5-year Arctic research plan, and a matrix of the research priorities are shown in Figure 6.[9] The preparation and publication of the Research Policy and the Plan are only the beginning on an implementation process. The IARPC is conducting meetings on a regular basis to coordinate the research being conducted by Agencies within the U.S. Government, and are encouraging the focus to be placed on the priority subjects.

A dominant theme that has emerged from the Committee's efforts, thus far, is the need for long-term baseline data. While the collection of such data is not generally considered to be research, it forms a needed base for future research efforts and is essential to understanding global change. Stable funding and logistics support is required if these long term data bases are to be acquired and maintained. A workshop on Arctic data requirements necessary to address long-term needs was held this spring (1988) by the IAPRC.

RESEARCH TO ADDRESS NATIONAL ISSUES	NATIONAL ISSUES IN THE ARCTIC: ARCTIC AS A NATURAL LABORATORY	NATURAL HAZARDS	NATIONAL DEFENSE	CLIMATE AND WEATHER	ENERGY AND MINERALS	TRANSPORTATION	COMMUNICATIONS	RENEWABLE RESOURCES	POLLUTION	ENVIRONMENTAL PROTECTION	HEALTH AND ADAPTATION	NATIVE CULTURE
UPPER ATMOSPHERE AND NEAR EARTH SPACE PHYSICS	✓		✓				✓					
ATMOSPHERIC SCIENCES	✓	✓		✓					✓			
PHYSICAL AND CHEMICAL OCEANOGRAPHY	✓	✓	✓	✓	✓	✓		✓		✓		
MARINE LIFE SCIENCES	✓			✓	✓			✓	✓	✓		✓
GLACIOLOGY AND HYDROLOGY	✓	✓		✓	✓			✓	✓			
GEOLOGY AND GEOPHYSICS	✓	✓		✓	✓							
PERMAFROST RESEARCH	✓	✓	✓	✓	✓	✓		✓		✓		
ARCTIC ENGINEERING	✓	✓	✓		✓	✓	✓	✓		✓	✓	
TERRESTRIAL AND FRESH-WATER BIOLOGY	✓			✓				✓	✓	✓		✓
MEDICINE AND HUMAN BIOLOGY	✓								✓		✓	✓
SOCIAL AND CULTURAL RESEARCH	✓				✓		✓	✓			✓	✓
ECONOMICS	✓				✓	✓		✓		✓		✓

Figure 6. *Matrix of major research priorities. The tick marks indicate which research fields have high priority in relation to the national issues. They are arranged with the physical sciences on the top and the biological and social sciences at the bottom. This does not imply any order of priority.* (Taken from Reference 8)

Earthquake Hazards

The occurrence of earthquakes poses a hazard to offshore facilities unless appropriate engineering countermeasures are employed. To provide an adequate degree of safety at an affordable cost requires a knowledge of the energy properties of earthquakes, the influences of soil conditions on ground motion, and the dynamics of structures that are moved by ground shaking. In verifying the design of platforms that may experience seismically-induced loadings, the Minerals Management Service (MMS) requires that dynamic analyses of the structure be performed using earthquake motions appropriate to the site in question. Joint and member stresses from a "strength level" analysis must remain within allowable limits. The motions can be described by applicable ground motion records or by response spectra consistent with the recurrence period appropriate to the design life of the platform. For design purposes, preferably, site-specific studies are performed to determine the intensity and characteristics of seismic ground motion. Factors considered in the studies include the active faults existing in the region, the type of faulting, the maximum magnitude of earthquake that can be generated by each fault, the regional seismic activity rate, the proximity of the site to the potential source faults, the attenuation of the ground motion between these faults and the platform site, and the soil conditions at the site.

In lieu of a lengthy site-specific determination of the intensity and characteristics of seismic ground motion, the MMS permits the use of defensible standardized spectra applicable to the region of the installation site when such spectra reflect those site-specific conditions affecting frequency content and energy distribution.

When using the "time history" method for structural analysis, the MMS requires that at least three sets of ground motion time histories be used. These may consist of recorded or constructed (synthetic) earthquake time histories. The manner by which they are used must account for the potential sensitivity of the structure's response to variations in the phasing of the ground motion records. Ground motion descriptions are required to consist of three components corresponding to two orthogonal horizontal directions and the vertical direction.

As a second level of verification, some platform designs are required to demonstrate sufficient reserve capacity to prevent collapse, though not local failure, of the platform under a rare, intensive earthquake. One of the most difficult factors to be considered in designing or verifying offshore platforms in an active seismic area is the effect of earthquake loading upon both the structure and the soil. For deepwater facilities, the soils are subject to high hydrostatic pressure, which affects their seismic response. Therefore, data from instruments that record seismic ground motion onshore cannot be used directly for predicting offshore structural responses. However, seismic offshore ground motion records are scarce, and lacking a better alternative, onshore data are often used without consideration of their applicability to the offshore environment.

The MMS has initiated two research projects to better understand the effects of earthquake loading on the dynamic response of an offshore platform. The Seafloor Seismic Data Study project is being conducted by the Sandia National Laboratories to obtain and analyze seafloor earthquake motion data for seismically active areas off southern California. The program is focusing its efforts on the use of the Seafloor Earthquake Measurement System (SEMS) to collect and store seafloor seismic events.

Figure 7 is a diagram of the SEMS concept and illustrates the major subsystems and their interfaces. The Data Gathering System (DAGS) collects data from the Sensor Package, which contains the seismic sensors (accelerometers) and magnetometers. The Command and Recording System (CARS) is a portable shipboard unit that provides the operator interface with DAGS. The CARS records the data sent from DAGS on a digital cassette tape recorder for subsequent analysis. The Buoy Repeater Station (BRES) is a portable acoustic transmitter/receiver station that interfaces CARS with DAGS. The BRES takes commands from CARS and relays them to DAGS. Conversely, BRES receives data from DAGS and transfers them to CARS. All three subsystems are controlled by similar microcomputers.

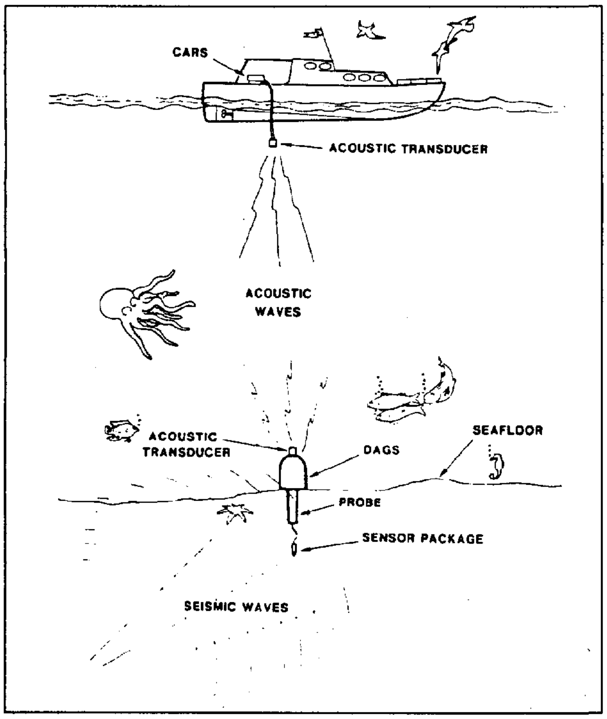

Figure 7. *Subsystems of SEMS concept for obtaining and recording subsea seismic events.*

As an adjunct study, a project entitled "Seismic Response Analysis of Offshore Pile Supported Structures" is being conducted by the University of California, San Diego, to assess the reliability of current state-of-the-art computational pile/soil interaction models used to predict the amount of energy transmitted to a platform. Seismic accelerograms will be obtained from SEMS units located on the seafloor and from onboard adjacent instrumented platforms. Data that Tokai University recently obtained from an instrumented structure offshore Japan will also be used in the study. It is hoped that these studies can attest to using the ability of present day standards to accurately predict platform responses and, if necessary, to propose changes to the standard to make them more reliable.

CONCLUSION

This paper has highlighted the major technologies that have been or are currently being developed to open the deep ocean and Arctic to offshore oil and gas operations. It has not been possible to present a complete account of all the technologies, such as subsea production systems, well control procedures, or oil spill and containment procedures that must supplement platform developments in order to proceed in a reliable manner; however, developments are progressing in these areas as well. Industry has historically demonstrated the ability to develop required technologies to meet the needs arising from a need to move into new areas of resources. Because of the extensive research being conducted by both Government and industry and the continual accumulation of frontier area experience, the future holds much promise for the development of these areas.

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Offshore Leasing Boundaries Along the Receding Alaskan Coastline

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ABSTRACT

Natural coastal processes and complicated legal questions present difficult resource-management problems for oil leasing in the Alaskan Arctic Ocean. The Beaufort Sea is eroding the Alaska coastline at an average rate of almost 3 meters per year, and offshore islands are migrating shoreward at an even more rapid rate. The Federal/State offshore-leasing boundary follows the retreating coastline shoreward. In addition, various interpretations of laws and court decisions allow several different versions of the boundary to be drawn from the same data. Cooperative shoreline surveys are conducted by the State and Federal Governments resulting in major mapping projects utilizing a series of tide stations, survey control, and aerial photography. The resulting data are being used to establish boundaries, update nautical charts, and provide information for scientific studies.

1. INTRODUCTION

Disputes between the Federal Government and the various coastal states over the location of Federal/State offshore boundaries have consumed the energies of lawyers and surveyors for many years and have left managers of oil and gas resources without the security of knowing exactly which submerged lands fall under their jurisdiction. Along the Alaskan Arctic coast, where the State and Federal Goverments have been in litigation over their common boundary since 1979, the questions of law are complicated by a very unstable shoreline. The disintegration of the permafrost coastline has become increasingly rapid in the last few years, as the area of seasonal open sea has increased and allowed a number of severe storms to make significant morphological changes. The solution to this problem appears to be in the cooperative establishment of a permanent fixed boundary that is not tied to an ambulatory shoreline.

2. DETERMINATION OF OFFSHORE BOUNDARIES

In 1953, the Submerged Lands Act (43 U.S.C. 1301-1315) granted to the states the rights to the natural resources of submerged lands generally out to 3 miles from the coastline of those states. This legislation left unanswered the many questions about how such a line would be projected from an irregular and dynamic coastline. The U.S. Supreme Court interpreted this law as incorporating the provisions of the 1958 Convention on the Territorial Sea and the Contiguous Zone (1964)15 U.S.T.(pt.2) that were applicable to an ambulatory coastline. That is, as the coastline changes, the baselines from which to measure the 3-mile territorial sea change. Since many questions regarding the interpretation of the 1958 Convention had little--if any--precedent, and the lands involved were potentially so valuable, many offshore-boundary issues were resolved only after protracted litigation. Today, one major suit is still pending before the Supreme Court: <u>United States vs. Alaska</u>, Original, No. 84.

In theory, the Outer Continental Shelf (OCS) boundary is determined by locating the most seaward, or "salient," points along the coastline and using these points to project the 3-nautical-mile offshore boundary. There are exceptions, however. For example, in the case of a bay or a rivermouth, a straight line is drawn across the mouth. The salient points and associated straight lines from which the boundary is projected are termed the baseline. Rules for when arcs are used and when straight lines may be drawn are based primarily on the provisions of the Convention on the Territorial Sea and Contiguous Zone. The State of Alaska and the Federal Government presently are not in agreement on a variety of legal issues regarding the application of the 1958 convention. As a result of differing interpretations of the application of international rules in the vicinity of the Beaufort Sea, the ownership of some acreage leased to oil companies will be resolved only when the Supreme Court hands down its decision in <u>United States vs. Alaska</u>. This case will have important ramifications for many offshore areas, not just the Beaufort Sea.

3. THE BASELINE STABILITY PROBLEM

According to recent studies by the U.S. Geological Survey, the western Beaufort Sea is the most actively eroding coastline in the United States. Excluding the Colville River Delta, shoreline retreat from 1950 to 1980 in the western Beaufort averaged 2.5 meters per year **and in some areas** approached 18 meters per year. On the other hand, accretion rates near the mouth of the Colville River Delta are as high as 20 meters per year. Since the offshore Federal/State boundary moves with changes in the shoreline or baseline, the leasing line is subject to frequent change in this area. While some may assume that lease boundaries are fixed, there is no guarantee that the lessor would not change by virtue of court action because of shoreline realignment.

4. THE VERTICAL-DATUM PROBLEM

The U.S. Supreme Court recognizes mean lower low water (MLLW) to be the vertical tidal datum defining the location of salient points. This means that acceptable shoreline surveys must show the MLLW line so that arcs and closing lines can be properly projected. This cannot be done with complete accuracy along the Bering, Chukchi, and Beaufort Sea coastlines of Alaska, because there are no permanent tide stations and no long-term tidal record from which to compute a datum. In order to account for all lunar effects, at least 19 years of continuous tide records are required. In northern and western Alaska, the longest record is for less than 2 years. In the Beaufort Sea, the problem is complicated by the fact that the range of astronomic tide during open water is less than one-half foot, while the meteorological effects frequently exceed 5 feet. In addition, the behavior of tides during the 9 months that the Beaufort Sea is frozen is different from that exhibited by the tides during the brief open-water periods. Surveys must, however, be done during open water because the shoreline is impossible to locate at other times.

5. THE FEDERAL/STATE BOUNDARY PROJECT

By the fall of 1983, it had become obvious to State and Federal managers that Alaska's offshore-boundary problems could not be solved in the near future by improved surveys alone or by continued litigation. Thus, the Federal/State Boundary Project was organized to aid in the collection of data on which each could base its determination of a leasing boundary and, at the same time, to make the best use of survey capabilities and determine where agreement could be reached upon the location of the boundary. Officials from the Alaska Department of Natural Resources; the U.S. Department of the Interior, Minerals Management Service; and the U.S. Department of Commerce, NOS; with occasional participation by other agencies, constitute the Boundary Working Group (BWG), which is the operational committee of the project. The BWG, equally funded by MMS and the State of Alaska, holds periodic meetings where project objectives, plans, and operations are formulated. Lease schedules, physical data, available funds, and agency directives are all considered by the BWG in planning field operations. The BWG fieldwork can be divided into three major categories: shoreline reconnaissance, shoreline surveys, and tide stations.

6. SHORELINE RECONNAISSANCE

In all areas that are scheduled for lease, an aerial reconnaissance is conducted to compare the existing shoreline with available nautical charts and other source materials. During this process, the State and Federal representatives determine to what extent there is agreement on salient points. Where there is disagreement, corrective surveys are recommended. All prospective salient points are documented with 35-mm still photography (nonphotogrammetric) and videotape.

7. SHORELINE SURVEYS

The areas recommended for survey are reviewed by the BWG for priority and available funding. The type of survey recommended depends on the nature of the differences observed during reconnaissance. If the problem is area-wide, a planimetric map is proposed showing both mean-high-water (MHW) and MLLW lines. This type of approach requires photogrammetric flights to be coordinated with the desired stages of tide. Combined with the accompanying tide-gauging and photo-control work, this approach is expensive. The advantage is that the product can be valuable to more than one user. The NOS has used the data from past projects of this nature to update the shoreline on nautical charts. The by-products, such as a densified horizontal control net and tidal benchmarks left at the tide-gauging sites, provide much needed survey data to aid other development. Almost the entire Alaskan Beaufort Sea shoreline has been photogrammetrically surveyed at least once since 1979, and approximately one-half the shoreline has been surveyed twice since that time.

If the problem is of limited scale, a simple on-the-ground topographic survey tied to tidal benchmarks could suffice. Small barrier-island features along the Beaufort Sea coast near Pitt Point have been surveyed in this manner.

8. OUTLOOK FOR THE BOUNDARY PROJECT

The goal of the Alaska Federal/State Boundary Project, when established in 1983, was to save money by working cooperatively in gathering factual data and determining areas where no disagreements existed. This goal has been largely achieved.

Several U.S. Senate bills have been introduced over the years to allow the Attorney General and the Interior and Commerce Departments, when in agreement with the various states, to establish a fixed boundary. None of these bills have become law. The boundary in the Beaufort Sea between Icy Cape and the Canadian Border could, however, be fixed by judicial decree under present Supreme Court litigation. Under a recently passed law--the OCS Lands Act Amendment of 1985--if a point is decreed by coordinates in a final decree of the Supreme Court, the point will remain fixed, at least until superseded by another decree.

Protectors of Federal interests have argued that a fixed boundary will permanently deprive the Federal Government of submerged lands that result from an essentially nationwide retreat of shorelines. This is particularly true along the Alaskan Beaufort Sea, where the coastline appears to be in severe disequilibrium. Resource managers argue, however, that a known boundary is necessary for an orderly leasing program. The decision to fix the Alaskan Arctic Ocean boundary will probably be made in the near future.

DEVELOPMENT AND ANALYSIS OF DCF COMPUTER MODELS FOR EEZ MARINE MINING

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ABSTRACT

The U.S. Minerals Management Service (MMS) within the Department of the Interior is responsible for administration and regulation of minerals extraction and development done under public lease on the Outer Continental Shelf (OCS). Traditionally, these activities have focused on mineral fluids (oil & gas). With the 1983 Presidential Proclamation establishing the U.S. Exclusive Economic Zone (EEZ), the MMS has been given the task of promulgating development of nonenergy solid minerals offshore (for example, cobalt-rich manganese, titanium, phosphorites, placers). This paper focuses on initial formulation and analysis of computer models that incorporate discount cash flow (DCF) methodology to be used by MMS as a tool to assist in determination of estimated fair market value for a variety of nonenergy marine minerals in the Federal Exclusive Economic Zone.

Within the general area of ocean minerals mining, the United States currently has no "offshore hard minerals industry" similar to those found in several foreign countries and few "off-the-shelf" discount cash flow computer models directly applicable to the OCS-EEZ Federal submerged lands where nonenergy marine minerals may be recovered. Development of such a model is required for Federal evaluation of minerals prior to allowing private industry timely accomplishment of research, exploration, and ultimate development of the EEZ strategic and critical minerals. Simultaneously, the MMS must strive to ensure receipt of fair market value of those minerals by the U.S.

Any DCF computer model officially used by the MMS, then, must necessarily properly incorporate geologic, engineering, and economic parameters while also providing a sound rationale for estimating marine mineral values prior to public leasing. The overall objective of any DCF computer model must be the aggregate economic appraisal, or valuation, of the nonenergy marine minerals within specific areas offshore from the continental United States or its holdings (such as Johnston Island). The model itself should adequately address the quantitative geologic estimates of potential resources/reserves within that area (i.e., the "mineral endowment" of any given Federal area), and apply the correct engineering and economic/tax/financial variables in order to estimate the return from that potential mineral extraction. Further, the model should be unbiased, statistically accurate and incorporate parameters that affect evaluation of those marine minerals.

This last factor is particularly important since most often any single Federal tract offered for exploration and development will have a "menu of minerals" contained within it, rather than a massive deposit of only one strategic mineral. There will be exceptions to this, of course; therefore any computer model must be able to adequately address both instances.

To accomplish this task, the MMS has taken several different approaches which, when integrated, should be able to estimate fair market value for virtually all strategic and critical minerals found in the OCS-EEZ. One of the initial approaches taken since the inception of the Office of Strategic and International Minerals (OSIM) was to formulate joint Federal-State Task Forces with interested coastal States. The first joint endeavors for the EEZ were the Interior-Hawaii and Interior-Gorda Ridge Task Forces formed in 1984. The latter was formed co-jointly with the States of California and Oregon, with participation from the Navy, Corp of Engineers, NOAA, EPA, and the Interior bureaus of U.S. Geological Survey, Bureau of Mines, and Fish and Wildlife Service plus the Federal co-chair from MMS. Subsequent to 1984 other joint Task Forces for offshore marine minerals included the States of North Carolina, Georgia, Alaska, and the Gulf States of Alabama, Mississippi, Louisiana, and Texas.

[1] Former OSIM location from 1984 until 1988 was in Long Beach, California.

In each of these individual Task Forces, either one specific marine mineral or several minerals are being reviewed for potential extraction and development. For example, the author previously has served as the Federal Co-chairperson for two different joint OCS-EEZ Task Forces -- both Georgia and North Carolina. In the offshore Georgia Task Force, there are two principal marine minerals being considered, each of which is different in sale, processing, and ultimate usage. Titanium, found in both the ilmenite and rutile ores offshore, has a far different development strategy than deposits of phosphorite, which are also quite extensive in breadth as well as quality of P_2O_5 content [9]. In North Carolina, however, several minerals exist, yet currently only the phosphorite deposits appear to be marginally recoverable at some time before the turn of the century except in the most optimistic cases [2].

In each of the above cases, however, the official Task Force found it suitable to have outside contractors complete initial economic feasibility studies (EFS) before the MMS considered the area for environmental evaluation or ultimate public leasing. Similarly, each area has had different expressions of interest by private industry in potential offshore development of its marine minerals. Each resulting EFS had to develop a DCF model to address the questions of mineral value offshore from each State. Further, the MMS has issued offshore exploration permits to two different firms in the Georgia area, while not firm has sought a similar permit for phosphorites offshore North Carolina. Other joint Task Forces, however, have had no EFS completed; for example, the Interior and State of Alaska endeavors have concentrated on proceeding with any required environmental work prior to public lease sale since offshore recovery of gold in the State of Alaska waters already exists.

Regardless of the initial approach taken by the separate joint Task Forces around the United States, an evaluation of each of the nonenergy marine minerals must take place [6]. That evaluation, done with the primary assistance of a DCF computer model for the various offshore minerals must consider physical parameters, such as quantity, quality, and location of ore bodies, and also engineering and economic variables such as tax rates, price, depreciation, depletion, equipment usage and replacement, and fees.

The following is a list of variable parameters that should be included in any DCF model to accurately address offshore marine minerals extraction and development evaluation:

Discount Cash Flow (DCF)
Variable Parameters

Mining Data

Average Water Depth   Average Ore Depth
Average Overburden Depth Matrix Density
Overburden Density   Average Mining Depth
Average Stripping Ratio
Maximum Stripping Ratio

Operating and Recovery Data

Number Days Operational   Total Cycle Time
Mechanical Availability   Total Load Time
Mining Recovery (%)   Mineral Grade
Production Hours per Year
Number Days Lost (annually)

Capital Costs of Project

Barges & Tugs   Matrix (ore) Dredge
Onboard Plant   Overburden Dredge
Beneficiation Plant   Artificial Islands
Pipelines   Vessel Berths   Calcination
Scalping Plant   Flotation Plant   Docks
Water Supply   Waste Disposal
[whichever combination of items that apply]

Operating Costs

Federal/State Royalties   Lease Fees
Port Authority Fees   Insurance Fees
Pre-production Permits   Subcontract Fees
Other Exploration & Development Costs

Indirect and Non-operating Costs; Other

Engineering Overhead   Accounting Costs
Depreciation   Depletion   Amortization
Taxes   Interest Payments   Storage Costs
Security Costs   Spare Parts/Inventory
Individual Mineral Price(s)
Rate of Change of Price - individual mined

The listing above is by no means intended to be definitive -- indeed, there are several alternative scenarios in which each of those variables could be used or not depending on the exact strategic marine mineral being examined, the sea conditions, the procedure used for extraction, any onboard chemical treatment, and the aggregate physical plant and its economics [1,2, 4,5,8,and 9]. For example, there appear to be only two fundamental types of dredges that are both feasible and economic in offshore usage -- the suction head dredge and the cutter head dredge. Each of these has different specifications and different economics in its usage.

In any case, the objective of the DCF model usage must remain to provide the decision-maker the most reliable, statistically unbiased results of overall economic appraisal which integrates both the physical and engineering/economic parameters. In most minerals cases today, the DCF rate of return on investment (aka DCFROR) is the methodological approach used to provide that kind of minerals evaluation (both offshore and onshore). Indeed, this author's experience has been that every major firm operating in energy and nonenergy minerals has some type of DCF model that allows cash flows, cumulative cash flows, and DCF rate of return measurements. Most of those computer models incorporate DCF methodology and use or have used models that have an internal random number generator (of some type) within them to allow unbiased, automated "Monte Carlo" repetitive passes for variable parameters which cannot be specified as single point values. For example, maximum overburden thickness may vary from some minimum to maximum on any given tract. Thus, different statistical tests may have to be performed (internally) by the DCF model in order to describe as accurately as possible the physical dimensions of the entire marine mineral deposit [6 and 7].

The following table reflects a hypothetical "mix" of nonenergy marine minerals which potentially could be extracted from the offshore Georgia EEZ area (excluding phosphorites). It also shows the estimated tonnages, prices, and potential revenues from the Georgia EEZ "menu of minerals" [9]:

Selected Marine Minerals - Georgia EEZ

Mineral	Annual Tonnes	% of Total	Sale Price $/tonne
Ilmenite	601,750	74.19	$ 46
Rutile	40,600	5.01	430
Leucoxene	81,460	10.04	385
Zircon	72,250	8.91	248
Monazite	15,040	1.85	570
	811,100	100.00 %	

Mineral	Annual Revenue	% of Tot. Rev.
Ilmenite	$ 27,680,500	26.88
Rutile	17,458,000	16.95
Leucoxene	31,362,100	30.45
Zircon	17,918,000	17.40
Monazite	8,572,800	8.32

As shown above, titanium (from both rutile and ilmenite ores) constitutes almost 80% of the estimated mined product, but would contribute less than half of the total revenues. While this result (estimated) would normally be expected where dollar-per-tonne market prices vary to such a large degree, any DCF computer model must be able to properly account for such a variance. Put differently, any DCF model which presumes to address fair market value of marine minerals must have within it the ability to integrate differences in price, costs, timing, and perhaps most of all, differences in the actual marine minerals themselves on each Federal offshore tract.

In reviewing several attempts at accurate development of cost models for deep ocean mining, it is noted that the Texas A & M study [4] concluded that "terms, conditions, and restrictions of licenses and permits for ocean mining are currently being generated. These terms, conditions and restrictions have an economic impact on any mining venture." [4, p. 108]. Since an economic impact could possibly result, the MMS has directed certain of the previously cited joint Task Forces to issue contracts under competitive bid for economic feasibility studies, as well as the promulgation of offshore regulations. This has been done under the authority of the OCS Lands Act, section 8(k)[6,p.138].

Separately, Interior's Bureau of Mines has been using an excellent computer model for undiscovered mineral deposits known as ROCKVAL, which combines specific probability estimates of geologists, mining engineers, and mineral economists within a statistical simulation package which has automated Monte Carlo passes. Their model is designed to account for most of the variables cited in this paper, although it does not appear to account for explicit offshore variable parameters -- such as flotation plant, types of dredge mining utilized, sea transportation costs, and complex onboard chemical treatment. Additions of such variables, however, are possible, as their model is programmed in FORTRAN 77 and is adaptable for inclusion of additional multiple variables.

Three other separate DCF models have been completed (or are being completed) by different organizations for offshore marine mineral evaluation. First, the NOAA Office of Ocean & Coastal Resources Management's Ocean Minerals and Energy Division has been developing a fairly unique DCF model (in Basic). Called the Seabed Minerals Project Finanical Analysis Computer Program (SMPFAP), their program is in three separate models (all interactive on any PC). Jugel [3] has been the principal person involved in testing, developing and debugging the models, and the three packages are designed for annual depreciation deductions, loans analysis, and DCF analysis. Each part may be used separately, although all three may be integrated to address a single marine minerals deposit. Finalization of these models is ongoing.

The NOAA model may be initially used where borrowing capital (obviously from sources external to the project/company) requires separate, but accurate, calculations prior to attempting integration into a DCF model for cumulative cash flows. Also as a separate submodel, the annual depreciation deductions allow the user to select a property that is best suited to the minerals project at hand. The user may then obtain an automatic printout of whichever class of asset depreciation range he or she has selected (3-, 5-, 7-, 10-, 15-, or 20-year property) and may change the life class through interactive prompts. In the DCF portion, net present values, payback periods, DCFROR (internal rate of return) are co-jointly addressed, and the user may (again, interactively) select either constant dollar or escalated dollar alternatives. An additional feature that enhances this model is the interactive prompting after the initial calculations which permit a full-scale sensitivity analysis so the user may alter any individual cash flow in any given year, change the period of mineral recovery, or perhaps best of all allow the user to return all data to a different computation option.

There are five different options for any given DCF calculation in the NOAA model. These include (1) NPV + payback and profitability index measures at 0% and four pre-selected standard rates; (2) all of (1), plus a single user specified rate; (3) zero percent and a user specified rate only; (4) DCFROR (Internal Rate Of Return) only; and (5) IROR, plus (1), (2), or (3) above. These options provide the user a large degree of flexibility in approach, especially when combined with the constant or escalated dollar options. While not as yet finalized, the NOAA model shows statistical accuracy and excellent flexibility for marine minerals calculations.

Another major DCF offshore marine model development was completed by a private consulting firm under competitive contract to the joint Interior-North Carolina OCS-EEZ Task Force in late 1987 [2]. Their model, composed of interactive modelization and separate cost centers with auxiliary spreadsheet listings, gives a fairly complete listing of all capital expenditures, costs, and fees that would reasonably be anticipated for a marine mining project. Although fully interactive, it is less sophisticated since it does not allow statistical Monte Carlo passes in any of the variable parameters. The user must have either a valid single point value, which is known in advance to be "the" value, or complete separate offscreen calculations prior to entering values into the model.

Printed results of this model's calculations, which only included offshore phosphorites, are accurate. Cash flows appear to be procedurally handled correctly (with borrowed capital or internal sources of funds). The model also provides internal rate of return measurements, allows users to specify startup years, and permits selection of debt-to-equity ratios to be used in any calculations. Although this DCF model was a fairly good attempt into an area where there are extremely few models available off-the-shelf commercially, this model was designed for a single marine mineral and its attendant locational costs and plant design were directed toward that final product. Thus, it was deemed to be somewhat less than adequate for multiple mixes of marine minerals offshore where alternative prices and costs exist (such as exists typically throughout the EEZ).

The third DCF model not developed within Interior or its bureaus has been done by Zellars-Williams (Z-W) in response and under contract to the joint Interior-Georgia EEZ Task Force in 1988 [9]. The Z-W DCF model has several interesting specifics which allowed a greater latitude in DCF model utilization for offshore minerals. Designed for multiple offshore nonenergy minerals, it is a more generic model than others examined.

Z-W initially began by recognizing the extensive, raw database which existed in various locations (e.g., Woods Hole Oceanographic Institute, U.S. Geological Survey Atlantic Marine Geology Branch, U.S. Bureau of Mines Minerals Availability Division, Georgia State University). Given that large database, and given the large menu of marine minerals that might prove to be economically feasible offshore Georgia, they chose Advanced Revelation as the appropriate software package -- especially since it is user friendly and may be expanded or edited easily for greater data assembly.

In their offshore mining development scenario, Z-W correctly derived large amounts of data from the various sources. These included offshore hopper dredge costs from the Bureau of Mines open file report for heavy minerals (placers)[8], and phosphorite data from MMS, Bureau of Mines, and the previously cited reports [1,2]. Previous studies had given strong indications of extensive heavy mineral deposits offshore Georgia, but database utilization and manipulation were important in order to integrate such diverse data properly.

Several separate DCFROR analyses were conducted for their four major phosphorite scenarios, and Z-W used their model findings to determine the optimum marine mineral extraction that could economically occur in this area. They also conducted several alternative DCF runs for the heavy marine mineral cases, and it is interesting to compare the variable parameters in each of these different cases.

In the first instance (phosphorites), the DCF model as specified by Z-W begins with production, price, and total revenue for each year of the project life. Allowance is also made for several potential years of the pre-production period which normally occurs in minerals extraction cases whether offshore or onshore. All production costs, both direct and indirect, are then listed -- again, for every year of the project. Separate line listings for total yearly cash costs, total yearly indirect costs, and total yearly production costs follow the previous breakdown, and a separate line item is shown for 'token' cash flow (defined in their model to be yearly revenues less all production costs). Next, investment follows, all scheduled in the pre-production years, together with construction capital and interest during construction.

During the production years that follow, the project analysis by Z-W correctly reflects principal dollars, principal repayment, any interest charges for capital (which could be either internal or externally borrowed capital), and working capital listings for every year of the project. Gross cash flow (after investment) is then computed, with the required adjustments of depreciation, depletion, and taxes. Separate listings for yearly taxable income, applicable tax rates, total yearly income tax, and net income after taxes are also reflected. Lastly, the Z-W model shows yearly cash flows, yearly cumulative cash flows, the DCFROR as a percentage of total investment, and the net present value at whatever discount rate had been selected together with the summed final NPV dollar value for the entire mineral project.

While each of the above parameters is variable both uniquely and over time, it is the direct production costs where we would expect to see differences in any economic model-building for various marine minerals. The Z-W DCF model complies with those expectations, and correctly reflects that ultimate sales of P_2O_5 phosphate requires costs be incurred for beneficiation rinsing, vessel loading, and handling and storage. Their model correctly specifies each of those, yet it is 'dynamic' in that it moves forward for the heavy mineral placers (in this case, the titanium-bearing ilmenite and rutile ores), and conducts a similar DCF analysis for them.

Examining a comparison of the two Z-W DCF models, which are virtually the same, it may be seen that the heavy mineral costs for on-board processing (wet mill) and platform processing (dry mill) and slurry transport costs are all present, while the unnecessary beneficiation costs for phosphorites have been properly replaced by them. This distinction allows the Z-W approach to be easily adopted to multiple marine minerals usages where valuation for deposits is sought by the owner -- no matter whether the owner is the State Government, Federal Government, or private parties. This DCF model correctly amalgamates all variable parameters cited in the text, fully accounts for all costs from whatever source, properly addresses cash flows, specifies all DCFROR's at alternative rates with final net present values, and provides a complete minerals project 'picture' of all revenues and costs in every year. Thus, this model appears to be one of the most complete done to date.

CONCLUSION

As cited in a recent article by John Smith and this author [6]:

> The program that is being developed by MMS/OSIM provides for a case-by-case examination of lease proposals based on industry interest, and national and local needs. These needs include reducing our import dependence on strategic and critical minerals...

In order to meet this challange, minerals in the Federal EEZ ultimately must be leased and developed. Offshore mining of nonenergy marine minerals, both sand and gravel, placers and others has been ongoing in foreign countries for several years with continuing technological and infrastructure development. We are seeing the beginnings now of a similar U.S. industry; for example, the interest in offshore Alaska placers and the public lease sale now scheduled for July, 1989 there.

Development of a DCF minerals model for valuation purposes would facilitate the development of those marine minerals.

Review, examination, and several man-month periods of testing DCF computer models described herein have been conducted. In order for the MMS to officially utilize (on a confidential, fair market value basis similar to other models) any DCF model for offshore marine minerals, that model must necessarily incorporate minimal statistical sophistication for unbiased accuracy in results, as well as proper integration of both physical and engineering/economic variable parameters similar to those cited in this paper. Several such models appear promising, yet they must be subjected to sensitivity testing, statistical review, and must ensure utilizable, unbiased results for the decision-maker.

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MINIMIZING ANCHORING IMPACTS DURING CONSTRUCTION OF OFFSHORE OIL AND GAS FACILITIES

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ABSTRACT

Reviewing the development proposed for the Point Arguello Field offshore California, one of the largest domestic oil fields discovered since Prudhoe Bay, has been a challenging experience for Minerals Management Service scientists. Due to the many unusual environmental conditions in this area, special precautions had to be taken to minimize environmental impacts and maximize operational safety. This paper describes the steps taken to identify impacts, develop requirements, and evaluate their effectiveness for one aspect of the permitting of the Point Arguello facilities. Our experience clearly shows that cooperation between biologists and engineers, and government and industry is the best way to assure that the final project is one which meets the concerns of all parties and is completed with a high level of quality.

MINERALS MANAGEMENT SERVICE

The Minerals Management Service (MMS) is the agency within the Department of the Interior responsible for the management of mineral resources on the Outer Continental Shelf (OCS) in accordance with the OCS Lands Act of 1953 as amended in 1978. The primary responsibilities of the MMS relate to the leasing of offshore Federal lands for oil and gas exploration and to the oversight of the subsequent drilling and development activities. Other functions of the MMS include collection of royalties from oil and gas leasing and production, and leasing of offshore Federal lands for hard mineral extraction.

MMS reviews each proposed exploratory drilling or field development project both for engineering soundness and for potential impacts to the environment. MMS employs specialists in many scientific fields including biologists, meteorologists, social scientists, geologists, and petroleum engineers to review varied aspects of each project. Once approved, these projects are inspected on a routine basis by petroleum engineers and technicians located in the MMS District Offices. Their job is to ensure operations are conducted in a safe and environmentally sound manner and, overall, to ensure compliance with MMS regulations.

Special requirements may be added to a given project by MMS to mitigate identified environmental impacts. In the case of the Point Arguello Field platforms, several special requirements were added to the letters of approval to minimize potential impacts to biological and fishery resources.

DESCRIPTION OF THE POINT ARGUELLO FACILITIES AND IDENTIFICATION OF ENVIRONMENTAL/ENGINEERING CONSTRAINTS

In 1982 Texaco and Chevron submitted development plans to MMS for the installation of three Point Arguello Field platforms (figure 1). These platforms were proposed to be installed in 400-675 feet of water and connected subsea to a system of consolidated offshore and onshore pipelines. Ultimate destination was proposed to be an onshore processing facility 20 miles from the central platform. Design capacity of the consolidated lines for the field and surrounding area is 250 thousand barrels of wet oil per day and 120 million standard cubic feet of sour gas per day. The Point Arguello Field is a giant domestic oil field with primary recoverable reserves estimated at 300-500 million barrels of oil. Installation of the platforms and pipelines to produce this field was proposed to commence in 1985 and continue through 1991. Production operations would be expected to last 30-35 years.

Several environmental and engineering constraints were identified in MMS's review of the project. The first constraint identified was the presence of numerous hard substrate features. These features, scattered throughout the area, interested both biologists and engineers. Government biologists had predicted in 1980 that these features might harbor sensitive communities and had required several biological surveys. To better understand the biology of the hard substrate features, site-specific surveys were required lease-wide prior to exploration and were required along both platform and pipeline corridors prior to submittal of development plans.

A total of five site-specific biological surveys were conducted in the Point Arguello area between 1982 and 1984. Both remotely controlled vehicles (RCV's) and manned submersibles were used to collect over 100 hours of color video and several

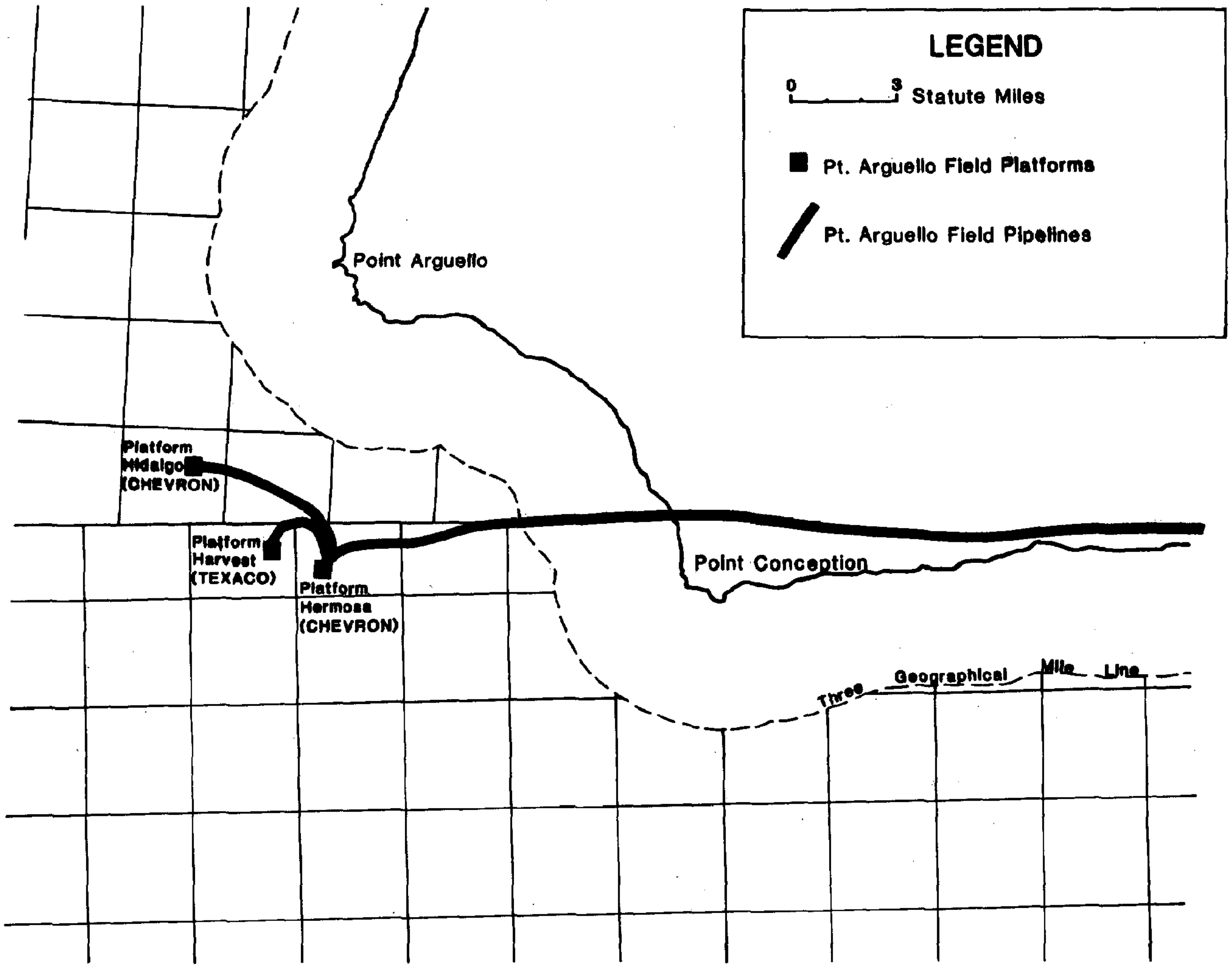

Figure 1. Location of Point Arguello Facilities Offshore Santa Barbara County.

hundred photos of the deep water communities. Manipulator arms attached to the submersibles collected rock, sponge, and soft-coral samples for species identification. The goal of these surveys was to characterize the biological communities and determine their sensitivity to proposed development activities. Results of the surveys indicated that, generally, the features located in the 300-400 feet water depth range and shallower were found to be predominantly sediment covered and exhibited younger, "disturbed" communities **[1, 2, 3]**. Scientists speculate that these features are periodically covered and uncovered by sediments due to seasonal storms or river runoff. A few smaller, but higher relief features located near Texaco's proposed platform and one large feature located south of Chevron's northern platform, proved to be of the most biological interest **[1, 4]**. These features in 600-700 feet of water were found to be free of sediment, possibly either due to prevailing currents or natural shapes of the features, and they exhibited longlived, diverse, biological communities. Several sponges and red gorgonia were identified which were predicted to be 25 years or older.

The presence of the features was of interest to the Chevron/Texaco engineers also, for the features provided a unique pipelaying challenge. To define the extent of the features and identify other potential geological hazards or constraints, several high resolution geophysical surveys were conducted by each operator. Shallow subsurface information associated with faulting, the location of possible gasified sediments, and shallow gas zones were also inferred from the geophysical surveys. Soil borings and sediment cores were taken along the pipeline route and laboratory tested to determine foundation characteristics, soil strength, and the potential for liquefaction. All these parameters as well as installation, seismic, and environmental loading on the pipeline were considered in the development of pipeline design and route selections. However, the layout of the hard substrate features in the vicinity of proposed platform sites made selection of four unobstructed pipeline corridors difficult, even without consideration for other geological or environmental constraints. Additionally, archeological interpretation of the geophysical records identified three potential cultural resource sites containing relief that also required avoidance.

In addition, environmental review of the installation activity identified potential conflicts with the commercial fishing industry. These conflicts would result if anchor scarring from the installation left the area untrawlable for some extended period of time. MMS's study of anchor scarring in other areas indicated that scarring was linked to the clay sediment type found at certain locations. However, excessive anchor scar lengths may also have been a factor. Though the soil type at the Point Arguello sites was silt rather than clay, MMS was still concerned that the pipeline activity create minimal anchor scarring and avoid unnecessary impacts to commercial fishermen.

The oceanographic conditions in the Point Arguello field area also warranted detailed study. Wave heights averaging 3 to 5 meters with periods of 5 to 10 seconds have been documented **[5]**, and winds greater than 20 knots occur 10-15 percent of the time **[6]**. These conditions have the potential to increase anchor scarring as well as magnify the stress to the pipeline during installation. Under favorable barge orientation (barge heading directly into prevailing sea), wave height in excess of 10 feet would require curtailment of the pipelaying operations. Based on the historical oceanographic data and curtailment plan submitted by operators, it was anticipated that up to 50% of actual field time would be spent waiting for oceanographic conditions to improve.

FORMING A MITIGATION STRATEGY

MMS's review of this project encompassed every aspect of the proposed activity from fabrication of the platform jackets, to installation of the facilities, and operation over the life of the field. However, one of the most challenging areas in the review of this project was the balancing of safety and environmental constraints for the installation of the offshore facilities.

The concern common to all of the environmental constraints identified was the need to carefully set anchors in fixed locations to avoid bottom anomalies and minimize slippage during placement or removal, which might lead to scarring.

Avoiding cumulative impacts from anchor scars was the primary focus. Impacts on the hard substrate from a specific anchor, while it could have locally significant impacts in the immediate area, would not be considered regionally significant given the actual area of the total anchor impact. However, given the proximity of the platforms and pipelines to the features, and the 1,500 to 2,000 anchoring events expected from the construction activity, it could be expected that a considerable area could be cumulatively impacted by anchor scarring if special precautions were not taken. Likewise, scars on soft sediments would not be expected individually to impact commercial fishermen, but given the number of anchoring events, a significant cumulative impact could occur if care was not exercised to minimize scarring.

Nevertheless, whatever measures were taken to minimize impacts to the environment, they could not compromise the overall safety of the pipeline operation. A pipelaying operation in deep water alone is an extremely complicated procedure in the best of conditions; MMS did not want to risk the integrity of the line, and its susceptibility to future leaks, in our attempt to minimize predicted impacts to the environment.

In developing conditions of approval, MMS had to also consider the enforceability of each requirement. Each measure needed to be an item that could be readily sighted or monitored in an onsite inspection, or could be monitored through review of data collected at the site. With these ideas in mind, the following conditions were included in the MMS Letter of Approval to each respective operator:

(1) Submit detailed anchoring plans. The corridors for anchor placement during installation procedures shall be selected to minimize impacts to hard bottom features and cultural resources to the maximum extent possible.

(2) Submit an Operations Curtailment Plan, which lists conditions (weather and other constraints) under which pipelaying operations will not proceed.

(3) Conduct post-installation geophysical surveying over the area of operation and submit a side scan sonar mosaic with survey results.

(4) Propose permanent mooring locations intended for consolidated use by supply and crew boats servicing the platform over the life of the project. Mooring sites shall be selected to minimize impacts to hard bottom features.

Detailed explanations of these measures and the corrective actions to be taken by MMS if not followed were contained in the decision document accompanying the Environmental Impact Statement known as the Record of Decision. These measures allowed MMS to oversee the pipeline installation through monitoring anchor drag and tension, and monitoring the location of anchors with respect to the identified anomalies and hard substrates. MMS could also ensure that operations were curtailed whenever meteorological or oceanographic conditions might impair safety of the activity, or increase seafloor impacts.

INSTALLATION PROCEDURES

The initial development plans for the Point Arguello Field called for the installation of 3 drilling and production platforms and approximately 37 miles of associated subsea pipeline. Installation activities commenced in June 1985 and continued off and on through October 1986. Pipelaying operations were conducted during a 5-month period between June and October 1986. Conventional installation equipment and methods were utilized during the emplacement of all project components.

Temporary seafloor disturbances associated with pipelaying operations are unavoidable. However, through an orchestrated effort, these impacts were limited to the identified soft bottom areas with only a few exceptions. To accomplish this, it was necessary for operators to convey the environmental significance of the area and the importance of proper anchor handling to their contract field personnel. Routine MMS inspections were conducted to further ensure that personnel aboard the installation barges and attendant anchor handling vessels utilized the Anchor Impact Mitigation plans.

Accurate positioning of anchors was obtained by coordinating the actions of the anchor handling vessels with the onboard positioning systems provided by marine surveyors. This was accomplished by the use of a radio positioning system, which provided continuous position of the anchor handling vessel in relation to the lay barge and objects on the seafloor. The repeatability of these systems varies, but most are within 20-50 feet. Depending on environmental conditions and water depth, the relative position between the anchor on bottom and the mobile positioning equipment at the surface may vary by up to 150 feet. Thus, it was possible to place an anchor with an accuracy of plus or minus 200 feet from a specific point.

The placement and retrieval of anchors were accomplished utilizing winches on the anchor handling vessels and pennant lines attached to the anchors. This arrangement allowed the anchors to be pulled and replaced in a vertical direction, thereby, minimizing additional seafloor scarring and anchor drag.

At times during the pipelaying installation, it was necessary to anchor near or pass anchor cables over hard bottom areas. In this case, the anchors were lifted off of the sea bed up to just below the anchor handling vessel. The lay barge would then increase tension on the anchor cable pulling the anchor and anchor handling vessel back to the barge. Once at the barge, the anchor handling vessel then headed out away from the barge in the direction of the new desired anchor location. This operation of pulling the anchor all the way up to the barge before running out to its new location tended to keep anchor cables straight and reduced the tendency for cables to drag on the seafloor.

Platform installations with the derrick barges produced significantly fewer anchoring events than the pipelaying operations. This is primarily because the lay barge utilizes the anchors to move along the pipeline route during installation. Also, only one pipeline is laid at a time, so for each corridor, the lay barge made two separate passes. In general, lay barge anchoring events tend to increase with decreasing water depth in order to maintain appropriate anchor scope to water depth ratios. The derrick barges, on the other hand, redeployed anchors only when necessary to move or change orientation. A typical derrick barge anchor drop consists of a depression where the anchor hits and of an associated gouge or scar (typically as much as 50-60 feet long) as the anchor is pulled and set. When the anchor is retrieved, any additional scarring is avoided by pulling the anchor either vertically or in a direction opposite from which it was set.

Long anchor scars occur when the anchor drags due to insufficient sediment strength or due to the type of operation. A lay barge sets up a number of anchor spreads and moves by pulling against them. The constant pulling generally causes much longer anchor scars than simply mooring a vessel over a fixed position, as with a derrick barge.

POSTCONSTRUCTION SURVEYING RESULTS

MMS has found that one of the most effective techniques to ensure compliance with our requirements is to require postconstruction surveys and reports that show exactly what was done in the field. In particular, our requirement for a side scan sonar mosaic of the area after construction has proved to be an excellent tool for installations such as this one. The mosaic provides a picturelike image of the seafloor clearly depicting scars, debris, and other features remaining on the seafloor after the construction.

At the time of writing of this paper, not all of the survey results and data were available. Postconstruction mosaics have been completed for the Hermosa to shore segment [7], which was the longest line, and preliminary information has been reviewed for the Harvest to Hermosa pipeline route and platform sites [8]. MMS expects to complete its review of the remaining survey within a few months. The following is based on a review of these surveys.

A total of 1,085 anchor drops were made for the Hermosa to shore pipeline installation [7]. The density of drops in shallow water (less than 150 feet) was probably three or four times that along the majority of the pipeline route. There is also a higher density near the platform, partly because of the other pipeline construction associated with Platforms Harvest and Hidalgo. The postconstruction survey report identified 682 bottom anomalies with 414 (60.7%) of the anomalies identified as anchor scars, 32 depressions as possible anchor scars, and 1 disturbed seafloor anomaly as a probable anchor scar **[8]**. They also mapped 83 cable drag marks (individual or zones) associated with anchoring. The other anomalies were construction features (i.e., pipelines, tap valves, probable mooring cables), isolated small outcrops, and unidentified objects. Three magnetic anomalies were also found that were not associated with the recent construction projects.

In the nearshore sandy environment, 250 anchors were dropped in waters less than 150 feet deep but only 5 scars (2%) remained in 1987. The area around this portion of the pipeline, which was buried through the surf zone, was impacted by numerous construction activities in addition to laying the pipelines. Based on this information, anchor scar longevity in this environment is believed to be measured in weeks or a few months.

Review of this information shows that the greatest number of anchor scars are short and that the number of anchor scars declines with increased length. One-third of the scars are less than 100 feet long and almost 80% are less than 500 feet. Only 4% of the scars are longer than 1,000 feet. This breakout indicates that, for the most part, conditions were fairly normal for the construction activity, with sufficiently strong sediments for a good anchor bite, no long storm periods to cause anchor drag, and no excessive dragging during retrieval **[9]**.

Along this longest segment from Hermosa to shore, six anchor scars were found to contact hard bottom areas out of the 1,085 anchors that were dropped (0.6%). Considering that only three of these crossed a major portion of an outcrop, and all were in the vicinity of the heavily constructed area around Platform Hermosa, this is a remarkably low incidence of impact. However, to determine the extent of potential hard bottom habitat impacted, on February 10, 1988, an RCV survey was undertaken on three mapped anchor scars and a cluster of cable scars in about 280 feet of water. Despite a number of passes over the area, no anchor, cable scars, or other unnatural bottom disturbances were observed. This report found that the bottom consisted of firmly packed silt and mud with evidence of ground swell, surface ripples, and sanding.

The preliminary results from the postconstruction survey over the Harvest to Hermosa pipeline route identified 277 anchor and 200 cable scars **[8]**. The mosaic indicates that anchor scars are as much as 10 feet wide and 100 feet long. The cable scars, in contrast, are probably less that 1 foot across and extend as much as thousands of feet long. Anchor scars are as much as several feet deep, whereas cable scars appear to be only inches deep.

CONCLUSIONS

The Point Arguello project pipelaying and subsequent surveying have increased our knowledge of the behavior of anchor scars in the deeper ocean environment. It has also allowed MMS an opportunity to evaluate new types of mitigation and determine their applicability for future projects.

Anchor scar longevity is thought to depend on the surficial sediment type and the intensity of the degradation process. These two variables are related because coarser grained materials exist in higher energy environments, whereas clays exist in much lower energy environments. Therefore, in most areas, anchor scars in deeper waters associated with finer grained material should degrade more slowly while scarring in the nearshore, higher energy, environment would be erased rapidly. As expected, fewer scars were observed in the nearshore sand environment than in the deeper water. We now have more evidence to suggest that the bathymetrically dependent surficial sediment distribution mapped by surveys can be used to predict anchor scar longevity.

Anchor scars in any water depth in this area offshore Point Arguello should be considered temporary based on the results from these surveys. Less than half of the anchor scars were evident from the pipelaying activity from Hermosa to shore when the survey was conducted less than 2 years after the construction. Also, virtually no anchor scars from the Platform Hermosa installation are visible on the 1987 data (2-year time period).

The mitigation as proposed and performed was successful in mitigating impacts to biological resources without compromising the safety of the operation. It had been anticipated that the anchor impact mitigation requirements placed on the operators could result in increased installation time and weather induced delays, and contribute major additional expenses. It was of concern to MMS that the additional time required to accurately position anchors in moderate seas might also result in prolonged installation induced stresses on the pipeline. These stresses were carefully monitored and calculated in the field and at no time were they determined to exceed allowable levels. In addition, the orchestrated efforts to minimize anchoring impacts did not result in significant additional installation time nor expense. It became apparant during installation that welding of pipeline joints on the lay barge and maintaining a stable pipeline at the touchdown point with the ocean floor were more sensitive to sea conditions than the operations associated with anchor placement.

As shown in the preliminary postconstruction surveying results, impacts to the hard-substrate features appear to be extremely small. We expect additional surveying results to confirm this. The cause of the three anchors that strayed onto the hard substrate is believed to result from a mapping error, rather than an operational error. Also, based on the distribution of the scars on the soft bottom, the relatively short lengths, the type of bottom sediments, and the fairly rapid degradation of scars, little, if any, impact is expected to bottom trawl fishermen.

We believe that much of the success of this installation is due to the conscientiousness of the operators in recognizing the environmental concern and accepting the challenge to overcome it. This type of mitigation requires a high level of coordination between biologists and engineers, government and industry. Projects such as the Point Arguello development demonstrate that operations are compatible with the environment when everyone works together.

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