Joining Forces With Industry

Proceedings
Third International Conference on Open Ocean Aquaculture

May 10-15, 1998 Corpus Christi, Texas

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Open Ocean Aquaculture 1998

Proceedings of the
Third Annual International Conference
May 10-15, 1998
Corpus Christi, Texas

Robert R. Stickney, Compiler

A Texas Sea Grant College Program Publication

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STATE OF TEXAS
OFFICE OF THE GOVERNOR

GEORGE W. BUSH
GOVERNOR

March 9, 1998

Greetings:

Welcome to Corpus Christi for the Third International Conference on Open Ocean Aquaculture on May 10-15. This conference, sponsored by the Texas Sea Grant College Program, provides a great opportunity for leaders in government, science and industry to meet, exchange ideas about aquaculture and work together to conserve and promote our marine resources.

I am pleased that you have chosen to hold this conference in Texas. The Texas Parks and Wildlife Department has been a leader in using abandoned oil platforms and discarded ships to create artificial reefs off the Texas coast. These reefs provide a home for many species of fish and a major tourist attraction for divers and sportsmen. By encouraging innovative and cooperative approaches between government and industry, we are making Texas a beacon state.

Laura joins me in sending best wishes for a successful meeting.

THE STATE OF TEXAS

Sincerely,

GEORGE W. BUSH

POST OFFICE BOX 12428 AUSTIN, TEXAS 78711 (512) 463 2000

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Introduction

Open Ocean Aquaculture'98 (OOA'98) was the third in a series of what have been annual meetings sponsored by various Sea Grant programs to delve into the state of our knowledge and explore what research and development needs exist to develop a mariculture industry in open waters. The first of these meetings was held in Hawaii, the second in New Hampshire, and OOA'98 in Corpus Christi, Texas.

Exposed culture systems of various types have been designed, tested, and in some cases put into commercial production in Europe and Asia. There has been some experimental work in North America as well. Such systems may float at the surface or they may be fully or partially submerged. Systems have also been designed that float at the surface in good weather but can be partially or fully submerged during storms.

The Gulf of Mexico currently has several thousand oil and gas platforms in place, all of which will at some time in the future be removed, or in some cases, dropped in place. Current Mineral Management Service regulations call for removal of platforms within one year after production ceases (though variances can be obtained when production is stopped temporarily as may occur when the global price of petrochemicals is low). When the wells under a platform become depleted, the structure may still have a useful life that can often be measured in terms of decades (some estimate that a properly maintained platform has a life of 50 years, while production may be terminated in 10 to 15 years). Clearly, the platforms represent a resource that could be of great value to those interested in offshore aquaculture.

Given the location of OOA'98, it seemed logical to have a focus on the potential use of oil and gas platforms as aquaculture sites, and much, though not all of the meeting was devoted to that topic. Of major importance was the need to examine the regulatory environment in both state and federal waters to determine what impediments would be faced by the mariculturist interested in utilizing either a producing platform or one that was out of production but not yet dismantled.

There was a great deal of discussion during OOA'98 about the regulatory environment, both in the formal sessions and in informal conversations. Many left with the idea that the regulatory environment would not be conducive to mariculture in conjunction with production platforms. Yet,

since the meeting, there has been such activity in at least Texas and Louisiana, both in state and federal waters.

Other topics of interest included economics, engineering, candidate species, and various aspects associated with the actual production of fish in net-pens and cages. The meeting was attended by a relatively small number of people, but it was highly successful in that the proper mix of people were in attendance. A flavor for the issues that were covered can be found in the pages that follow. While no follow-on meeting was planned during OOA'98, there continues to be interest in future gatherings of this type and the topic should certainly be revisited in the not-too-distant future. At such time that future Open Ocean Aquaculture meetings are planned, there may even be commercial or, at least, demonstration facilities in place that can provide a clearer picture of what the potential offshore mariculture entrepreneur might expect to face and what profit potential might exist.

Robert R. Stickney, Director
Texas Sea Grant College Program
October 19, 1998

Agenda

Opening Plenary

Rear Admiral Paul Gaffney, Chief, Office of Naval Research, Arlington, Virginia; Dr. E.W. (Joe) Friday Jr., National Oceanic and Atmospheric Administration; and Dr. Brian Belanger, Deputy Director, Advanced Technology Program, National Institute of Standards and Technology. Moderator — Dr. Robert R. Stickney, Texas Sea Grant College Program Director

Session 1 Background—Sociological and Environmental Issues

- Moderator — Win Thornton, WINMAR Consulting Services, Inc. Houston, Texas

Ann Bucklin, University of New Hampshire Director, New Hampshire/Maine Sea Grant Program. Progress and Prospects from New Hampshire's Open Ocean Aquaculture Demonstration Project.

Joseph McElwee, Managing Director, Turbard Iarthar Chonamara Teo., Galway, Ireland. The Sociological and Environmental Impacts of Open Ocean Aquaculture.

Michael De Alessi, Center for Private Conservation, Washington, D.C. Marine Tenure and Aquaculture in the Gulf of Mexico.

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- Moderator — Villere Reggio, Minerals Management Service, New Orleans, Louisiana

David A. Dougall, Manager, Environmental Affairs and Safety, Agip Petroleum Co., Inc., Houston, Texas. Platforms and Fish Pens — An Operator's Perspective.

Peter M. Smith, Sc.D., P.E., Waldemar Nelson International Inc., New Orleans, Louisiana. Northern Gulf of Mexico Mariculture Project.

Bernard J. Kruse, Minerals Management Service, New Orleans, Louisiana. MMS Liability Issues and Bonding Associated with Offshore Platforms.

Hal Osborn and Jan C. Culbertson, Texas Parks and Wildlife Department, Austin, Texas. Mariculture Options with Texas Rigs to Reef.

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Wilbur Johnson and Bill Breed, Oxy USA, Inc., Houston, Texas. Open Ocean Aquaculture — An Oil Company's Perspective.

Dr. Charles A. Wilson and Dr. David R. Stanley, Coastal Fisheries Institute, Center for Coastal Energy and Environmental Resources, Louisiana State University, Baton Rouge, Louisiana. Constraints of Operating on Petroleum Platforms as It Relates to Mariculture: Lessons from research.

Sebastian Belle, President, EconAqua, Groton, Massachusetts. The Move Offshore Costs, Returns and Operational Considerations from the Entrepreneurial Perspective.

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- Moderator - Neville Thomson, Marine Production Systems, Ltd., New Zealand

Neville Thomson, Marine Production Systems, Ltd., New Zealand. Offshore Aquaculture Development in Australasia, Four Issues to Overcome. A strategic assessment indicating economic aspects, infrastructure, technology and markets.

Frank Conforti, Solicitor's Office, U.S. Department of Interior, Washington, D.C. Liability, Regulatory, Policy Issues and Concerns Involved in Dedicating Platforms in Mariculture.

Dr. Gary Matlock, Director, Sustainable Fisheries, and Edwin Rhodes, Aquaculture Coordinator, National Oceanic and Atmospheric Administration, Silver Spring, Maryland. NOAA Fisheries and Aquaculture.

Clifford Goudey, Marine Advisory Leader, MIT Sea Grant College Program, Cambridge, Massachusetts. Design andAnalysis of a Self-propelled Open-ocean Fish Farm.

Gary Loverich, Ocean Spar Technologies, LLC. Recent Practical Experiences with Ocean Spar® Offshore Sea Cages.

Ralph Rayburn, Director of Intergovernmental Affairs, Texas Parks and Wildlife Department, Austin, Texas. Offshore Aquaculture from the Perspective of a State Regulatory Agency.

Panel discussion with speakers from Session 4 moderated by Neville Thomson.

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• Moderator — Dr. Anthony C. Ostrowski, Oceanic Institute, Hawaii

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Dr. Daniel Benetti, Andrew Clark and Michael W. Feeley, Harbor Branch Oceanographic Institution, Aquaculture and Engineering Divisions, Fort Pierce, Florida. Feasibility of Selected Candidate Species of Marine Fish for Cage Aquaculture Development in the Gulf of Mexico with Novel Remote Sensing Techniques for Improved Offshore Systems Monitoring.

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Michael Chambers, Oceanic Institute, Hawaii. Current status on the development of bluefin trevally (Caranx melampygus) and greater amberjack (Seriola dumerilii) for offshore aquaculture in Hawaii.

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Progress and Prospects from the University of New Hampshire Open Ocean Aquaculture Demonstration Project

Ann Bucklin
Director, University of New Hampshire Sea Grant Program
Professor, Department of Zoology
University of New Hampshire
Durham, NH 03824
and
Hunt Howell
Professor, Department of Zoology
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Abstract

Aquaculture will play an increasingly important role in meeting the global demand for fisheries products as the world population continues to expand and fish stocks approach their biological limits. Aquaculture will also contribute to economic and community development, particularly in areas such as New England, where wild capture fisheries are experiencing a crisis of unparalleled proportions. In order for open ocean finfish and shellfish aquaculture to become a reality in the next five years, a sizable capital investment by the private sector will be required. Before that is likely to happen, investors and commercial ventures must have reasonable assurance that the practice is biologically, technologically, economically, and socially feasible. The University of New Hampshire is currently engaged in a multi-faceted open ocean aquaculture demonstration project, involving researchers, outreach specialists, commercial fishermen, aquaculturists, and public educators. The demonstration project will provide a commercial-scale test site for applying the culture and grow-out protocols developed in recent research efforts. Additional goals include: to generate economic data and evaluate commercial feasibility; to quantify risk assessment parameters; and to educate future aquaculturalists, investors and the public about the biological, environmental and socioeconomic realities of open ocean aquaculture.

Introduction

Declines in the wild harvest of traditional fish species (cod, haddock, flounders) in New England have resulted in a regional fisheries crisis of unparalleled severity (Anonymous, 1993). Stocks are at record low levels, harvesters are having an increasingly difficult time making a living, products are scarce and expensive, and fisherman's cooperatives are finding it difficult to survive financially. There have been many responses to this crisis, including the implementation of management plans designed to decrease fishing mortality, direct aid to fishermen and their families, and a reduction in fleet size via a government program to remove vessels from the groundfish fishery. While all of these measures will help rebuild depleted stocks, it is widely acknowledged that the resource will not be able to support historical levels of effort. For this reason, long-term solutions must be found to produce more seafood, and to provide economic opportunities for harvesters that become displaced from the harvest fisheries. Among the most logical of the long-term solutions is the further development of aquaculture. This practice, which is the aquatic equivalent of agriculture, has the capacity to produce the needed seafood, and also to provide economic opportunities for displaced harvesters. Indeed, the successes of aquaculture ventures in many parts of the world has led to a universal recognition that aquaculture has enormous potential, and it is generally agreed that it will play an increasingly important role in meeting the global demand for fisheries products as the world population continues to expand, and fish stocks approach their biological limits. Aquaculture will also contribute to economic and community development in areas such as New England.

Documented successes in aquaculture throughout the world have caused a resurgence of interest in raising several marine taxa in New England, both for human consumption and stock enhancement. This interest, in turn, has resulted in an enormous amount of activity. Dozens of research projects designed to facilitate the raising of fish, shellfish, and macro-algae are underway; hatcheries (both experimental and commercial) have been built; numerous conferences and workshops have been held; and there have been pilot scale releases of hatchery reared fish for stock enhancement. While much has been accomplished, there are still significant biological, technical and socio-economic issues that will need to be resolved before aquaculture can become part of the solution to our fisheries crisis. Among the most significant of these issues is siting an aquaculture industry in New England. Our inshore coastal waters are already heavily used for recreation, commercial fishing, and shipping, so there will undoubtedly be some resistance to aquaculture development. For this reason, it's likely that at least some

aquaculture activities will need to take place in offshore areas where there would be fewer conflicts with existing user groups. The high energy (winds and waves) of such exposed locations present significant technical challenges in the design, testing and construction of aquaculture systems that are capable of surviving in these areas. In addition to these technical challenges, there are many biological, regulatory, and social problems that must be solved. The progress with technological and commercial development, the status of related sociological and legal issues, and the challenges facing us in our efforts to bring open ocean aquaculture to US waters have been summarized in two recent conference proceedings (Polk, 1996; Helsley, 1998).

Recognizing these challenges, scientists, engineers and outreach specialists at the University of New Hampshire have developed a comprehensive program in offshore aquaculture. UNH engineers have analyzed and physically modeled net pens, designed and tested mooring and anchoring systems, evaluated and tested construction materials, developed acoustical deterrents to marine mammals, developed materials which resist biofouling, and developed and tested offshore aquaculture structures (Gosz et al., 1996; Savage et al., 1998). UNH biologists have examined and refined culture techniques for summer flounder, winter flounder, witch flounder, yellowtail flounder, American plaice, Atlantic cod, haddock, oysters, scallops, urchins, and macrophytic algae (Howell, 1980; Johns and Howell, 1980; Johns et al., 198 1; Laurence and Howell, 198 1; Howell, 1983; Howell and Caldwell, 1984; Jones et al., 1991; Grizzle et al., 1992; Lesser et al., 1992; Lesser and Shurnway, 1993; Langan et al., 1994; Howell, 1996; Howell and Litvak, 1999; King et al., 1999). UNH social scientists and resource economists have evaluated the role of aquaculture in coastal communities, studying issues related to ocean management, and evaluating the fishing industry's views and interests in aquaculture (Gempeshaw et al., 1995; Robertson et al., 1996). And UNH outreach specialists have disseminated the results of this research to potential user groups, investors and the public. Numerous workshops have been held, an excellent communication network has been created, and the many partnerships with our outreach efforts are well coordinated. A major achievement of UNH extension specialists was the organization of an international symposium on open ocean aquaculture in 1996 (Polk, 1996) which was repeated in Hawaii (Helsley, 1998) and now Texas (this volume). These efforts ensures that all interested members of society are informed of our efforts, and that there are opportunities for interested parties to participate in our activities.

Research and demonstration efforts on cage design, anchoring systems, culture of finfish and shellfish species, and the role of the commercial fish-

ing industry by LJNH ocean engineers, biologists, and sociologists have provided the basis for UNH leadership in open ocean aquaculture (see Howell et al., 1997). We are now ready to move toward practical application of this technical capacity by means of a demonstration project. The demonstration phase is a critical step toward commercialization: demonstration of technical feasibility will attract private sector involvement; demonstration of economic feasibility will attract new investment. The UNH open ocean aquaculture demonstration project will test prevailing research concepts and equipment designs, will determine economic viability of these operations, and reduce the usual time lag between basic research and commercial application. A primary focus will be to scale-up the research endeavors of the past three years to commercial size, with the ultimate goal of determining the feasibility of open ocean aquaculture in New England.

The role of demonstration projects in the development of commercial aquaculture

In moving basic research to commercial application, the interim step of a commercial-scale demonstration project has proven invaluable. Such a model is credited with establishing the dominance of U.S. agriculture some 100 years ago. The Land Grant University concept was built on the premise that basic and applied agricultural research could be carried out and demonstrated through the University Agricultural Experiment Stations. Cooperative Extension agents and specialists then assisted with the transfer of the research-based information and technology to the commercial agricultural community. Several University/State-supported aquaculture demonstration projects have proven vital to the successful development of new industries. The most prominent include:

1. *Hybrid Striped Bass Demonstration Facility.* This demonstration site allowed scientists at North Carolina State University, in collaboration with commercial partners, to evaluate the feasibility of raising hybrid striped bass on a commercial scale. Approximately eight years of Sea Grant -supported research resulted in development of successful techniques to raise hybrid striped bass on a laboratory scale. The demonstration facility, funded in part by the National Coastal Resources Institute, proved this aquaculture venture could be successful economically. It resulted in the birth of hybrid striped bass aquaculture industry, which now includes 18 growers in North Carolina alone and had approximately $40 million in farm gate value in 1996.
2. *Wadell Aquaculture Center, Hilton Head, S. C.* This state-supported research and demonstration facility has been active in developing and testing culture techniques for shrimp, clams and oysters at commercial

scales. The shrimp aquaculture industry, in particular, has benefitted greatly from these projects both in terms of increased yields per pond-acre and total harvests. Scientists and industry partners work collaboratively at the demonstration ponds, testing a variety of species, diets, and harvesting techniques.

3. *Recirculating System Demonstration Facility at N. C State University.* This facility is designed to evaluate commercial-scale recirculating systems. Research conducted at this facility has allowed the development of aquaculture facilities in virtually any location, has reduced water use and effluent problems, and resulted in a dramatic increase in U.S. aquaculture production.
4. *Harbor Branch Oceanographic Institution Aquaculture Centerfor Training, Education and Demonstration.* This facility supports a comprehensive training and demonstration program on a variety of species including hard clams, shrimp, ornamental clown fish, flounder, grouper, conch and others. It includes an Aquaculture Development Park where scientists and commercial companies can collaborate in refining existing and developing new aquaculture species, systems and technologies.
5. *Offshore Summer Flounder Aquaculture Demonstration Project, Long Island, N. Y* This project was supported by the National Marine Fisheries Service - Fishing Industry Grant (FIG) program. Several different types of floating net pen cages were put into Gardiner's Bay and stocked with juvenile summer flounder. The demonstration project was designed to evaluate the survival, growth and economic feasibility of summer flounder grow-out in commercially available cages.

Two additional aquaculture demonstration facilities / projects are either in the advanced planning stages or have just been initiated. These include:

1. *The Aquaculture Technology Transfer Center.* This effort is a partnership between Rutgers University and Cumberland County College. When completed, this Center will have the capability of culturing a wide range of species at a commercial scale, including those possessing current aquaculture potential, suitable candidates for future culture, and species that possess important uses other than food consumption.
2. *Red Drum Aquaculture Demonstration Project.* This Sea Grant-supported project (Texas, South Carolina and Louisiana) involves research to optimize recirculating aquaculture systems for hyper-intensive production of red drum. The primary goal is to develop a commercial scale, high density, indoor fingerling production facility that uses minimal outside water. The demonstration part of the project will be done in conjunction with an industry partner and should resolve unanswered questions about the technological and economic viability of these recirculating systems.

UNH Demonstration Project Objectives

For open ocean finfish aquaculture to become a reality in the next five years, a sizable capital investment by the private sector will be required. Before that is likely to happen, investors and commercial ventures must have reasonable assurance that the practice is biologically, technologically, economically, and socially feasible. We have therefore proposed a multi-year Open Ocean Aquaculture Demonstration Project that will provide a commercial-scale test site, complete with infrastructure, in order to: apply culture and grow-out protocols developed in recent research, assess the economics of such operations, and measure the parameters related to risk assessment. Specific objectives of the UNH Open Ocean Aquaculture Demonstration project include:

1. Develop partnerships between cage manufactures, commercial fishermen, aquaculturists, regulatory personnel, and university scientists who will jointly participate in commercial-scale projects at the demonstration site.
2. Regionalize the project through meetings and workshops to ensure broad based planning of both the initial deployment and the long-term use of the site for a variety of studies and purposes.
3. Select and characterize the demonstration site, focusing on possible locations for the project near the Isle of Shoals and in nearby New Hampshire waters.
4. Obtain commercial aquaculture permits by synthesizing and presenting site information and proposed biological and technical methods, in the appropriate format and at necessary level of detail for the regulatory agencies.
5. Develop (in consultation with state and federal regulators) a site monitoring program of hydrography (temperature, salinity, dissolved oxygen, and transmissivity profiles), water quality (turbidity, suspended sediments, chlorophyll and nutrients), and benthic conditions.
6. Evaluate existing commercial-scale containment structures, select those suitable for use in the Northeast US, modify and improve them as necessary, and deploy them in a comparative, evaluative scenario.
7. Demonstrate the feasibility of open ocean aquaculture for summer flounder and blue mussel by stocking the fish into containment structures and growing the mussels using suspension culture technology.
8. Conduct detailed economic and sociological analyses of each stage of the open ocean culture process (i.e., hatchery culture, grow-out, cage design, environmental impacts, marketing, processing, insurance, etc.).
9. Transfer appropriate and workable technology developed at the demonstration site to interested individuals and groups.

10. Continue to use the site and its infrastructure to demonstrate the feasibility of open ocean aquaculture for additional species and combinations of species, for various techniques, cages, and deployment strategies.

Partnership Building and Regionalization

Involvement of regional representatives in the UNH Open Ocean Aquaculture Demonstration Project has been accomplished through a series of formal and informal meetings between technologists, scientists, regulators and commercial fishermen. Technical and scientific partnerships were fostered at a one-day regional planning meeting (held December 5, 1997 at the University of New Hampshire). The meeting was attended by scientists, regulators and administrators from throughout the northeast. Following presentations by UNH participants, there was an open discussion involving much give-and-take between participants and the diverse audience. We received .excellent suggestions that have been incorporated into the final project design, and many individuals indicated that they would like to participate in the project in upcoming years.

Project Leadership

Project management has also been established: a three-member executive committee has been elected by those who are participating in the project. Additionally, a regional Advisory Board, composed of regionally and nationally recognized experts in fisheries and aquaculture has been established. The Board will: a) broadly oversee the project; b) offer guidance and advice; c) assist in planning; d) ensure that the project is meeting its intended purpose; and e) ensure that tasks are being done on schedule. As envisioned, the Board will meet twice per year to resolve any problems, review progress, and plan future work.

Site Selection and Monitoring

The site of the UNH demonstration project has been selected by evaluating the oceanographic conditions within the region, and selecting the general area whose characteristics best suited the project (Fig. 1). The proposed site was discussed with members of the commercial fishing community to minimize potential user conflicts. Numerous decisions remain, including: exact cage placement and positioning, mooring configuration, and optimization for fish biology and behavior.

The geology of the New Hampshire inner continental shelf has been the subject of numerous previous studies, including seismic surveys, sedimentologic studies, and descriptions of the benthic communities. Bottom

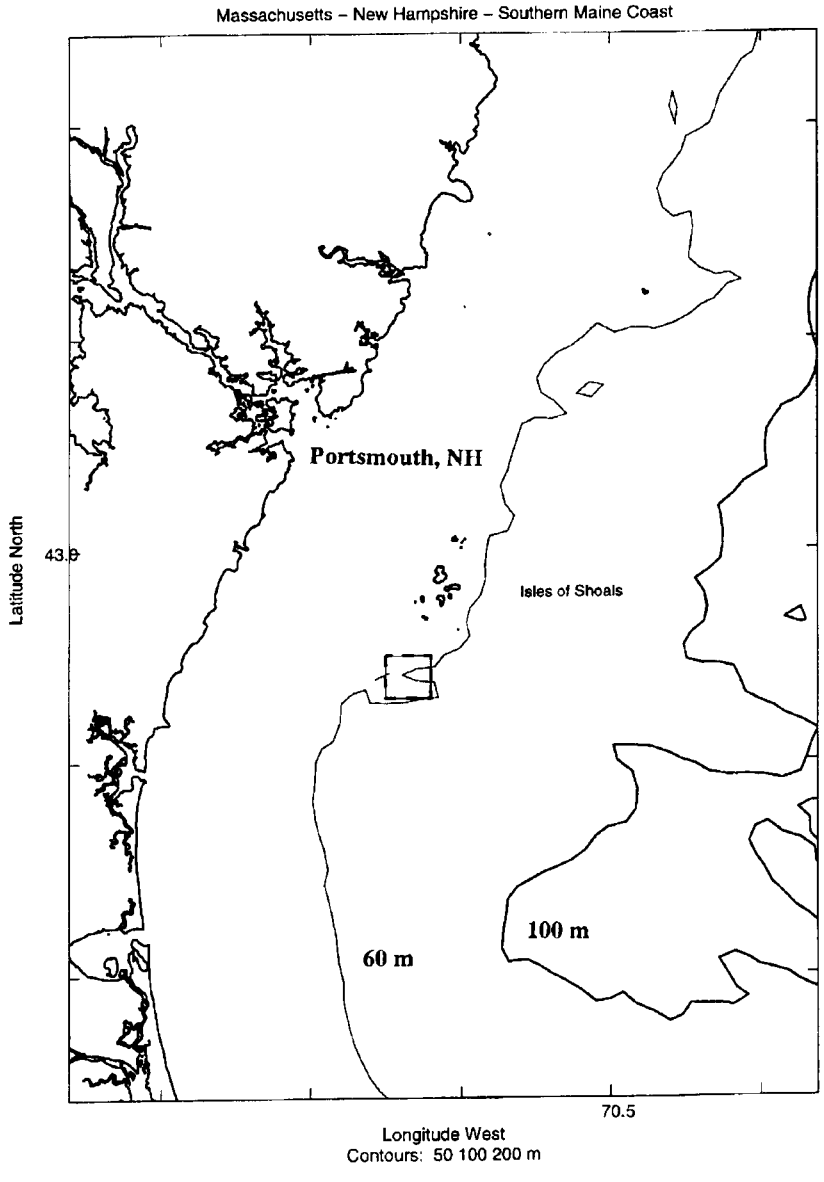

Fig. 1. Anticipated site of the UNH Open Ocean Aquaculture Demonstration Project (indicated by box). The site is about five miles off the New Hampshire coast line (darker line) near Portsmouth, NH in ~50 m of water. Depth contours are 60 m and 100 m isobaths. For additional information on the physical characteristics of the project site, see the website, http://ekman.sr.unh.edu/AQUACULTURE.

sediment types along the Maine and New Hampshire inner shelf (to the 100 in contour) have been mapped (see e.g., Kelley, 1997). Maine sediment maps are available through the Maine Geological Survey and the New Hampshire maps are presently being prepared. However, the existing data are insufficient for final cage placement decisions, and do not provide an adequate baseline for the required environmental impact monitoring of the aquaculture project. We have thus begun to collect, analyze, and map bottom geological and benthic data, in order to comply with requirements for complete descriptions of the seafloor at the test site prior to the demonstration project.

Both historical and real-time data are needed to characterize and monitor the water column structure of the New Hampshire inner shelf region in anticipation of placement of aquaculture cages. Of special interest are the seasonal evolution of salinity, temperature, and density; current structure; waves; suspended sediments; nutrients; and chlorophyll. Meteorological information and air-sea exchanges are also valuable. This information will assist in the selection of cage sites, will help us observe and report on any environmental changes in a timely manner, and will provide valuable information on how changes in the ocean environment determine rates of fish and shellfish growth. In addition, environmental data are required by government regulatory agencies for permitting and monitoring during cage deployment.

Data on regional ocean and weather characteristics have been gathered and general descriptions and climatologies of the Isles of Shoals area have been developed (Fig. 2). Our immediate goals include producing maps of the New Hampshire shelf area, depicting substrate characteristics and bathymetry. We will develop high-resolution spatial data bases for the immediate vicinity of the project site. We also intend to conduct a seismic survey, using side scan sonar and sub-bottom seismics. Monthly surveys of bottom sediments and benthic infaunal assemblages have been conducted during Spring and Summer, 1998. Physical oceanographic characteristics of the area (including vertical structure of water temperature and salinity, currents, tides, and wave conditions) have been and will continue to be assessed from archived data, numerical models, a fullyinstrumented moored buoy (Fig. 3), and ship-board sampling. Water column characteristics in the vicinity of the test site (including hydrography, suspended sediments, turbidity, chlorophyll a, particulate organics, and dissolved inorganic nutrients) will be measured throughout the demonstration project. During cage deployment, the epibenthos will be monitored using in situ time lapse video photography. A low-light camera and video recorder, fitted to a steel tripod

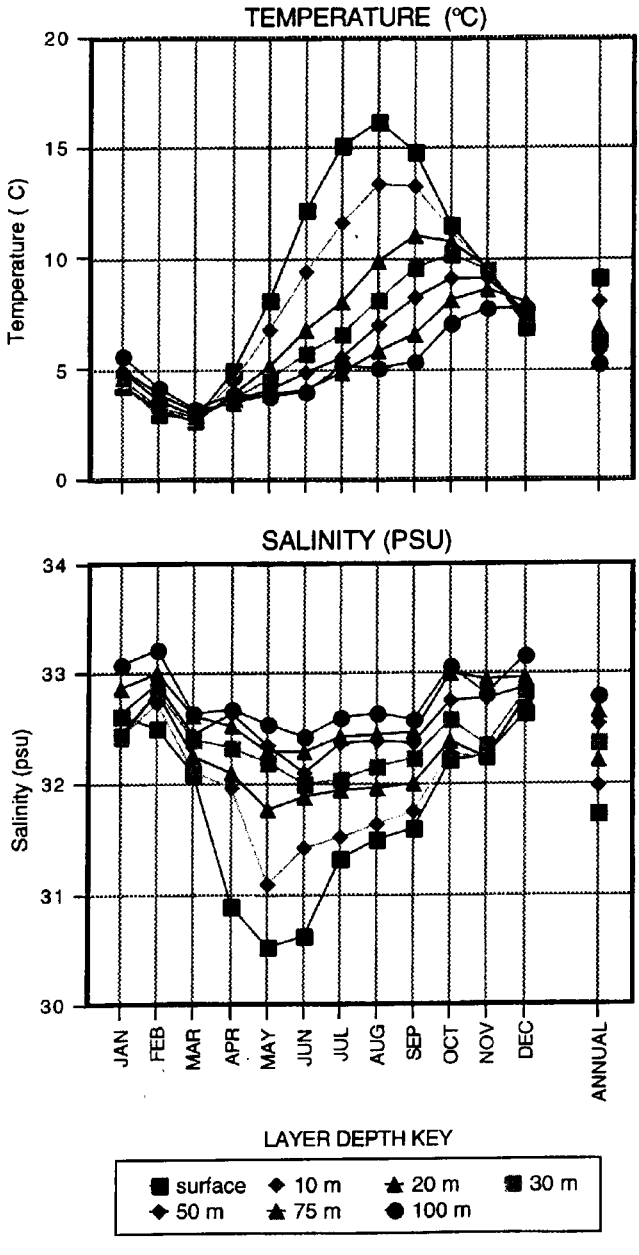

Fig. 2. Depth-stratified climatology for temperature (top) and salinity (bottom) for the period between 1900 and the present. The strongest temperature stratification occurs in August; the strongest salinity stratification occurs in May. During the winter months, the site is well mixed. Knowledge of ocean physics is crtical to understand and predict cage placement and fish health.

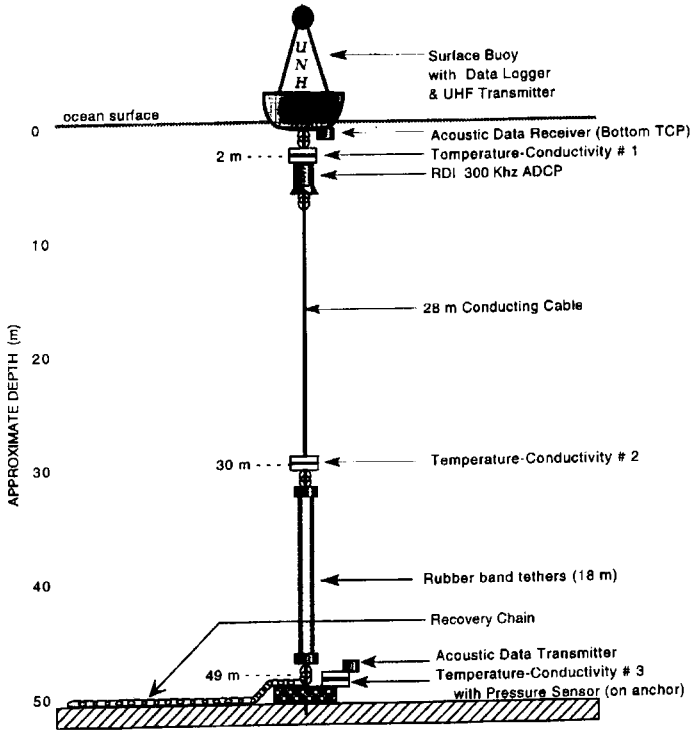

Fig. 3. Permanent oceanographic mooring to be deployed throughout the duration of the Open Ocean Aquaculture Demonstration Project. Data are relayed to a data logger in a surface buoy and telemetered to UNH. The moored array of instruments will include an acoustic doppler current profiler (ADCP) measuring flow at two-meter depth intervals; temperature and conductivity sensors at 2, 30, and 50 m; and a precision pressure sensor placed on the bottom (50 m). Instruments on this mooring and at nearby NOAA weather buoys will collect data on currents (direction and speed), hydrography (temperature, salinity and density), wave conditions (height and period), and weather conditions.

frame equipped with lights, will be deployed on the seafloor beneath the cages for periods of 24 to 72 hours. The abundance, behavior, and activity of all epibenthic species in the area will be documented.

Permitting

Efforts to obtain commercial aquaculture permits for the Demonstration Project site are ongoing. We currently anticipate that fish will be placed in cages during spring 1999; formal permit applications, with all required information, will be submitted during theautumn of 1998. In January 1998, we held a "Pre-Application Workshop" to discuss the permitting process

Table 1. Federal, state, regional, and local governmental agencies and programs with oversight responsibility for permitting and leasing sites for aquaculture in New Hampshire states waters. The overlapping responsibilities for aquaculture permitting in state and federal waters (see Goldberg et al., 1996) creates a "regulatory jungle" that is perceived to be a significant impediment to the growth of commercial marine aquaculture.

Regulatory

State agencies and programs

- N.H. Coastal Program
- N.H. Department of Health and Human Services
- N.H. Department of Environmental Services
- N.H. Fish and Game Department
- N.H. State Port Authority

Federal agencies and programs

- NOAA National Marine Fisheries Service
- U.S. Army Corps of Engineers
- U.S. Coast Guard
- U.S. Environmental Protection Agency
- U.S. Food and Drug Administration

Non-regulatory

- Commercial fishing
- Recreational fishing
- Commercial shipping and navigation
- Recreational boating
- Non-governinental and environmental groups

with representatives of the appropriate federal and state regulating agencies (Table 1). Representatives of other user groups of the shelf site (in particular, the fishing community) also attended and provided suggestions. Additional activities include presentations at public hearings and forums.

We thus have a clear understanding of the information needed to obtain commercial permits for open ocean aquaculture, and have developed a detailed plan for monitoring the site both before and during the demonstration project. Several oceanographic cruises have been made to the site to collect the needed data, which will be included (along with detailed descriptions of the work to be performed) in permit applications. A key result of this work will be the development of a standard set of procedures, required data, and timetable for permit application procedures.

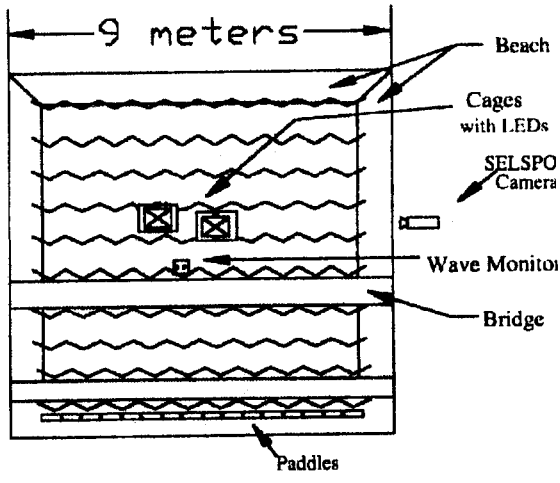

Fig. 4. Diagram of a scale model of a surface cage in the wave tanks at the UHN Ocean Engineering test facility. The cage is subjected to excitations (waves and currents) at appropriate scales and intensities; cage responses are observed and quantified. Both cage performance and potential impacts on the cultured fish will be evaluated.

Selection of Containment Systems

Two containment structures will be deployed for the Demonstration Project: one will be primarily a surface cage and one will be primarily a submerged cage. Each will have a flat bottom (approximately 170 m' in each cage) and accommodate about 6,000 summer flounder. Over the duration of the project, the fish cages may be exposed to high environmental loads (see Loverich and Gace, 1998). In order to predict cage behavior in strenuous physical regimes, 1/20 scale physical models of the fish cages are being tested in the UNH wave/tow tank Fig. 4). During these experiments, cage sea-keeping responses to average and extreme conditions are measured, cage motions are recorded, mooring and structural loads are inferred, and the relative movement of cage and seawater are ascertained to characterize the motion environment of the contained fish.

In addition to cage design, mooring design and deployment are critical to the Demonstration Project's success. There are a variety of mooring designs, each with its own advantages and disadvantages. Tension-leg moorings may be most desirable for the UNH project since they minimize the costly footprint area. However, multi-point and straight-chain moorings, and mooring lines with compliant segments will be considered and compared for both surface and subsurface cage positions.

Computer modeling also plays an important role in the design of struc-

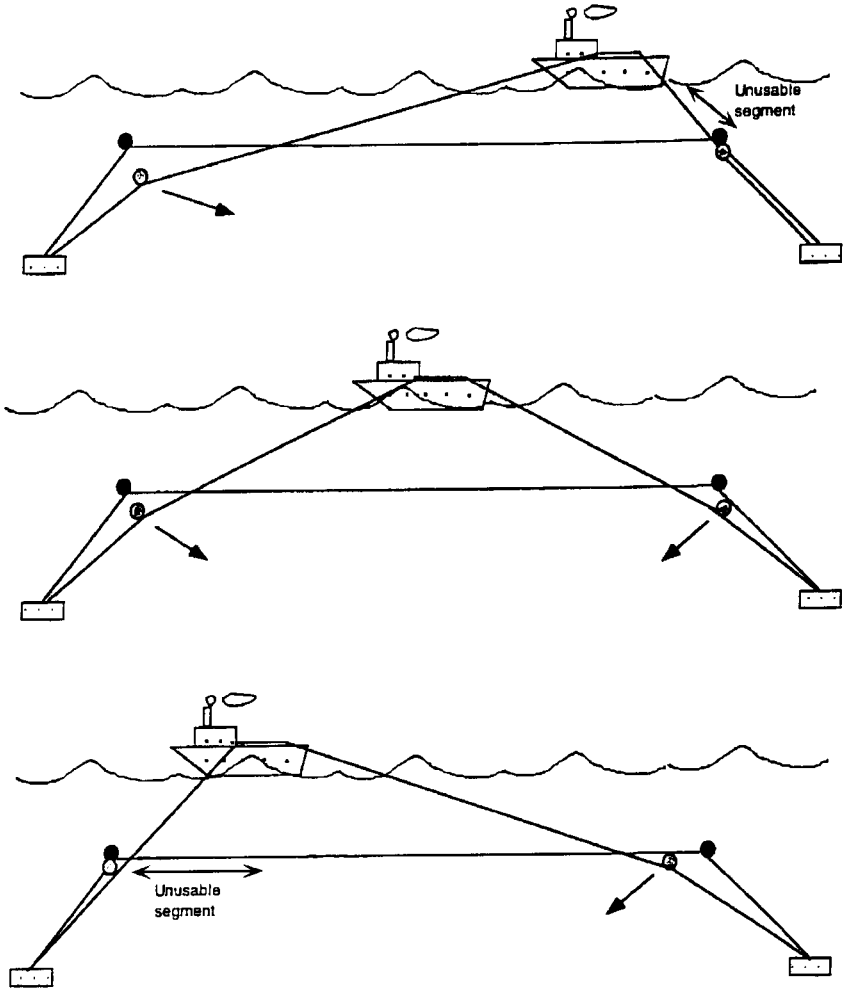

Fig. 4. Modeled responses of the containment structure to excitation from wind, waves and currents. Numerical analyses allow prediction and assessment of the impacts of ocean forces; the models can be used to predict actual cage responses. Dynamical monitoring of the cages during the UNH Demonstration Project will allow refinement of the models.

turally sound and reliable fish cages (Gosz et al., 1996; Gignoux et al., 1998). Models may predict the dynamic response of a cage subjected to complex current and wave loading and may reduce the risks of construction and testing of prototypes (Fig. 5). Based on a finite element computer program developed at UNH (Gosz et al., 1996), finite element analysis models of full-scale fish cages - with their associated mooring systems - will be developed. These models will be used to predict the dynamic response of the cages and to analyze deformations and stresses in their structural components.

Cage modification and deployment

Modifications to existing commercial cages will be made by the engineering team to suit the biological and environmental requirements applicable for our selected site. Selection of the cages for comparative deployment as part of the Demonstration Project will be based on both the physical and computer modeling results, with full consideration of the sociological, economic, and biological aspects of the project.

The selected containment structures and mooring systems will be delivered to the Portsmouth (NH) Port Authority in modular components, and final assembly will be completed at a nearby waterfront location. Deployment of the mooring system (including anchoring, leg positioning, and any final adjustments) and the cages will be done in association with a contracted marine construction firm, which will provide handling equipment (barges, onboard cranes, and winches) for this purpose.

Monitoring and Maintenance of Cages

Throughout the Demonstration Project, both the excitations (wind, waves, and currents) and the cage responses will be monitored, using measurement systems (accelerometers and pressure transducers) integrated into the cage system. Since the cages will initially be used to raise bottom-dwelling flatfish, the motion of the cage bottom is an important environmental parameter affecting the fish behavior and growth. It will also be essential to monitor loads in the mooring lines to verify the dynamic models, assess fatigue, and guide maintenance. All of these data need to be available on a real time basis and therefore retrievable from the site via a telemetry link.

Planned maintenance over the duration of the Demonstration Project will consist of regularly-scheduled inspections, biofouling removal, and incidental repairs. A diver will perform weekly visual inspections of the overall condition of the cage, including: mooring lines and nets, predator nets, evidence of fatigue in pen structure, biofouling, and fish mortality. Once a month, the anchors for all the mooring lines will be inspected for signs for

dragging by a remotely operated camera. The nets will be cleaned by water jets several times during the project. A contingency plan will be developed to respond to catastrophic events. This plan (involving federal, state, and local agencies, commercial fishermen, and UNH resources) will be modeled after the oil spill response strategies developed by UNH in cooperation with state officials and private industries on the New Hampshire coast.

Open ocean cage culture of summer flounder

Summer flounder *(Paralichthys dentatus)* was selected for use in the UNH Open Ocean Aquaculture Demonstration Project after consideration of a number of species, including also: winter flounder *(Pleuronectes americanus),* Atlantic cod *(Gadus morhua),* black seabass *(Centropristes striatus)* and tautog *(Tautoga onitis).* The selection criteria included: high likelihood of fish production at the required time; available laboratory and hatchery space for production; survivability over temperatures ranging from 0 to 18°C; and sufficiently high market value.

Summer flounder met more criteria than any other species. Great Bay Aquafarms, Inc. (Newington, NH) produces juveniles on a commercial basis, thus nearly ensuring the availability of fish to stock into the containment structures. Researchers at the Universities of Rhode Island and New Hampshire have extensive laboratory experience with the species (e.g., Johns et al., 1981; Howell, 1983; King et al., 1999), and a demonstration production project represents a logical "next-step" for these research programs. In addition, there are major aquaculture research programs for a congeneric species (P. *lethostigma)* in the southeastern United States (Waters, 1996). The species is valuable relative to most other flounder species, particularly if sold live to East Asian markets. However, summer flounder are not tolerant of ambient winter water temperatures in northern New England, requiring the species to be placed in the net pens only during the warmer portion of the year.

Six thousand summer flounder juveniles, 500 g in weight, are being produced by Great Bay Aquafarms for this project following standard hatchery procedures. Just prior to stocking in late May, when seawater temperature reaches I 01C, we will measure and weigh a representative sample of fish to obtain initial sizes. Prior to moving the fish from the hatchery to the net pens, UNH veterinarians will conduct a thorough diagnostic study of the fish, and certify that their movement into the pens will not introduce any pathogens into the natural environment. Fish will be moved from the hatchery to the net pens in insulated seawater containers.

Once in the pens, fish will be fed daily (approx. 3% of total biomass per day) on a pelleted, formulated diet (approximate composition 15% fat, 50%

protein, 35% carbohydrate). Pellet size provided will increase as the fish grow. Daily observations of feeding behavior will be made, and once per week SCUBA divers will check the pens for damage and any fish mortality. At biweekly intervals, a random sample of fish will be removed from each pen, weighed, measured, closely inspected for any health problems, and returned to the pen. This will allow us to monitor growth, food conversion efficiency, and health of the fish. Based upon our previous research, we anticipate that fish will have a feed conversion ratio of about 1.5, and that they will grow to nearly a kilogram by October or November when the fish will be harvested and marketed.

Fish health will be monitored, and any problems diagnosed and treated, by UNHveterinarians associated with the project. A representative sample of fish will be inspected before the fish are moved from the hatchery into the pens. Transfer will not occur until a health certificate is obtained. Fish will be observed daily during feeding. Any abnormal behavior (reduced feeding, lethargic swimming), or any abnormal appearance (dark coloration, lesions, fungus) will be reported to UNH veterinarians associated with the project for immediate diagnosis and treatment. In the absence of any problems, a routine veterinary inspection of a representative sample of fish will be done every 6 weeks after stocking. The only antibiotic that will be used is oxytetracycline. In this event, it will be added to the diet at the rate of 75 mg/kg of fish/day.

Open Ocean Culture of Blue Mussel

The UNH Demonstration Project will include culturing blue mussels (Mytilis *edulis)* using submerged, high tension, suspension culture techniques similar to methods used in Canada and New Zealand (Bonardelli and Levesque, 1996; Fig. 6), but never before used in the U.S. Our objective is to establish a test system for open water, submerged suspension shellfish culture in New England that is applicable to several species and other site locations.

A field study will be conducted with the assistance of Great Eastern Mussel Farm (Tenants Harbor, ME) during 1998 to determine optimal times and places of spat collection. The time of peak larval abundance in coastal New Hampshire waters (probably June-July) will be established by bi-weekly plankton tows. Spat collection ropes will be deployed, monitored weekly for spat settlement and density, and left in the collection areas for ~ 1-2 months. The optimal settlement sites and time will be correlated with environmental parameters. This initial study will help us optimize our seed collection efforts in 1999, in order to maximize the quantities of mussel seed collected.

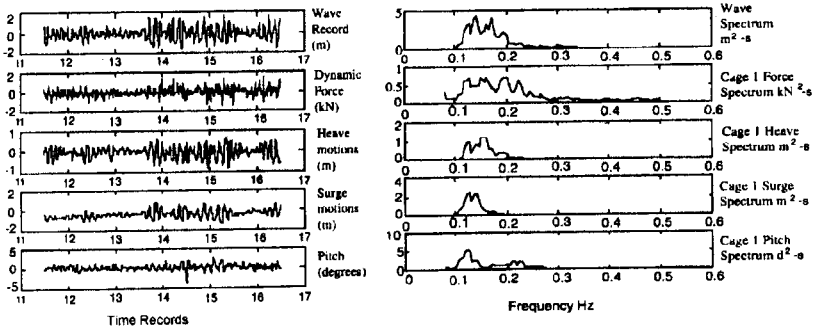

Fig. 6. Vessel tending a long-line culture system for blue mussel. The lines are taut, minimizing the likelihood of marine mammal entanglement. Harvesting is done from a specially equipped vessel that steams along the length of the long-line, removing the mussels without necessitating removal of the entire system. (Figure courtesy of J. Bonardelli, G.R.T. Aqua-Technologies, Ltd.)

A long-line culture operation for blue mussel will be established in mid-summer, 1999. A single, 100-m long, subsurface, high tension, suspension culture system will be moored at the aquaculture site under the direction of G.R.T. Aqua-Technologies, Ltd. (Riviere-au-Renard, Quebec, Canada). Configuration will be tailored to the site characteristics, direction of current flow, and cage design and configuration.

Since long-lines may present an entanglement hazard to Northern Right Whales, the system will be designed to eliminate those factors thought to cause Right Whale - fishing gear interactions. In addition, the proposed aquaculture site is considered a "low risk" site (personal communication, S. Kraus, New England Aquarium). In the past 20 years, no Right Whales have been observed in the area and only a single sighting has been reported several miles seaward of the site. The main line will be designed for high visibility (i.e., line thickness and color) and high tension (i.e., no loose lines in the water) Only one line will run vertically to the surface (to a buoy) and it will have a breaking strength of less than 300 lbs. Mussel socks, which will be suspended vertically from the high tension main line, will be attached with break links with breaking strengths of <300 lbs. The site will be visited daily during Right Whale migration (May through October). The initial deployment, with only a small quantity of seed suspended from the main line, will provide valuable information on marine mammal interactions with the culture gear and will guide our commercial-scale deployments in the second year.

The top 15 m and the bottom 5 m of the water column will not be used

as a growing zone in order to avoid surface (eider ducks) and bottom (sea stars) predators, and wave action. The submerged backbone with attached mussel ropes will remain in place until the mussels reach market size (approximately 18 months from settlement). Mortality, growth, production and condition index will be monitored monthly during most of the year, and bimonthly in winter.

Expected time of first harvest will be in November-December 2000, approximately eighteen months after spat settlement. Estimated production is 16 kg/meter of mussel rope. Thus, the submerged backbone of 100 m will support 840 m of mussel rope, capable of producing 13,440 kg (29,568 lbs) of mussels valued at $.75/lb for a total of $22,176 for each 100 m of longline. Data on food availability, seston flux and mussel growth and condition index will be used to develop a production/carrying capacity model that will have an economic assessment component.

Economic and Sociological Analyses

The economic element will focus on the actual monetary costs accrued throughout the life of the demonstration project. Results of prior economic analyses will be considered (see e.g., Anderson, 1996; Croker, 1996; Forster, 1996; Bonardelli and Levesque, 1998). Two categories of cost will be evaluated: fixed and variable costs. Typical fixed costs to be investigated will be: capital costs (e.g., cages, rafts, boats, etc.); depreciation of capital stock; indirect operating costs (i.e., maintenance, insurance, power inputs, etc.); and other incidental costs identified during the project. Variable costs to be considered will be: feedstuffs/fertilizers; supplies of seed/fry; labor; other production costs (i.e., energy consumption, fuel costs, etc.); and selling costs related to marketing (i.e., transportation, preservation, quality control, etc.). Costs of regulation will also be evaluated. Data will be collected on an ongoing basis throughout the project. Another focus of the Economic Component will be the evaluation of possible economies of scale related to the demonstration project. The following potential economies of scale will be investigated: dimensional size (i.e., optimal efficiency level); labor costs (i.e., optimal labor force size); specialization (i.e., integration of activities); bulk purchase (i.e., possible cost savings); risk spreading and research and development.

The social assessment component will include the identification, description, evaluation, and estimation of the social impacts of the Open Ocean Aquaculture Project on local communities and a variety of groups of individuals, consistent with previous efforts (Robertson et al., 1996). The assessment will focus on the positive and negative social consequences of the

demonstration project during the planning, development, operation and decommissioning phases of the project. Methods will include personal, open-ended interviews with government officials, institutional and community leaders. The social assessment will also measure potential demand for charter cruises for education and tourism during the operation phase of the open ocean aquaculture demonstration project. Within the overall study priorities, the assessment will give greatest attention to those most affected, especially those with greatest involvement with and knowledge of the project and those who will experience effects in the near and long term. The social assessment will begin with a field reconnaissance in the primary study region to identify organizations to include in assessment. Semi-structured interviews will be conducted with fifty persons directly or indirectly associated with the project. Additional interviews will be completed with federal, state and county agencies, nongovernmental organizations, and fishing-dependent industries.

The sociological assessment will provide a direct link to Regional Planning Commissions, State Offices of Planning, City Planning Departments, the Gulf of Maine and Estuarine Research Reserves. This coordination effort will provide all those involved with a better understanding of the project and the typical scope and range of issues addressed in the socioeconomic analysis. The proposed assessment will also build on the substantial history of social science research relating to the study of the role natural resources have played in the location, function and growth or decline in communities.

Outreach and Education

LNH Sea Grant Extension, the Portsmouth Commercial Fishermen's Cooperative, and the Seacoast Science Center (Portsmouth, NH) will coordinate to achieve the outreach objectives of the Demonstration Project. The goals of this effort are: to engender the support and cooperation of the commercial fishing industry, to disseminate information, and to produce documents that will facilitate the development of private aquaculture ventures. Early in the project, UNH Sea Grant Extension will conduct formal and informal meetings with representatives of commercial fishermen's cooperatives. Sea Grant Extension personnel will also assist with the permitting process, and will produce a complete set of guidelines for obtaining an aquaculture permit. All stakeholders (e.g. commercial fishermen, the news media, the general public, decision makers, state and federal agencies, environmental groups) will be kept informed about the project through workshops and meetings. UNH Sea Grant Extension will also submit grant proposals for additional funding, and help fishermen obtain funds to begin aquaculture businesses.

The Portsmouth Fishermen's Cooperative will be actively involved with many aspects of the project, including information exchange, logistical support (hiring of fishing vessels and their crews, making available unloading winches, forklifts, coolers, live tanks, and work and storage space). The manager will investigate marketing opportunities for the fish and shellfish grown by the demonstration project.

The Seacoast Science Center, with over 100,000 visitors per year, will link the Demonstration Project with the general public through interpretive programs and exhibits about the technology, science and resource issues associated with aquaculture in the Gulf of Maine. Seacoast Science Center exhibits will focus on project technology, science and related marine issues, the history of fishing in the Gulf of Maine, and the environmental problems that aquaculture may be able to address. Center staff will develop exhibits and program designs, will research additional funding sources, write grant proposals for additional funding, and train volunteer interpreters to assist in delivering programs.

One of the major strengths of UNH's previous research on aquaculture is the extent to which we have involved undergraduate and graduate students. Numerous graduate students are doing thesis projects related to our research in aquaculture; undergraduates have prepared Senior Theses, pursued independent projects, obtained work-study positions, or simply volunteered. This type of project provides a perfect training ground for future aquaculturists, ocean engineers, marine policy analysts, resource economists, fisheries biologists, and marine biologists. From outside the University community, commercial fishermen have actively participated in our past and current studies and routinely visit our laboratories. Our methods and results will be immediately available to this user group, who will ultimately benefit from aquaculture activities in New England.

Conclusions

The University of New Hampshire is currently engaged in a comprehensive demonstration project to provide evidence of the feasibility of commercial open ocean aquaculture at the systems level. The Demonstration Project is an integrated, multidisciplinary effort involving biology, oceanography, engineering, sociology, economics, outreach, and education. Our goals include: 1) working toward streamlining of the regulatory and permitting processes that now impede the expansion of commercial aquaculture; 2) demonstrating the technical feasibility of producing fish of market size through hatchery culture and cage grow-out; 3) providing leadership in ocean engineering for cage design, evaluation, and deployment; 4) creating a re-

gional facility for experimental and educational programs; 5) providing economic data for risk assessment for capital investors and insurance companies; and 6) building a new marine industry that attracts new potential entrepreneurs, with particular focus on our endangered commercial fishing industry.

Acknowledgments

This paper represents the effort and expertise of all the participants of the UNH Open Ocean Aquaculture Demonstration Project. We acknowledge their role in the preparation of this manuscript and in the design and implementation of the Demonstration Project. They are (all from UNH except where indicated): Ken Baldwin, Rollie Bamaby, Frank Bub, Barbaros Celikkol, Chris Duffy (GreatBay Aquafarms), Richard Langan, Bruce Lindsay, George Nardi (GreatBay Aquafarms), Wendy Lull (Seacoast Science Center), Robert Robertson, M. Robinson Swift, and Larry Ward. We gratefully acknowledge the support and advice of James P. McVey (Aquaculture Program Director, National Sea Grant Office). We also acknowledge the assistance of the organizers of the Third International Open Ocean Aquaculture Conference, Robert Stickney, Granville Teece, and Amy Broussard (all of Texas Sea Grant). Funding was provided by the UNH, Texas, and National Sea Grant College Programs.

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The Sociological and Environmental Impacts of Open Ocean Aquaculture

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Farming of the oceans has existed since man realized the potential and the rewards, be it the basic supplement of nutrition to financial gain. Harvesting produce from the seas in the forms of fish, seaweed's or shellfish has resulted in many coastal communities and industries establishing themselves in their own rights and with world-wide recognition as associated fishing ports or centers of fish related industries from landings to processing and sales.

This of course has an effect on a number of parameters including economy, demographics, people skills and availability and the environment. Just how this occurs is directly related to the type of industry, the government support (of the day), grant availability and industry perception amongst the general public.

In order to understand the problems and advantages in terms of the socio and environmental impact of open ocean aquaculture, we must examine current successes and failures, certainly as applied to the Irish situation, which in perspective is not all to dissimilar to any other country, just multiplied in magnitude.

Definition

- **Sociology**: The study of social groups as pertains to their surroundings.
- **Environment**: The local, or habitat of an area.

For the purposes of this talk, I intend to refer to the interactions of the local communities and the effects on the environment that fish farming has had in Ireland, and how it will be in the future, with regards to a worldwide scale.

Ireland is a small island nation surrounded by the open sea, with an environmentally clean image and clear pristine Atlantic water lapping at its shores. It has a huge market in Europe for it's produce and is a member of

the European Community, allowing trade within European countries on a level par with the big players. What Ireland does not have, is a comparable sized fishing fleet or Aquaculture industry to rival may of it's European colleagues thus we are always having to develop newer or better method's for our industries.

As up to the 1950s we were considered an Agri based country, our main food supplies came from the land farming sectors, which down through the years have generated their own social communities and environmental problems. These have been dealt with by monetary funding or getting the public to accept or adapt to the situation i.e. deforestation, silage and carcass removal. This has resulted in many problems, but as Agriculture is worth so much, it's worthwhile to put a concentrated effort into developing and overcoming any arising problems.

The Aquaculture industry started to develop in earnest in the 1970s in Ireland, and many of the Agriculture avenues of success were utilized, such as funding methods, disease diagnostics and most importantly markets and marketing of the produce. However we then started to run into social misperceptions, environmental laws and ecologically related problems.

The government realized that the interactions and involvement of local communities was of paramount importance, whilst a revamp of environmental laws as applicable to Aquaculture would need to be undertaken. This was set motion in the late 1970s and only last year did some of the laws actually change or get ratified! Due to the rapid expansion of Aquaculture, the farmers themselves realized that certain environmental parameters would change anyway, from biological to aesthetic. Naturally there was, and still is, problems related to the environment and Aquaculture, but due to a better understanding and perception amongst the different representative bodies. Things are changing for the better.

The positive aspects of Aquaculture include the need to maintain good water quality in a biologically attractive environment, and the need to employ large numbers of skilled people from college graduates to local people with specific hands on knowledge of the areas. However Aquaculture is also widely perceived as having a negative interaction with other interests such as intrusion of coastal areas, the use of water space, use of chemicals and damage to the benthos and bentic populations. In reality the choice of location of the Aquaculture installation will either attract or detract from many of these issues. The importance of a clean unpolluted environment as a resource for economic development is increasingly recognized and underpins the production of quality food products.

Naturally, an area of concern developed amongst certain factions within

political circles, as to the importance and aesthetic value of certain areas as they pertained to Aquaculture. Many people wanted job creation enterprises, but not in their back garden, so to speak, if it had the potential to effect their scenery, or they were misinformed as to the exact nature of the business. We suffered immeasurable damage in the early days of our industries development, due to misinterpretation and incorrect information in the media and in the locality.

Without a doubt, this hindered our industries development, as almost everyone became anti-fish farming, and it started to reach political circles. The environmentalists then expressed their concerns, a lot of which were unsubstantiated due to lack of correct information, and good old-fashioned prejudice! Nothing better than an Eco-political controversial issue!

This is also where we must take some of the blame. Put plainly, we didn't stand up for ourselves, nor did we promote the industry, in a professional aggressive manner. We spent large amounts of money on trying to disprove theories and prove scientific facts, which still weren't enough.

Let's not detract from the issue here though, and that's what we learnt from all of this.

Firstly, be informative, and unequivocal in your beliefs, and don't be bullied!

Secondly, have the relevant scientific data to hand, and know that somewhere in the world, someone else has this data, or is working on it!

The whole environmental issue is complicated, but any fish farmer will tell you the same thing world wide...To grow fish, you need unpolluted, clean and disease free environments, anything less and your stock will not perform. If your stock doesn't perform...no money!

Accordingly, over the last number of years, we as an industry are working in tandem with the environmental lobby, and with their support are now getting political and local results, that satisfy all concerned. It's not easy, and there are still contentious issues, but an all around openness has developed, and it is working. There are still many issues to be dealt with from navigation rights to chemicals, but there is a solution, as we are learning.

In the west of Ireland we had a tremendous people haemorrhage in the early 1980s, due to immigration, as there was little future in these barren unproductive shore's all along our seaboard. However, with the introduction of Aquaculture in these regions, immigration ceased as communities came together, worked together and once more developed a sense of self-awareness and commitment to a progressive industry that had their involvement. Communities started to grow, schools became populated once

again, but more importantly, the economics in the areas improved, which resulted in better living standards, and most importantly, subsidiary industries set up, and created even more employment. Community camaraderie improved and they let the politicians know this! Their voices became powerful, and they were noticed once more. Services and infrastructure improved and both the Aquaculture and local industries availed of this.

Environmentally perceived problems concerned with aquaculture

- The Aesthetic problem - unsightly, located in Tourist/Scenic areas.
- Use of navigation and water space - direct competition.
- Competition over valuable land on the shoreline.
- The so-called abundant use of chemicals.
- Potential conflict with other forms of wildlife.
- Water Pollution.
- Inhumane keeping of large numbers of animals.
- Consistent activity - Fish don't have holidays!
- The development of infrastructure.
- Escapees - Dilution of genetic pool.
- Harvesting procedures and practices.
- All licenses and government red tape issues.

Sociological perceptions concerned with aquaculture

- The right to privacy, not in may back yard syndrome.
- Introduction of outsiders to the locality.
- Employment issues.
- Reputation of area - Tourism etc.
- Suspicions and Hesitation of acceptance/change.
- Lack of confidence in industry.
- Lack of knowledge/information with regards to the Aquaculture venture involved.

So these have been handled in a number of ways including;

- Public participation, whereby the values, concerns and aspirations of the community affected was accommodated.
- Steps by which relevant policies, legislation and institutional arrangements can be developed and implemented to meet local needs and circumstances while recognizing national priorities.
- Collaboration between Farm owners, Scientists in interpretation and application of R&D policies.

Conclusion

Everyone wants to integrate and be part of a community, and ensure all environmental rights/issues are agreeable to all concerned. So, how can we encourage this?

Sociologically

- Involved all the community in the project and employ those qualified and with the hands on experience that is required.
- Ensure the company is open in its dealings and disseminates the correct knowledge to those who matter.
- Don't allow the area to suffer due to progress, enhance and encourage it along.
- Be a conduit for success, and encourage/support local industries that set up in your wake, i.e. net repairs etc.

Environmentally

- Establish from the start your intentions and any physical/biological sub-sequences.
- Involve the environmental lobby in your prospective plans, and keep them informed of the future developments.
- Allow for a trusting environment and working relationship, which is a two way street!
- Ensure the scientific data is available for general consumption.
- Be active on the political front yourselves, and help create or have input into legislative matters that may affect your operation.
- Keep the farm clean and tidy!

Marine Tenure and Offshore Aquaculture in the Gulf of Mexico: A Public Policy Perspective

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The importance of secure marine tenure is hardly a mystery to anyone in the aquaculture business – they cannot survive without it. Secure tenure provides the essential stability and motivation for innovation that are so crucial to any business venture, and thus is perhaps the most important measure of success for any potential aquaculture operation. Convincing others of this, however, is another matter, and as aquaculturists consider moving offshore in the Gulf of Mexico and elsewhere, they will necessarily have to convince a host of policy makers, environmentalists and others that aquaculture is a good thing – and once again tenure is the key.

Tenure is more than just the right to site a facility in a particular place, it also extends over what is contained in the facility (e.g. the fish), and over the surrounding area (e.g. water quality). All three forms of tenure should be an integral part any attempt to develop aquaculture offshore – to help bolster the arguments in favor of aquaculture development and to build coalitions with other parties, especially those interested in the conservation benefits of secure tenure.

The importance of the first kind of tenure is obvious. Without a site there is no aquaculture facility. In the Gulf of Mexico, luckily, there is a great deal of precedent to start with. Offshore oil and gas leases are well established and nearshore leasing arrangements exist in most Gulf states for oyster cultivation and even for live rock in Florida. Although these leases are generally very restrictive – normally for only one specific activity such as oil and gas exploration – there is at least a model in place and a general understanding of its importance.

The second form of tenure accounts for the amazing gains in productivity experienced by the aquaculture industry in recent years. Tenure within an aquaculture facility is what separates aquaculture from wild fisheries, where the rule of capture all too often reigns. Thus, harvesters of wild fisheries routinely destroy their own livelihoods because any fish they leave

in the sea may simply be left for someone else to harvest. Aquaculture facilities, on the other hand, literally fence in the seas, solving the problem that has plagued so many fisheries by getting the incentives right and by rewarding stewardship.

Any number of examples illustrate this point, but perhaps the most vivid is the oyster harvests of the Chesapeake Bay. Oyster beds in Maryland typically are and have been public resources, while those in Virginia have tended to be leased privately. Prior the onset of the oyster diseases in the Chesapeake in the 1970s, two economists from the University of Delaware compared the Maryland and Virginia oyster industries and found that the oysters produced in Virginia tended to be larger, healthier, and of better quality than their Maryland counterparts, because Virginia oystermen were stewards of the resource while their Maryland counterparts simply exploited it (Agnello and Donnelley, 1975).

The third form of tenure is over what surrounds an aquaculture facility, whether it be a river, a bay or the seas offshore. This form of tenure is also responsible for some of the negative public perception that have recently plagued the aquaculture industry, for it is a lack of tenure outside of an aquaculture facility that often leads to pollution problems. In fact, these pollution problems are caused by the same factors that have plagued wild fisheries. Fish and the clean water they swim in are both valuable resources subject to depletion. Whether an aquaculture facility is a culprit or a victim of pollution, the problem is a commons problem. Thus, in places like Thailand and Ecuador, it is hardly surprising that unowned mangroves are destroyed.

But the problems created by a lack of tenure are also an opportunity. Strengthening tenure outside of a facility also strengthens the conservation benefits of aquaculture. Again the oyster industry provides an example, this time in Washington state, the only place in the U.S. where subtidal areas may be owned in fee simple. This ownership created a vested interest in clean water among the oystermen there, which over the years led one conservationist to remark "Willapa [Bay in Washington state] is the cleanest bay in the country, and it is the oystermen who have kept it that way" (De Alessi, 1996). Similarly in England and Wales, the rights to fish for salmon in streams and rivers is a heritable, private right, and an organization called the Anger's Cooperative Association (ACA) has prosecuted "more than fifteen hundred cases of pollution and recovered hundreds of thousands of dollars in damages to enable riparian owners to restore their fisheries" (Bate, 1994).

Thus, it is important to recognize that some problems with aquaculture do exist, but also to recognize *why* they exist – a lack of tenure. It is an

institutional problem, not one with aquaculture per se. If marine tenure is really complete, then the bottom line is that it makes a clean, productive environment a valuable asset.

Aquaculture entrepreneurs should not gloss over the fact that they are in business to make money, but should also keep sight of the potential conservation benefits of their activities as well. For example, if all three forms of tenure are addressed, then leasing areas for offshore aquaculture will not create pollution, but a bulwark against pollution – an array not only of water quality monitors, but also collectors of oceanographic data.

Once the conservation benefits of aquaculture have been established, the next logical step is coalition building. Look for others who would benefit from similar leasing arrangements, for example, artificial reef builders. The Gulf of Mexico is host to an astounding number of artificial reefs, mostly oil and gas structures in Louisiana and Texas and smaller materials in other states. Currently, all of the reefs in the Gulf are public reefs, and many are overfished or otherwise in poor condition for exactly that reason. Many people remark that they see as many fish outside an aquaculture facility as inside – so most aquaculturalists are all already in the artificial reef business. Sportsfishermen are natural allies who would also benefit from more and less restrictive leasing arrangements.

Additionally, even though environmental groups seem to be more antagonistic than supportive of late, those who genuinely want to improve conservation practices should be natural allies. The Environmental Defense fund, for example, is often critical of aquaculture, yet they support market incentives in the wild fisheries. Convince EDF that the same tragedy of the commons that has plagued wild fisheries is also responsible for aquaculture's problems, and they could be one of aquaculture's strongest leasing proponents.

In sum, to create secure tenure for offshore aquaculture in the Gulf of Mexico or anywhere else, much of the challenge will be to communicate just why there have been some problems for aquaculture, to emphasize the conservation benefits of aquaculture under the proper institutional arrangements, and to look for natural allies to help along the way, such as artificial reef users and many more environmentalists than one might think.

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Session 2: Industry Perspectives, Feasibility Studies and Rigs to Reefs

Platforms and Fish Pens — An Operator's Perspective

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Introduction

Harvesting fish and shellfish has been a major source of food throughout the history of civilization. Recent overharvest of our ocean resources has raised concern about the future of our fish stocks. In the United States, the authorities have evolved a system of allocating fisheries resources through a combination of seasonal closures, zone closures, and catch limits, administered by the National Marine Fisheries Service (NMFS).

Today, cultivation of fish and shellfish is a major business. Farm-raised trout, catfish, and crawfish are familiar to most of us. These commercial operations take place in ponds and raceways from the extremely large to the quite small. Within the last several years, considerations have been given to the use of oil and gas structures to aid in marine aquaculture-mariculture. This paper provides an industry perspective on the opportunities and obstacles presented by the use of petroleum production platforms in mariculture operations.

Perspective

This paper presents a review of the possible use of offshore platforms for mariculture from the perspective of an offshore oil and gas operator. Views and concerns expressed in this paper are solely those of the author, but are believed to be fairly typical of those in the industry.

Oil and Gas Platforms

There are nearly 4,000 oil and gas platforms in the Gulf of Mexico. These structures vary widely in age, size, and complexity. Water depths range from a few feet to well over 1,000 feet, and in distance from near shoreline to more than 130 miles. Platforms consist of a supporting structure (jacket or caisson) and a topside structure (deck), which supports pro-

duction, processing, storage and safety equipment, quarters (if any), and helideck (if any).

Platforms present some obvious opportunities for mariculture operations:

- They would provide a more or less permanent, solid platform from which to conduct operations. The decks would provide a stable place for storage, feed delivery equipment, and utilities (power, navigation aids, communications, and environmental monitoring). The structure would provide above and below-surface support for anchoring containment and winching systems. An infrastructure for transportation and communication already exists.
- Platforms are well known as artificial reefs, providing healthy ecosystems that are major destinations for recreational fishing. This abundance of associated sea life suggests a healthy environment suitable for cultivation of fish and shellfish.
- The offshore location tends to moderate swings in water temperature, and water currents make the system largely self-cleaning, providing new, oxygenated water and removing wastes from fish and feeding.

Successes

Mussel Harvest

Platforms located offshore of the California coast are particularly prone to a buildup of sea life attached to the underwater platform support. This "biofouling" creates wave and current drag sufficient to cause structural concerns. To alleviate this problem, operators pay up to a few hundred thousand dollars every few years for divers to remove the growth.

A Santa Barbara, California firm, Ecomar, has capitalized on this market by harvesting this biological abundance and separating, cleaning, and marketing the mussels thus removed to restaurants.

Two things to bear in mind about the Ecomar harvesting operation:

1. Operators view this as a very good way to conduct **essential** platform maintenance. Because Ecomar is able to market the product, the operators get a cost break on the removal operation. An additional benefit is showcasing the healthy environment that surrounds these platforms.
2. In spite of what should seem an obvious win-win proposal, it took Ecomar's owner, Bob Meek, the better part of ten years to sell the idea to the oil and gas operators and the regulatory authorities. Operators' reluctance can be summed up in two issues: liability and interference in operations.

Rigs-to-Reefs

Another success is the Rigs-to-Reefs Program in Texas and Louisiana. At the end of a platform's useful life, oil and gas operators are required to plug abandoned wells, sever all structures below the mud line, and physically remove the structure from the lease. Simply stated, the Rigs-to-Reefs Program offers an operator the opportunity to move the structure to a designated reef site rather than transporting it to shore to be cut up for scrap.

From the oil and gas operators' point of view, the Rigs-to-Reef Program is highly successful for two very good reasons:

1. **Liability**: The Rigs-to-Reef Program presents the operator with an opportunity to fulfill his responsibilities in clearing the oil and gas lease in such a way that long-term liability for the structure is transferred to another ***financially responsible entity*** (i.e., a government agency).
2. **Economics**: The cost to clear a platform from a lease can be up to $15 million or more, depending on water depth, location, condition and configuration of the structure, and salvage value of parts. This cost can sometimes be dramatically reduced by participation in the Rigs-to-Reef Program. One-half of the estimated savings goes to the agency to pay for long-term maintenance of the reef and for accepting liability.

Operator Concerns

The following issues are of primary concern from an oil and gas operator's perspective.

Liability

The greatest concern of oil and gas operators is liability, liability for accidents and liability for lease abandonment. Whether mariculture operations are conducted on a producing or an inactive platform, there are issues of liability for personal injury, environmental damages, and property damage. Not only are authorized personnel working on and under the platform at risk, so are intruders, on and under the platform. Risk of injury, property and environmental damages from collision and natural disasters also must be resolved.

The longer term issue is liability for lease clearance. If an inactive platform is to be used for mariculture operations, somehow the ultimate fate of the structure and eventual cost for dealing with it must be resolved.

The willingness of an entrepreneur to accept the liabilities associated with a platform-based mariculture operation is likely not to be adequate. Somehow, the oil and gas operator needs to be relieved of liability as a *previous* owner.

Finally, there are requirements for platform maintenance. Navigation aids, cathodic protection, and repair and upkeep of the structure are expense items that must be factored into the economics of such an operation. Together, these costs can exceed $10,000 per year.

Operating Priorities

If shared use of an operating platform is contemplated, interference with platform operations is another major concern. Operations on these facilities are entirely focused on production of oil and gas. Any activities that do not fall within that focus are likely to met with reluctance, unless they can be shown to be: (1) valuable and (2) conducted in a manner that do not interfere with operations.

Permitting

Oil and gas operators work within a tightly regulated environment. However, the agencies with which we work generally have well-defined and understood areas of authority. Reportedly, working through the regulatory framework to obtain all the necessary authorizations to conduct a mariculture operation from an oil and gas platform can be a *major* challenge. Conflicts include overlapping areas of authority and standards to be applied to the operations.

Suggestions

Ultimately, the concerns expressed above should be resolved. From the perspective of an oil and gas operator, the following are some suggestions that, if implemented, would help move mariculture toward commercial reality.

Relief from Lease Responsibilities

Long-term liabilities and lease clearance responsibilities are a major obstacle to mariculture on oil and gas platforms. Proponents may be inadequately prepared to take on these responsibilities; at the same time, oil and gas operators are likely to be unwilling to retain long-term liabilities. A possibility to consider is a mechanism for site clearance to be funded up front and placed in an appointed trust and the oil and gas operator provided with a legally binding release from future liabilities. There may also be some possibility through or similar to the Rigs-to-Reefs Program to make platforms available.

Streamline Permitting Requirements

Some means of simplifying the permitting process is needed. Use of a

lead agency, and work between the agencies to clarify roles, eliminate overlap, and streamline the process would help dramatically.

Conclusion

Oil and gas operators consider offshore platforms to be something of an idyllic microcosm of sea life. We provide structure where one did not previously exist, and sea life is attracted and thrives. It makes a great deal of sense that these circumstances should be capitalized upon somehow. The Rigs-to-Reef Program is a positive step.

Commercial farming in association with these structures appears to be an additional opportunity. Over time, the obstacles, both institutional and technological, will probably be resolved, and mariculture could evolve into a major business and a major food source contributor.

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Abstract

Northern Gulf of Mexico Mariculture Project

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A cooperative agreement between the National Marine Fisheries Service (NMFS) and Waldemar Nelson International Inc. (WNI) stimulated an evaluation of the feasibility of initiating offshore finfish mariculture in the Northern Gulf of Mexico using the oil and gas production platforms situated in the Gulf. The scope for the feasibility study included an assessment of the biological, technical, regulatory, environmental and economic feasibility, together with an assessment of the type and size of platform required and preferred water depths and locations in the northern Gulf. The project evaluation team consisted of an attorney, engineers, industry businessmen with expertise in fish food manufacturing, seafood processing and marketing, and scientists with expertise in marine biology, fisheries, fish pathology, fisheries economics, and international expertise in offshore mariculture operations.

Thirteen marine finfish species were evaluated in detail with respect to their biology, status of nursery and grow-out methods, nutritional and feed issues, suitability for cage culture, disease issues, fillet yields, economic value, and other considerations. With the exception of red drum, all species required some additional research or trials in the hatchery or grow-out phases to enable it to be considered viable for offshore culture in the northern Gulf of Mexico. The feasibility study also evaluated the technical (equipment) side of establishing an offshore finfish mariculture industry and determined that there is suitable off the shelf or commercially available equipment for net pens with anchoring systems and feed storage and delivery systems to implement a successful operation. An evaluation was made of the regulatory issues affecting permitting of an offshore mariculture operation.

Other than the standard permits required through the federal and state agencies, the two issues which must be resolved prior to commercial scale operations are the ownership of fish in cages and current restrictions on possession of certain species with size or quota restrictions. The economic analyses of offshore mariculture included estimation of capital and annual

operating costs for a abase case. The base case consisted of a relatively large scale commercial operation with up to nine large net pens each holding up to 500 metric tons of product. It also accounted for the demand for finfish products in the U.S.

The economic analysis indicates a large future demand for a cultured product. There are ample numbers of offshore platforms in the northern Gulf of the appropriate size and in ideal water depths for use in mariculture ventures. The environmental impact analyses indicated that a base case project in areas of the Gulf with sufficient depth and current velocities would not create a water quality problem around a well operated and monitored venture. Negative and positive socioeconomic impacts were not considered to be significant for a single venture, but obviously could become significant with multiple installations. In summary, the project team did not find any insurmountable issues that would preclude the development of offshore mariculture in the Gulf.

Abstract

MMS Liability Issues and Bonding Associated with Offshore Platforms

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The MMS Supplemental Bonding Program was implemented to address the abandonment liability issues resulting from the growing of number of offshore leases and properties in the Gulf of Mexico that have been sold by offshore oil and gas platform operators. Under the provisions of the MMS Supplemental Bonding Program, an operator of an offshore oil and gas platform is required to post a bond to cover the abandonment liability of the oil and gas lease including removal of the offshore platform.

Covered in this presentation will be a discussion of the details of the MMS Supplemental Bonding Program including how the MMS determines the estimated abandonment liability. Also included will be a discussion of MMS areas of concern which have resulted from the implementation of the MMS Supplemental Bonding Program including safety, potential risk to the environment and areas of opportunity for the program.

The presentation will be concluded by outlining the impact the MMS Supplemental Bonding Program has on Mariculture Operations in the Gulf of Mexico from the standpoint of the operator of the oil and gas platform and the operator of a potential mariculture project that intends to use the oil and gas platform.

Mariculture Options with Texas Rigs to Reefs

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Introduction

Resource managers have been involved in artificial reef development off Texas for nearly 50 years. However, most of the early materials used were not durable and stable and, thus, had little long-term success as artificial reefs. The first highly successful artificial reef development occurred during the mid-1970s when 12 obsolete liberty ships were sunk at five different sites in the Gulf of Mexico.

The most extensive set of artificial reefs placed off Texas were, in fact, unintentional. These include the more than 800 offshore petroleum production structures that have provided extensive underwater havens for reef fish communities. Platform structures are ideal materials because of their engineering and construction design to be able to withstand the horizontal wave forces of 100-year storms. The rounded steel legs of the jackets provide the maximum surface area for biological growth and attachment of sessile organisms.

The sea floor in the Gulf is dominated by soft sediments with only limited quantities of suitable reef habitat. In fact, throughout the Gulf, petroleum platforms account for about 28 percent of the hard substrate critical for reef fish production. With an estimated 900,000 saltwater anglers and 250,000 divers in Texas, demand remains high for fishing and diving opportunities at these easy-to-find sites. With an escalation of rig removals in the early 1980s, the need to preserve the diverse ecosystems created by these offshore rigs was widely recognized.

Texas Artificial Reef Plan

To realize this goal of creating and preserving these valuable habitats, the Texas legislature in 1989 directed the Parks and Wildlife Department to develop the artificial reef potential off Texas for enhancing fishery resources and fishing and diving opportunities. To guide future placement, the Department produced the Texas Artificial Reef Plan in 1990, which followed

an exclusion mapping approach. This technique describes criteria for selecting reef locations in order to provide the optimum benefits to the reef fishery resource and users, while minimizing impacts to other stakeholder groups in the Gulf. Geographic, hydrographic, geological, biological, social and economic considerations are evaluated as siting criteria. The program incorporates a user-resource planning framework when evaluating each donation offer that includes advanced site planning, permitting requirements, location and design criteria, buoy maintenance, consistent fisheries management goals, and re-evaluation of the program goals.

The enabling legislation also provided a means for the Program to be financially self sufficient by establishing a dedicated Artificial Reef Fund for the revenues received through a requirement that donors, if applicable, provide 50 percent of any monetary savings they realize from the donation. This Artificial Reef Fund is used exclusively to support administration of permits, maintenance of buoys, liability, construction of inshore reef sites, and research monitoring activities. Maintenance of buoys marking each new reef are currently major costs to the Program.

Flexibility is a major strength of the Program and the guiding principle of the Artificial Reef Plan. Acceptance of any reef material donation is assessed on a case by case basis to assure maximize benefits to the State. The Program is mandated by law to facilitate access by fishermen, minimize conflicts among competing users, minimize environmental risks, and not create unreasonable obstructions to navigation. To assure broad-based public input on these issues, the Program established an independent advisory committee composed of Gulf stakeholders to ascertain the appropriateness of each donation. The Artificial Reef Advisory Committee is represented by a salt water fishing group, an oil and gas industry representative, the Texas Department of Commerce representing tourism, the Texas General Land Office representing petroleum and mineral leasing interests in State waters, a commercial shrimping organization, a Texas diving club, the Attorney General's Office, a Texas University, an environmental group, and a Texas marine archeologist. As appropriate for each donation offer, the Program solicits additional input using public hearings and other outreach methods.

Rigs to Reefs

The heart of the Texas Artificial Reef Program is Rigs to Reefs. A key recommendation of the Artificial Reef Plan was to actively pursue the acquisition of offshore petroleum structures and to preserve them in "as near their current form as possible" in order to maximize their biological, social

and economic benefits. The normal method for turning an obsolete rig into an artificial reef is for the legs of the jacket to be severed 15 feet below the mud line using explosives. The jacket is then pulled over on one side. Some disadvantages of this toppling method, however, include the reduction of hard substrate in the upper water column, the loss of the biofouling community formerly at the top of the jacket now lying on the bottom, and the loss of organisms shaken loose and/or killed by the explosive shock.

To overcome these disadvantages and better achieve the Plan goals, the Department in 1995 created the first artificial reef in the Gulf using only mechanical cutting of the top portion of the jacket with the remainder of the jacket left standing in place. The top portion was lifted off by crane and placed next to the remaining structure in an upright position. By cutting off only the top 86 feet, for required Coast Guard clearance, the platform now projects 166 feet above the sea floor as opposed to a 64 feet profile using normal toppling procedures. Three additional reefs have been created using this removal method and another is planned in 1998. These artificial reef creations represent the wave of the future in which ecological niches throughout the water column will be preserved for the benefit of the fishery resources and man alike.

Since the Plan was approved, 30 artificial reef sites have been developed including the placement of 39 rigs and donations of over $4 million. Other materials of opportunity which meet the Plan's criteria for complex, durable, stable structures at these reef sites include: 12 Liberty ships, a tugboat, 4 barges, 44 concrete culverts, 300 fly-ash blocks, 100 reef balls, 50 quarry rocks and a welded pipe structure. All of these materials have been placed at shallower, nearshore sites to provide better access for small boat anglers and divers.

Permitting Flexibility

The Program also offers flexibility for donors by providing several alternative permit options which do not restrict reef development to a specific number of planning areas as is characteristic of some other state artificial reef plans. The Department may apply to the Corps of Engineers for individual artificial reef sites. Each 40-acre permitted reef site encompasses one quarter square mile (1,320 ft by 1,320 ft) and has enough space to cluster at least nine jacket structures on the bottom.

The initial donor at a permitted reef site is allowed to topple the structure in place or partially remove it. Other jacket donations are encouraged to be transported from nearby, with no additional permitting required. There are exceptions to this 40-acre reef size, as exemplified by the five 160-acre

Liberty Ship reefs along the Texas coast, and the 418-acre South Padre Island reef site. These larger permitted areas were created before the current Texas Artificial Reef Plan and were subsequently transferred to the Department.

Although most of Texas' artificial reef sites are individually permitted, the Program also has the advantage of creating artificial reefs in the High Island (OCS) leasing area, under the authority of a General Permit from the Corps of Engineers. In this 2500 square mile area, artificial reefs may be created without the requirement of a 30-day public comment period. To date twelve reef sites have been established within this General Permit area. The special conditions of this permit require the structure location to: be at least five nautical miles from another reef site; be at least two nautical miles from any safety fairway; have at least 85 feet of clear water over the highest portion of the structure; be at least a distance of seven times the depth of water away from any active pipeline; not disturb any abandoned pipelines; and be at least one nautical mile away from any specific hard bottom communities (such as the Flower Garden Marine Sanctuary East and West Banks).

Mariculture Potential

Because of their stability and a manned presence, platforms offer unique opportunities for working long-term in the Gulf. One of the goals of the Program is to be flexible in providing opportunities for other beneficial uses of a platform, including mariculture operations. Accepting an intact platform, including the above water deck, into the Artificial Reef Program can be justified, if a greater benefit to the State can be identified, and if the Program does not suffer financially. For example, there have been discussions about the Program acquiring an intact platform that would then be leased by a consortium of research institutes to conduct scientific studies in the Gulf. In the same way, the Program could serve as a lessor of an intact platform with a mariculture company being the lessee. While there is no specific precedent to guide us, the Program is ready to explore the options to make this concept a reality.

Before such an arrangement can be finalized, specific criteria for leaving the structure in place need to be negotiated with the donor. Numerous other government entities with a vested interest in platform use offshore, ranging from the Department of Agriculture to the Department of Defense, would have to be included in the discussions. Proper maintenance and marking of the structure would have to be assured since the Department

would still be liable for the structure as a navigational hazard. Painting decks, replacing cathodic protectors, and maintaining lights and horns will likely cost hundreds of thousands of dollars each year.

When the life of the rig is exhausted or mariculture is no longer feasible, there must be a pre-approved and funded plan to convert the structure into a permanent artificial reef, which would involve cutting or toppling the jacket in place to meet current navigational clearance requirements. This could be a particularly difficult issue given the unknown number of years before that final reef conversion operation is required. What will be the government and industry standards for rig removal in the future? How much money should be escrowed to cover this operation? How do we handle the 50% donation of realized savings from a normal donation? How does the Program keep from incurring a financial penalty or undue liability for serving as a lessor? What is reasonable mitigation for the loss of accessibility to the artificial reef site by other Gulf user groups? Forums such as the Third International Conference on Open Ocean Aquaculture offer excellent opportunities to find answers to many of these questions.

Conclusion

The Texas Artificial Reef Program recognizes a need to proceed with caution and patience but also with a sincere expectation of success in trying to merge artificial reef development with environmentally and economically sound offshore mariculture. The State looks forward to building on the accomplishments of our current Program through coordinated planning and research with other government agencies and universities as well as private industries. The future is bright for the efficient and effective creation of artificial reefs in the Gulf. The potential benefits to the State and Gulf stakeholders for mariculture operations that are also artificial reefs justifies a bona fide effort to create this win-win situation.

Proposed Gulf of Mexico Finfish Mariculture Experiment

John D. Ericsson, President
Gulf Marine Institute of Technology
Sea Pride Industries, Inc.
Gulf Breeze, Florida

Introduction

Since 1989, Sea Pride Industries, Inc., has been developing a concept for growing native finfish species in the Gulf of Mexico. Initial scientific feasibility of this concept has shown a vast potential for economic development. It is now necessary to conduct *in situ* experiments to validate the concepts and the capability of establishing the technical and economic viability of the constituent mariculture processes. Sea Pride has received the first permits ever granted by the U.S. Army Corps of Engineers (ACOE) and the Environmental Protection Agency (EPA) to conduct experiments and eventual commercial mariculture operations in federal waters.

Project Goals

The goals of the Gulf of Mexico finfish mariculture experiment are as follows:

1. To develop new technology for the commercial culture of native Gulf of Mexico finfish species;
2. To develop new technology for offshore commercial mariculture facilities;
3. To develop markets for cultured species; and
4. To determine environmental impacts that may result for intensive mariculture activities.

Oil Platform Based Five-phase Mariculture Project

A five-phased approach will be used to accomplish the Gulf of Mexico Ocean Farming Project goals. Phase I consists of initial environmental sampling activities to determine baseline water and sediment characteristics. Initial growout trials will be conducted with selected native finfish to determine suitability for Phase II growout experiments. In Phase II, at-sea equipment trials will be conducted to evaluate each system's performance in the

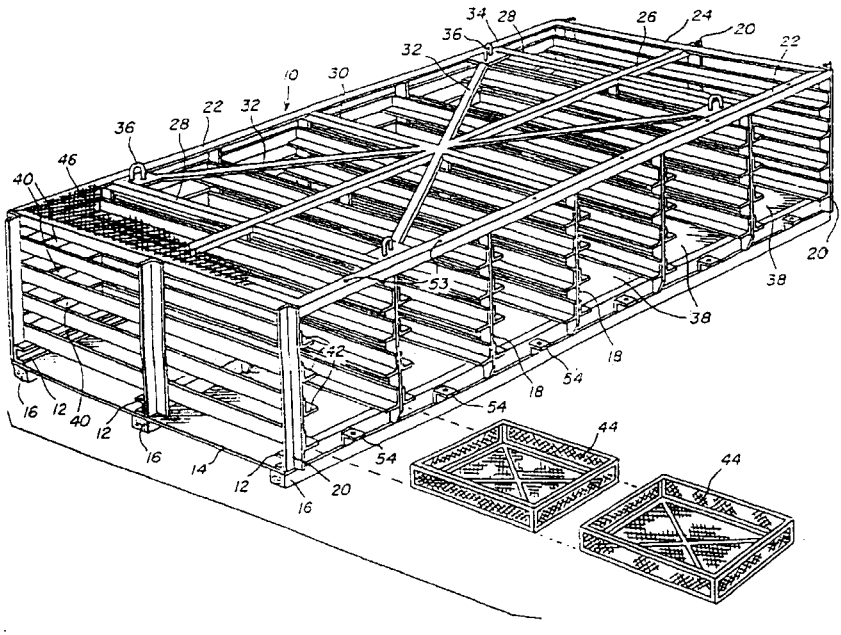


Fig. 1. Isometric view of a Gollot Oyster Rack.

subtropical, shallow Gulf of Mexico environment. Of primary concern is the ability of these test units to withstand severe weather and sea-state conditions such as hurricanes. A floating barrier will be evaluated for its ability to repel debris, dampen surface wave energy, and prevent unauthorized vessels from entering the project area. Environmental monitoring will also be conducted during this phase.

Phase III will involve the addition of four to five cages once the systems are evaluated in Phase II.

Phase IV continues the expansion of the operating plan by incorporating four to five more cages.

Phase V is for total buildout of systems with maximum utilization of all cage and platform capabilities.

Sea Star Industries, Inc.

Hundreds of thousands of hectares of natural oyster reefs, beds, farms, etc. throughout the Gulf of Mexico are lost annually from production because of polluted land runoff and domestic wastewater effluents. As a result of the expanding pollution, millions of dollars worth of oysters cannot be utilized and/or must undergo an approved cleansing method (e.g., controlled purification: depuration or relaying).

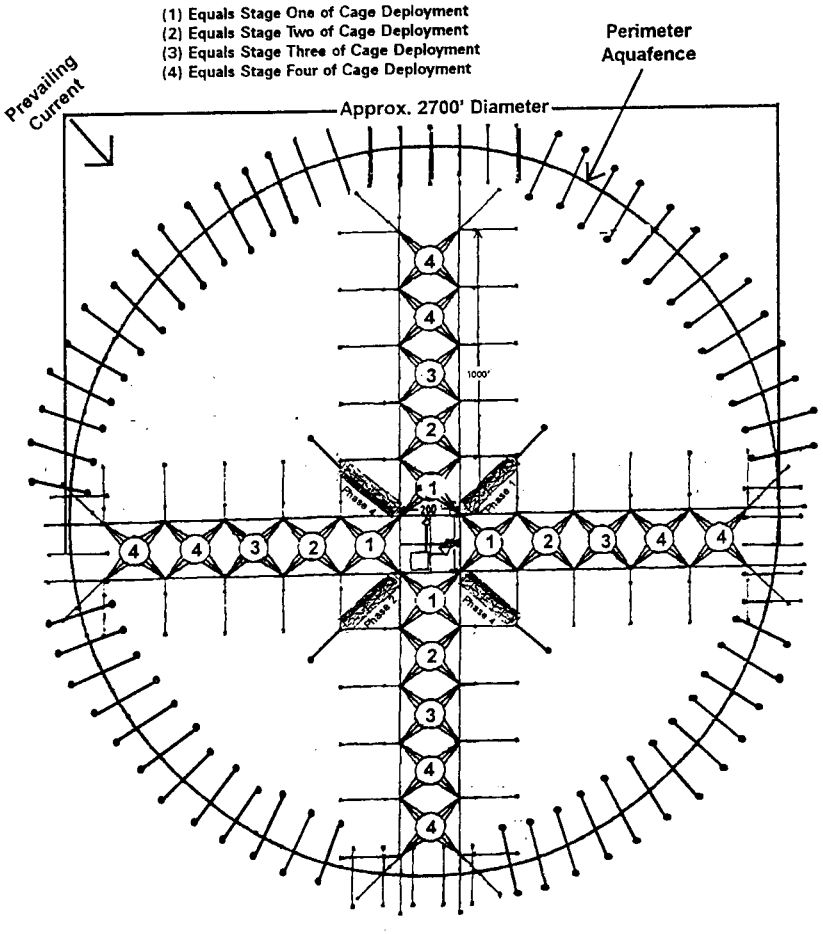


Fig. 2. Proposed anchoring outline for the first four phases.

In addition, the invasion of coastal waters by the marine bacterium, *Vibrio vulnificus*, has resulted in the deaths of numerous at-risk humans who have HIV/AIDS, advanced diabetes, cirrhosis, age-related or other immuno-compromised conditions. The Center for Disease Control (CDC) reports that from 1988 until 1995, 302 *V. vulnificus* infections were reported in the Gulf Coast region. The human mortality rate from *V. vulnificus* is more than 50 percent. The CDC describes symptoms of the infection to "include fever, nausea, myalgia and abdominal cramps in the 24 to 48 hours after eating contaminated food."

The FDA has threatened to shut down the Gulf of Mexico half-shell oyster industry from April through October when *V. vulnificus* is prevalent

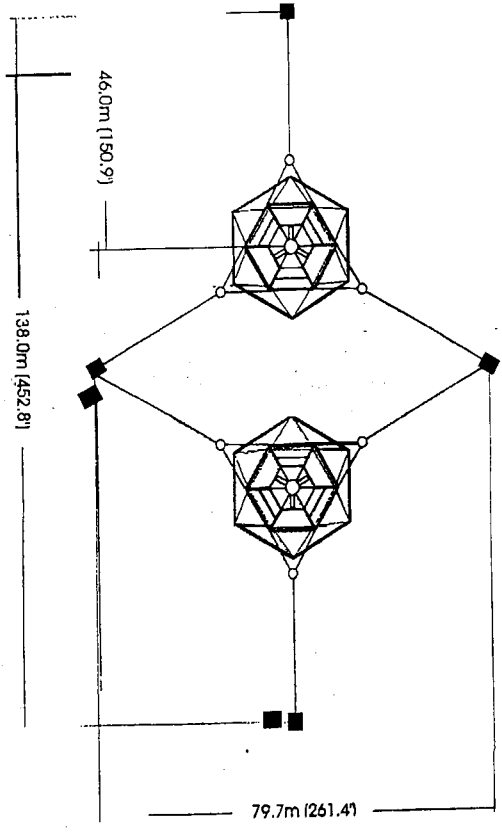


Fig. 3. Top View of SADCO-Shelf Underwater Cages.

in natural estuarine waters and oysters. In addition to these problems facing the oyster industry, large quantities of oysters throughout the estuarine bays and sounds along the U.S. coast have been lost to harvest for direct consumption because of deteriorating water quality and harvest-area closures. The "approved" oyster-growing areas are decreasing in size annually as potential and/or actual pollution sources from domestic, industrial, and mariculture developments continue to encroach, thus resulting in the reclassification of those areas to "closed" area status. Concomitantly, unfavorable environmental conditions caused poor oyster recruitment, increased mortality from freshwater flooding, increased prevalence of oyster predators, pathogens, and pests, and increased fishing pressure on the remaining stocks that are available for harvest, thus further reducing oyster production.

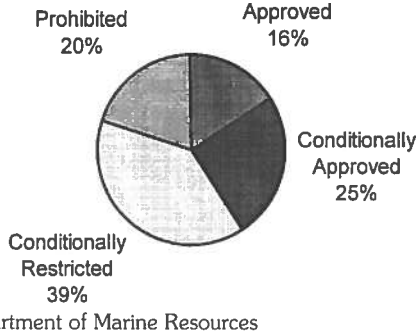
Also, the nation's wild oysters stocks and their growing areas are declining precipitously through habitat destruction and pollution, and inappropriate management while domestic demand for nutritious and healthy shellfish products is increasing. Sea Star Industries, Inc., has spent three years and tens of thousands of dollars researching, developing, engineering, patenting, building, and obtaining permits for an advanced oyster cleansing facility: "The Sea Star Oyster Relay System."

The Sea Star oyster relay device is a ballastable system for at sea cleansing and enhancement of oysters from coastal waters that cannot be marketed without completing a FDA-approved cleansing process. Sea Star's rack-relaying technology could help avert the FDA-threatened shut-down of the Gulf of Mexico commercial oyster industry by providing a cost-effective alternative to total cessation of oyster harvesting and/or less inefficient on-bottom relaying. The Sea Star oyster relay device offers an economical and biologically sound method for cleansing V *vulnificus-infested* oysters as well as cleansing oysters from coastal waters that are closed to direct harvest of oysters (i.e., from "conditionally-closed," or "closed" waters). The Sea Star relaying system could test natural removal of other contaminants (viruses and bacteria) and enhance the salty flavor of the cleansed oysters.

Mississippi was chosen as the source of oysters for this project and its eventual commercial application. It is a stark example of declining shellfish-growing water quality. The figure below shows Mississippi's current status of available area for harvesting shellfish.

Deteriorating water quality has closed 80% of Mississippi's natural oyster reefs. Mississippi's commercial oyster harvests averaged 81,000 sacks per year in the 1980s and ranged from a high of 366,000 sacks in 1983 to

Mississippi Sound Shellfish Growing Area Status



Source: Mississippi Department of Marine Resources

a low of 5,000 sacks in 1984. The annual harvests have declined drastically to an average of 14,300 sacks per year in 1990 and 1991, a 570 percent decline. While the 1992 and 1993 harvests have increased to over 150,000 sacks, harvest potential is still severely depressed because of frequent closures of "conditionally" approved and approved areas resulting from deteriorating water quality. (Cirino, J., 1995)

Sea Star Industries has been granted permits by the U.S. Army Corps of Engineers (ACOE) for installation, testing, and operation of the first Sea Star relaying test systems in U.S. federal waters offshore of Fort Morgan, Alabama, and Ship Island, Mississippi. The ACOE Section 10 (Rivers and Harbors Act) permit is the first ever granted for an oyster cleansing operation.

The FDA recognizes two types of controlled shellfish purification: depuration and relaying. Depuration is accomplished in onshore, closed systems utilizing recirculating seawater that is disinfected with ultraviolet radiation, ozonization, or other methods. Contaminated shellfish are harvested and transported to the depuration facility for 48- to 72-hour, mandatory cleansing periods that must be followed by confirming microbiological testing to insure completion of the cleansing process. The process is relatively expensive and practiced primarily in the soft- and hard clam fisheries. To date there are no successful oyster depuration facilities in the United States because of high costs per unit of cleansed oysters.

Relaying is accomplished under natural conditions in "approved" or "open" waters and requires a minimum of 4 to 7 days with confirming bacteria and *E.* coli tests on the relaid shellfish stocks. The relaid shellfish are transplanted from "closed" to "open" shellfish growing waters where they purge contaminants and potential pathogens during natural feeding and elimination processes.

On-bottom relaying involves the harvesting, transplantation, cleansing, reharvesting, and landing of bivalve mollusks. Relayers risk stock losses from burial and sedimentation, predation by high-salinity predators, and incomplete final harvests. These factors can reduce initial relaid stocks by 25 percent or greater, thereby increasing financial risks of the shellfish producer. Off-bottom or containerized relaying as proposed with this grant request, involves the use of holding devices that reduce these losses by protecting the shellfish and ensuring their complete post cleansing recovery. These off-bottom devices use multiple-tiered "bottoms" for the relaid shellfish, thereby using smaller areas more efficiently.

Containerized relaying of oysters was pioneered in the late 1970s by Mr. Richard Gollott of Biloxi, Mississippi, with the support of Dr. Ed Cake

and his associates at the Gulf Coast Research Laboratory. The relaid oysters successfully purged and laboratory tests confirmed the cleansing of *E. coli*; however, no economy of scale, capital funding problems, resistance from private oyster fishermen, and the tragic sinking of the dredge/transport barge and the loss of its captain ended Mr. Gollott's containerized relaying efforts.

On-bottom and off-bottom relaying is not extensively used in the Gulf of Mexico region at present because of seasonal availability to harvestable oysters in "open" (approved) growing waters. The continuing decrease in "open" shellfish growing areas, the decrease in shellfish production from over harvesting, mismanagement, and environmental problems, and the advent of *V vulnificus* (and the potential shut-down of the Gulf oyster industry) will result in an increased need for controlled purification of oysters if the supply is to keep up with consumer demand. Therefore, an economically viable method must be developed to insure a continuous market supply of high-quality oysters. The Sea Star oyster relay test device was specifically designed to potentially fill that purification need.

Abstract

Open Ocean Aquaculture- An Oil Company Perspective

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As an operator that has conducted several open ocean aquaculture projects, the discussion will focus on oil company attitudes regarding platform disposal vs. reuse for open ocean aquaculture. The discussion will include details on the advantages and disadvantages of the aquaculture scenario to an operator, particularly in the absence of enforceable liability relief, the normal contract restrictions of oil operations and the overlying problems with a myriad of governmental agencies/regulatory regimes. Essentially, without a significant change in attitude and government involvement it is doubtful whether open ocean aquaculture utilizing oil and gas platforms will ever be a viable option to disposal. A detailed discussion of our experience and what is required to conduct aquaculture operations in the Gulf of Mexico, specifically the problems and issues surrounding the four basic categories of biology, engineering, operations, and marketing will be presented. Included will be details on the limited species that are available for aquaculture in the Gulf and the absence of proven, viable open water containment systems. Further, any system that is established must deal with day to day issues of personnel, transportation, feed and general security around the farm site. Harvest, delivery and marketing of product will be discussed. Lastly, an overview of economics, i.e. the cost of offshore operations (manned or unmanned), will be presented.

Abstract

Constraints of Operating on Petroleum Platforms as It Relates to Mariculture: Lessons from Research

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As the opportunities for mariculture around petroleum platforms evolve the planning for these "new enterprises" will need to include the activities common on working production platforms. These activities include the logistical support via vessel and air transportation, daily platform operation as well as less frequent ventures that could potentially interfere with mariculture activities. Additionally there are safety policies, evacuation procedures and general cooperation that will be critical factors in assuring that the overall risk and burden to the platform operators is minimized while still maintaining a viable mariculture operation.

During 10 years of cooperative research activities on platforms in the northern Gulf of Mexico we have encountered events that limited our access to certain areas of platforms and in some cases halted work. Activities such as painting, welding, drilling and reworking wells, electronics repairs, and equipment repair and replacement may lead to short-term or long-term constraints to a mariculture operation. Increased activity on a platform can also lead to lodging shortages while common activities such as painting, drilling and reworking wells may close down access to certain areas due to safety concerns. Drilling activity also can include the discharge of drilling muds that decrease visibility and may have deleterious impact on cage culture operations in a limited area. The logistical support required by oil and gas activities can also include the long-term stationing of vessels on site, creating significant surface currents and hazards to mariculture activities.

Unfortunately, many of the events mentioned here occur with little advance notice so mariculture operations should have contingency plans for such interruptions.

Abstract

The Move Offshore: Costs, Returns and Operational Considerations from the Entrepreneurial Perspective

Sebastian Belle, President
EconAqua
Groton, Massachusetts

A number of cage systems are available that facilitate the movement of fish farms into offshore exposed locations. Using bioeconomic modeling techniques, currently available cage systems are reviewed in terms of their initial investments and potential impacts on the production economics of a theoretical farm. Major factors impacting production costs and Return on Investment are discussed. A review of several existing offshore projects is used to discuss theoretical and practical considerations in the operation of offshore facilities.

Abstract

Offshore Aquaculture Development in Australasia, Four Issues to Overcome

Neville Thomson
Marine Production Systems, Ltd.
Auckland, New Zealand

Offshore aquaculture in Australasia is greatly impacted by four major factors; the market, costs of production, technology/expertise and funding avalability.

The last three are well known to those who are involved in any aquaculture industry BUT especially those in the offshore industry.

We never have enough money, funding is incredibly hard to get and the industry (due to no significant historical borrowing record) is regarded as a venture capital risk. Even IF we could afford to pay the interest!! Offshore aquaculture costs money, don't go out there under funded.

Reliable tried and proven technology and personnel are now available The capacity to buy specialist expertise and the equipment has vastly improved and has been developed at someone else's expense. IF, you choose an unknown or commercially undeveloped species, you will be entering a major minefield. Double your budget!

Costs of production in most instances can be accurately assessed by sound financial feasibility studies based on proven systems and farm management cost comparisons. Feed technology is required to ensure that your major expense is competitive. Cost control and financial management in any farming operation must always be practised rigidly.

In Australasia, by far the greatest impact on the development of offshore aquaculture is that of the marketplace. In many instances in New Zealand and Australia, the major market is many miles and hours by plane, speaks a different language, is of a different culture, is not supported by an established distribution network, has a fluctuating market price depending on supply from wild fisheries, has different levels of hygiene and different levels of duties, agents fees and distribution costs.

The main part of the presentation will focus on the techniques applied and trends within industry to reduce the risks associated with offshore aquaculture development and planning in this type of environment.

Abstract

NOAA Fisheries and Aquaculture

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Sustainable Fisheries
and
Edwin Rhodes, Aquaculture Coordinator
National Oceanic and Atmospheric Administration
Silver Spring, Maryland

The National Marine Fisheries Service (NOAA Fisheries), part of the National Oceanic and Atmospheric Administration (NOAA), is one of the key agencies with responsibilities for aquaculture in the United States. Since its origins in the 19th century, NOAA Fisheries and its predecessor agencies have played a significant role in aquaculture. The efforts by the agency in its 126-year history have contributed some of the key science in the field of aquaculture, including research that led to the commercial development of salmon, shrimp and shellfish culture.

Since the 1980s, agency priorities focus on fisheries management, coupled with budget limitations, have restricted the participation of NOAA Fisheries in aquaculture. Very recently, aquaculture has reemerged as an important area for NOAA Fisheries as it plans for the new century. This new interest in aquaculture has as its basis the recognition that even restored and sustainable wild stock fisheries will not be able to support a growing domestic and international demand for seafood. Additional world production in fisheries products will largely come from aquaculture, and NOAA sees an excellent opportunity for the application of U.S. technology and management to sustainable aquaculture. The development of environmentally sound U.S. aquaculture will lead to economic opportunities both domestically and abroad from increased fisheries production and to the exportation of technology, goods and services.

The new interest in aquaculture within NOAA and NOAA Fisheries has led to the development of policies and plans to support the development of environmentally sound aquaculture. This planning and policy development stage is critical because it is through this process that agency priorities are set and budgets are driven. The new NOAA Fisheries strategic plan, published in May 1997, has as one of its objectives to promote the develop-

ment of robust and environmentally sound aquaculture and outlines some specific goals in the areas of technology development, siting, permitting and financial assistance. Particularly pertinent for offshore aquaculture is the strategic plan goal to identify areas in coastal waters and the EEZ suitable for environmentally sound aquaculture development.

NOAA has a new aquaculture policy made effective in February, 1998. For offshore aquaculture development, key goals of the policy are the facilitation of the permit approval process for the EEZ, while at the same time promoting responsible development of the industry. It is the intent of the policy to have NOAA identify areas within the EEZ that are apt for aquaculture development, taking into consideration the desire to reduce conflicts with other users of the EEZ and to minimize the potential for negative environmental impacts. Among other topics, the policy also addresses technology development and financial assistance to businesses.

This policy and planning activity has helped aquaculture achieve substantial new visibility within NOAA. NOAA looks forward to working with all constituents in implementing these plans and policies, and in fostering an important new industry.

Design and Analysis of a Self-propelled Open-ocean Fish Farm

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Abstract

The cage production of marine finfish is a well-established method of commercial aquaculture. To date, nearly all of this activity is confined to near-shore waters offering some measure of protection from environmental extremes. Concerns about the environmental impact of discharges from these operations and user conflicts has hampered the growth of this industry worldwide. New cages are being developed by industry that can withstand open-ocean exposure. This will greatly increase the opportunities for industry expansion and reduce user conflicts. The environmental concerns will also be reduced as the energy associated with these exposed sites will help in the dispersion of cage discharges. However, as long as a fish farm is associated with a specific site, concerns will remain over its impact on the seabed below.

This paper discusses a new concept in open-ocean fish farming - The Ocean Drifter. This system is an adaptation of the Sea Station™ cage manufactured by Ocean Spar Technologies® of Bainbridge Island, Washington, U.S.A. Unlike conventional operations, Ocean Drifter is not anchored. It would drift with ocean and coastal currents but have a capability for self-propulsion. The approach is particularly suitable for locations which experience reciprocal tidal currents or gyres. In such cases, a general operating area could be maintained with only minor use of propulsion. Windage and current shear would provide sufficient water exchange for the maintenance of a good growing environment. The current assisted movement of Ocean Drifter, combined with brief anchoring, could be used to exploit the movement of optimal temperature with season or allow the delivery of a crop to a convenient location for harvesting. Ocean Drifter could be designed to be manned or to operate autonomously.

Model tests on Ocean Drifter have recently been carried out by Massa-

chusetts Institute of Technology (MIT) at the David Taylor Model Basin (DTMB) in Bethesda, Maryland. Drifting and self-propelled operations were simulated in calm water and in waves. The results of these tests are reported in this paper. Motions and internal loads of the 1/10 scale model are analyzed. The power required for various levels of self propulsion are reported.

Implications of the Ocean Drifter on global finfish production will be discussed as well as issues of liability and registration. The implications of various modes of operation will also be presented and the economic efficiency of operating in reciprocal or gyre currents explained. Strategies for their operation as manned or autonomous platforms will be discussed.

Background

Increased demand for quality seafood together with reductions in commercial catch due to depleted stocks present unique opportunities for the growth of marine aquaculture. As a result, the global production of aquaculture products has increased by 200 percent between 1985 and 1994 to a level of 18.5 million metric tons (MMT) worth $33.5 billion (New, 1997).

Two growth areas have emerged, offering even greater opportunities for seafood production and sustainable coastal economi ‡development. These two areas are the land-based production of fish in recirculating systems and the culture of marine species in the open ocean.

Land-based recirculating aquaculture involves the use of tanks and water processing equipment to allow the culture of fish in a closed environment (Belle et al, 1996). Through a combination of filters, a bio-reaction unit for nitrifying ammonia, a sterilizer, and aeration, the same water can be used again and again. While it is possible to include a further treatment processes that totally eliminates the need for any water changes, a more common approach is to replace 5 to 10 percent of the water each day. Nitrates are thereby kept at a safe level, while water usage is such that controlled-temperature grow-out is feasible. In addition, water discharges are small enough that complete post treatment is achievable, allowing any discharge standard to be met.

The second emerging method of aquaculture is open-ocean fish farming. It differs from the conventional pen-raising of fish is several important ways. First, it is carried out in areas fully exposed to the ocean. The benefit of this high-energy environment is the rapid and effective dispersion of waste products produced by the fish, essentially eliminating the potential buildup of this material on the seabed beneath an installation. However, special measures are needed to ensure the survivability of the system and its

product. Survivability can be achieved by size or robustness of the system, by submergence, or some combination.

Outwardly appearing as the opposite ends of the aquaculture spectrum, these two emerging methods are actually very related. They are both technology based approaches which depend on recent advances for commercial cost-effectiveness (Croker, 1996). In the U.S. these methods are being developed in response to the requirements of the Clean Water Act, legislation that restricts the discharge of pollutants into U.S. waters. It is logical that the growth of aquaculture would include both approaches depending on the species under cultivation. In addition, open-ocean operations would likely be dependent on shore-based, recirculating hatcheries to supply animals for on-growing.

The Impediments

In the United States, an impediment to the growth of open-ocean fish farming is the array of regulatory requirements imposed on any proposed activities (Snow-Cotter, 1995). A second impediment is the lack adequate legislation to cope with user-conflict issues and matters of the exclusive use public waters for private operations (Goudey, 1996; Hayden, 1998).

It must also be pointed out that neither land-based recirculating systems nor open ocean systems are universally accepted as commercially mature technologies. In addition, the list marine species that can be considered fully commercialized is short, though progress is being made towards bringing additional species to commercial readiness.

To date nearly all applications of sea farming technology in the U.S. have been in sheltered-water locations. Aquaculture sites are typically established after a rigorous public review and permitting procedure. The finfish cages are typically rafts or circular plastic rings supporting netting enclosures whose shapes are maintained by weights along their lower perimeters. These cages or arrays of cages are held in place with elaborate anchoring systems.

The vast potential of the worlds oceans will remain untapped until finfish and shellfish grow-out systems are developed that reflect the harsh realities of full ocean exposure and are demonstrated to cost effective. The remainder of this paper describes an innovative approach that may revolutionize ocean-based fish farming.

Ocean Drifter

In 1996, a novel offshore fish farming system was introduced (Loverich and Goudy, 1996). This patented technology (U.S. Patent) is called Sea

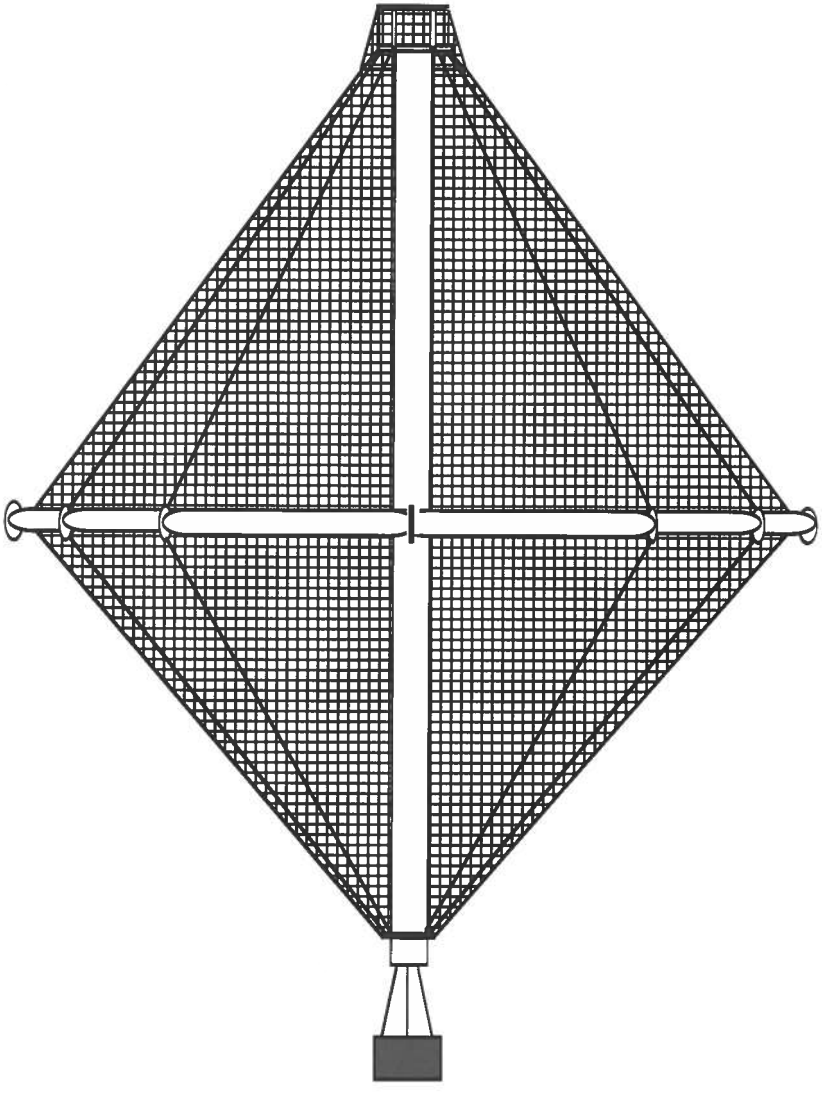

Fig. 1. A drawing of Sea Station™ prototype I.

Station™ and it is pictured in Figure 1. It is composed of a single vertical cylinder called the spar buoy. This central spar is surrounded by a large-diameter rigid ring. Running from the ring to the top and bottom ends of the spar are two cones of containment netting.

The advantages of Sea Station™ over conventional cages are numerous. Most important, however, is that the resulting volume of contained

growing space is stable and does not collapse in a current as with most cages. In addition, the taut netting is important for durability and predator control. The design has been proven in several locations worldwide including Puget Sound, Long Island, N.Y., and the Philippines. To date, these cages range in volume from 1,000 to 3,000 cubic meters. They are designed to be anchored like conventional cages but they can be submerged in the event of extreme weather.

The Ocean Drifter is an extension of this proven technology. It is larger than Sea Station™ and intended to be operated without a designated site, continuously moving within large, predetermined area. The advantages of this approach is that by drifting over a large area, concern over negative impacts to the seabed is eliminated and the operation becomes ecologically sustainable. The approach would simplify the often costly and time consuming permitting process associated with obtaining the exclusive use of a site. The ability to move would allow the operation to avoid toxic algal blooms or other pollution threats. Ocean Drifter could respond to the seasonal changes in water temperature, optimizing fish growth and health by strategic positioning . Obviously some form of control must be exercised over an unmoored pen to prevent catastrophe. Through constant position monitoring and a means of self-propulsion, the Ocean Drifter could provide important advantages over conventional fish-farming methods.

Through a project funded by the Sea Grant Industrial Fellowship Program, research has been conducted, aimed at the development of this novel approach to open-ocean aquaculture. The project, is a collaboration between the MIT Sea Grant College Program and Ocean Spar® Technologies, LLC.

Along with the advantages cites above, the Ocean Drifter introduces new challenges. A continuously moving sea farm will need to operate in the larger sounds, seas, and oceans and will have to survive the severest marine weather conditions.

Our initial task was the characterization of Sea Station™ using model tests. Tests were accomplished in the summer of 1996 on a 4.5 scale model using the DTMB wave tank. In addition, OST personnel towed Sea Station™ Prototype I, a 2000 m^3 cage, in Puget Sound, gathering additional resistance and operational data.

Based on these results, a propulsion/maneuvering system was devised. This system included two parallel propulsors on the submerged ring facing "aft" and one steering thruster facing "sideways." For the purposes of the model tests, the two primary propulsion units were thrusters from a Benthos MiniROVER Mk II remotely operated vehicle. The steering thruster was a

Table 1. Principal dimensions of the Ocean Drifter.		
Ring diameter	270 ft	82.3 m
Height	174 ft	53 m
Normal draft	150 ft	45 m
Light draft	75 ft	23 m
Volume	1,572,750 ft^3	44,550 m^3
Displacement	313 LT	317 T

Table 2. Model Description.			
Scale		1/15	
Diameter		18 ft	4.9 m
Height		11.6 ft	3.5 m
Draft		10 ft	3.0 m
Volume		466 ft^3	13.2 m^3
Displacement:	ring	73 lbs	33 kg
	spar	135 lbs	61 kg
	total	208 lbs	94 kg

smaller unit from a MiniROVER Mk I. These thrusters provided a convenient means of accomplishing the tests, though their design is not viewed as necessarily appropriate for this low-speed application.

We developed a preliminary Ocean Drifter design based on the geometry of the Sea Station™ model. The size of the system is aimed at equaling the largest of conventional sea cages currently in commercial production. Table 1 provides the basic prototype dimensions. The model dimensions follow in Table 2.

The Ocean Drifter model tests were also done in the DTMB wave basin. This 360-foot long by 240-foot wide by 20-foot deep facility is ideal for the evaluation of such systems. A test program was developed to address the factors we viewed as important to the further development of the Ocean Drifter concept. This test program is described in Tables 3 and 4. All tests were done both with and without the net deployed.

Data acquisition was through a hard-wire tether from the model to the wave basin carriage. The sensors were connected to a Computer Boards CIO-SSH16 simultaneous sample and hold/gain adjust interface. This fed a PC-mounted Computer Boards CIO-AD16Jr A-D conversion board. Data capture and presentation was accomplished using Snap Scope.

Table 3. Model testing program.
Calm water resistance
Bollard tests
Self propelled tests
Seakeeping in regular waves
Drifting in irregular waves

Table 4. Model instrumentation.

Parameter	**Instrumentation**
Heave	Z accelerometer
Surge	Y accelerometer
Sway	X accelerometer
Ring bending Mom.	Strain gages (x 13)
Resistance	500-lb submersible load cell
Bollard thrust	500-lb submersible load cell
Speed	Carriage display
Wave data	Manual input
Thruster watts	Manual input

Model Test Results

The results of the Ocean Drifter model tests are presented below in Figures 2 through 5. In these figures, data points are typically based on the average of 20 seconds of measurements, recorded at a sampling rate of 1000 Hz. The resistance and bollard pull load cell was calibrated manually over the full range of these test loads.

As is our usual practice for cage seakeeping tests, regular waves were used to determine the response of the system to various input frequencies. However, the unrestrained drifting tests were done using computer-generated wave spectra. For the self propelled tests, the carriage speed was carefully adjusted to match the speed of the model for each thruster setting and the velocity was recorded from the on-carriage display.

The lines connecting the data points in Figures 4 and 5 are simply interpolations and included for clarity, not meant as fitted curves.

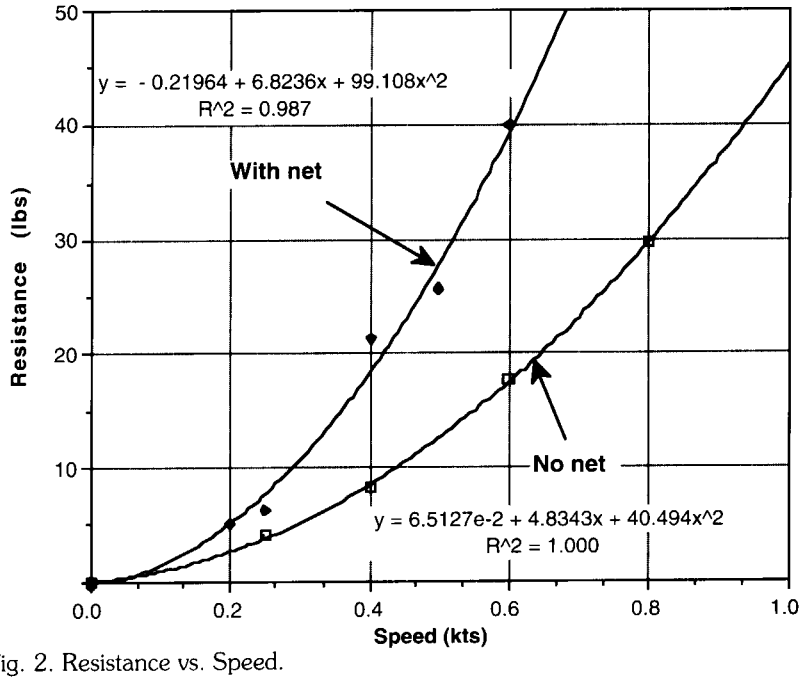

Fig. 2. Resistance vs. Speed.

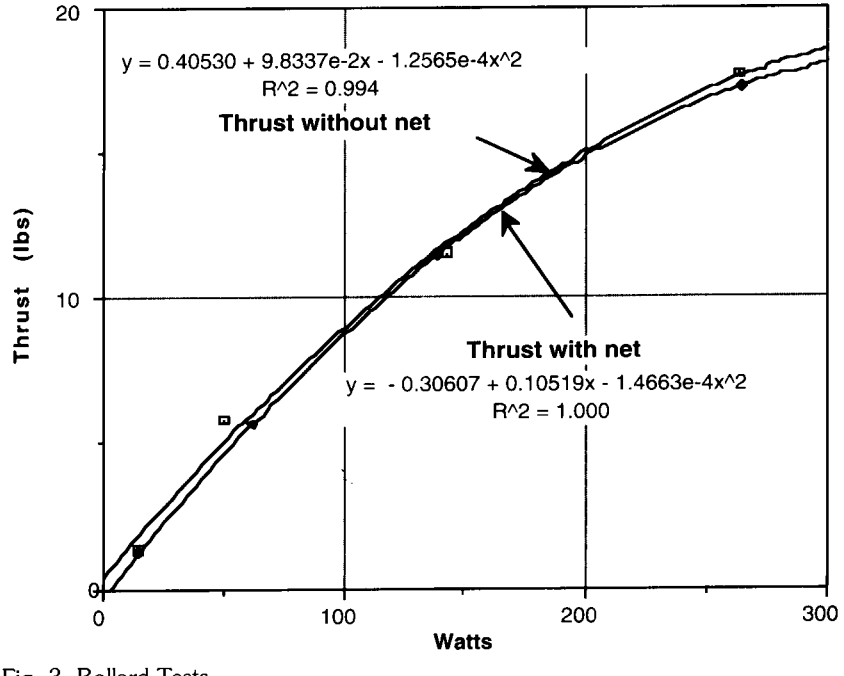

Fig. 3. Bollard Tests.

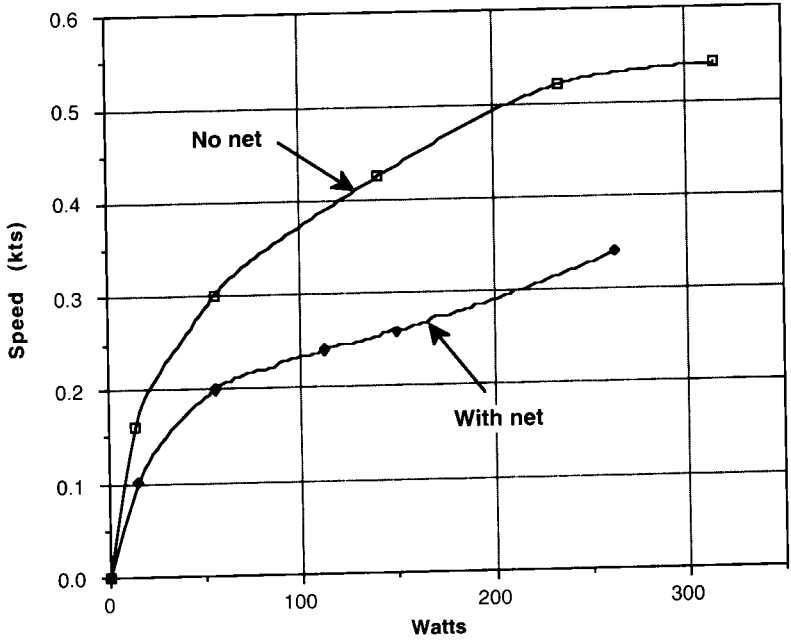

Fig. 4. Speed vs Power.

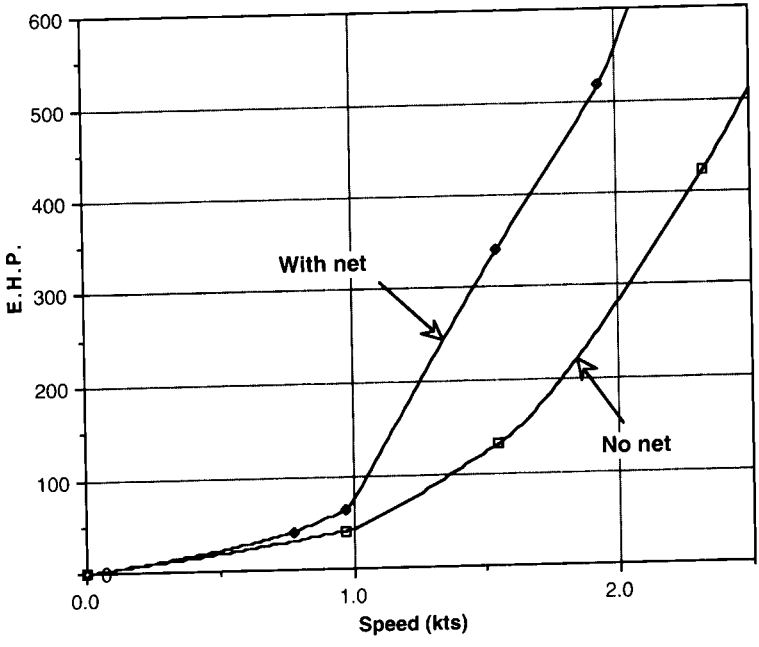

Fig. 5. Predicted Full-scale E.H.P. vs Speed.

Discussion

Figure 2 reveals that the containment net represents over half of the system resistance and therefore actual resistance will be a strong function of the netting used and level of bio-fouling. The predictions presented in Figure 5 were based on a simplified Froude-based scale up of the model results, ignoring the conventional ship model data reduction techniques which separate wave-making and frictional resistance components.

The similar results of the two bollard tests indicates that the net has only a minor influence on the zero-speed performance of the thrusters. In spite of the size and proximity of the net to the thruster intakes, the high porosity of the netting results in little change to the velocity field seen by the propulsor.

While the calculation is tempting, an extraction of an overall system efficiency is of little use. The performance requirements of the ROV propulsion units used in the model tests have no relation to those required for low-speed, high-drag cage propulsion. Optimal propulsors for Ocean Drifter would be larger in diameter for low-speed efficiency, with little regard for reverse performance.

It may also be advantageous to configure a structural system that includes two submerged rings, rather than one. This approach offers more growing volume for a given draft and dismeter. It also increases the ratio of volume to containment netting surface area. Both factors should offer increased cost effectiveness. An example of such a configuration is shown in Figure 6.

Conclusions

1. The ring-mounted propulsor arrangement provided effective propulsion with good maneuverability.
2. Propulsor performance is only slightly affected by the presence of the net.
3. Low-speed propulsion can be achieved with low power.
4. Maneuverability can be achieved without steering thruster.
5. The arrangement tested is tolerant of one thruster failure.

Future Plans

We have several data-analysis tasks ahead of us prior to completion of this phase of our development. An analysis of the Ocean Drifter model seakeeping data is planned as those results will be useful in determining the conditions under which husbandry operations can occur.

We will identify a preliminary operating speed and develop an optimal

propulsor arrangement using propeller prediction software. This propulsor design, combined with the effective horsepower (EHP) predictions will provide a sound estimate for our next project phase which is the modeling of Ocean Drifter performance in flow fields and realistic ocean circulation patterns.

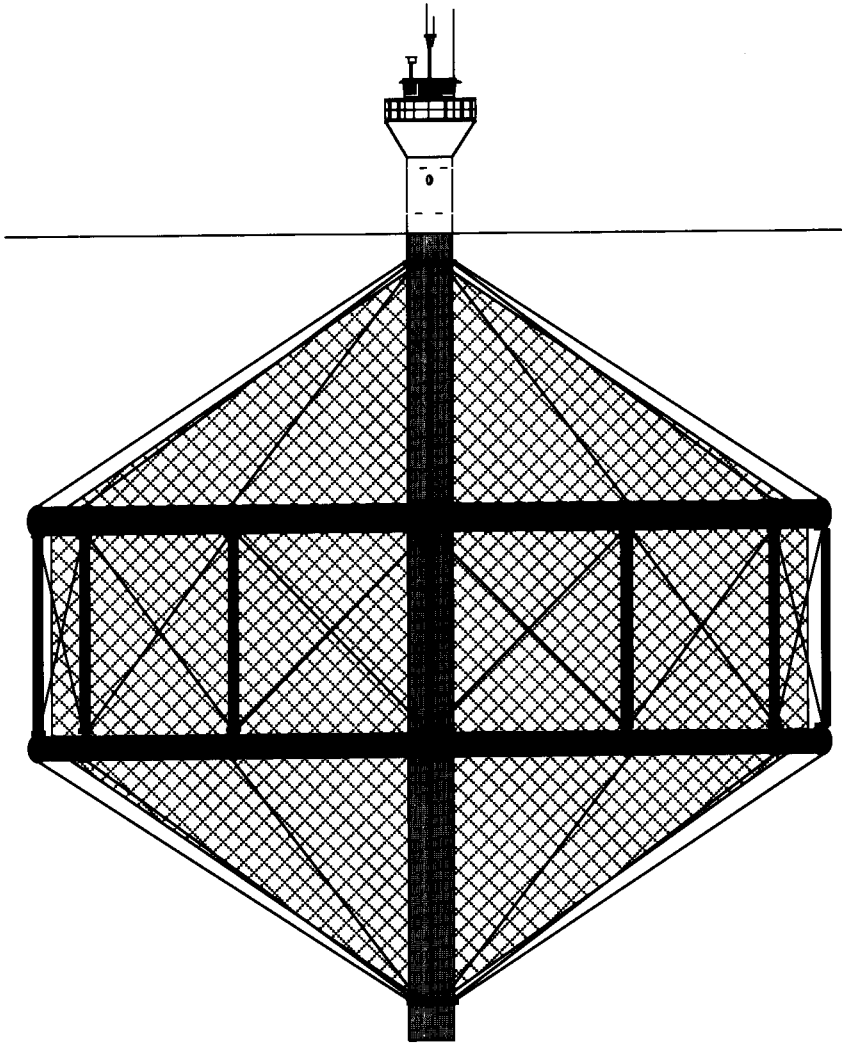

Fig. 6. A conceptual design of a two-ring ocean drifter.

As discussed earlier, the continuous movement of the fish farming operation is desirable from an environmental standpoint. However, given the substantial and predictable tidal driven currents in many of the world's oceans, this movement will not require continuous powered operation. Given the reciprocal or rotary nature of most tidal-driven currents, the propulsion system may see only occasional use for course corrections needed to counteract wind-induced currents.

Since tidal currents are predictable and subject to computation locally, the Ocean Drifter position corrections could be made at very low speeds compared to the local speed of the entraining current. Such corrections would keep Ocean Drifter within a designated area. For operations such as servicing or harvesting, the Ocean Drifter could be vectored to a temporary shallow water anchorage.

Strategies for the efficient operation of Ocean Drifter will be developed which will strive for minimal energy use, the development of techniques for achieving navigational way points, and methods of risk reduction in the event of approaching storms. This project phase will conclude with a detailed design of a prototype Ocean Drifter sufficient for cost estimation. This design document would include all the Ocean Drifter sub-systems required for deployment as an operational fish production system, including fuel, feed, fresh water, accommodations, etc.

Based on the availability of funds, we will begin the prototype Ocean Drifter construction, deployment, and evaluation. Initial evaluation will involve engineering trials designed to measure the predictive capabilities of our modeling methods and obtain detailed data on component performance and reliability.

With the engineering trials complete, Ocean Drifter will begin operational trials with its first crop of fish. Understanding the behavior of fish in a captive environment is essential to good husbandry practices. Due to the sheer size of Ocean Drifter, unconventional methods for fish observation may be needed. Scuba diving is a common approach to this task on conventional floating pens. Through the inclusion of a submerged diver lockout system, this practice could continue.

As a manned platform capable of self propulsion, Ocean Drifter would be governed by normal maritime laws. However, with the availability of command, communication, and control hardware, the autonomous operation of the system could be considered. Such unmanned operation would introduce a challenging area of regulation but the potential cost savings make its exploration attractive. We also plan to explore strategies for fleet operation where one service vessel would tend an array of Ocean Drifters, either manned or unmanned.

Acknowledgments

Research described in this paper has been sponsored by the Sea Grant Industrial Fellowship Program, the MIT Sea Grant College Program, and Ocean Spar Technologies®, LLC. I would like to acknowledge the assistance of several collaborators including Gary Loverich, R&D Director at Ocean Spar Technologies® whose advice and guidance has proved essential. Jon Etxegoien, an engineer at the DTMB has been especially helpful is providing support to the model tests.

Neil Best, currently an engineer at M. Rosenblatt & Son, Inc. was the first-year Sea Grant Industrial Fellow for this project. He helped launch the project and has maintained involvement ever since. Chris Lake is a graduate student in the MIT Ocean Engineering Department and served as the second-year fellow. Langley Gace, an engineer at Ocean Spar Technologies, and Bill Upthegrove, a model technician, assisted in the 1998 Ocean Drifter model tests.

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U.S. Patent 5,617,813 Anchorable mobile spar and ring fish pen.

Abstract

Recent Practical Experiences with Ocean Spar® Offshore Sea Cages

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The application of Class 2 Ocean Spar Sea Cages in New Brunswick and Puget Sound has again shown that this sea cage system has excellent performance in high current and at exposed sites where Class 1 gravity cage systems have failed. In addition, experience with in situ cage cleaning, mort collections, fish grading, transfer and harvest have shown that these cages offer operating advantages that yield cost reducing features needed by the cost competitive salmon market. Furthermore, the application of a high performance Spectra® knotless netting to the cages has reduced the drag of the cages, resisted biofouling, and reduced the overall weight of the net pen by a factor of 0.30 times that of comparable strength nylon netting. Of particular interest have been the underwater observations of sea lions attempting and failing to attack salmon raised in the Ocean Spar cages.

The Class 3 Sea Station sea cage has been employed on three working farms: One farm growing summer flounder in Long Island Sound and two farms growing milkfish offshore in the Philippines. Although each sea cage is the basic Sea Station design, the flounder cage and the milkfish cage required specialized designs suited to the fish species being grown. In particular, the anchoring systems for the summer flounder cage had to be enhanced to prevent wave induced rotation between the spar buoy and the rim so that twisting motions of the netting would not abrade the flounder resting on it. This has not been a problem with the Sea Stations used for other fin fish that routinely swim in the interior volume of the sea cage and away from netting. One innovative and progressive Filipino farmer has grown large saltwater prawns in a Sea Station along with milkfish. Of particular interest is the efficiency of growing fish in Sea Station compared to the traditional method of rearing in dikes ponds. The extensive pond culture practiced in the Philippines produces 1 ton of milkfish/hectare/year. On the other hand a single 3,000-cubic meter Sea Station that

occupies 1/20 hectare of sea surface will produce at least 255 tons of milkfish per year. This is particularly important in SE Asian countries where the practice of pond culture has ruined many coastal areas.

Our experience with Sea Station suggests that the configuration is particularly adaptable to the Gulf Coast of the United States. Our experience operating from small open boats proves that Sea Station can be utilized by smaller business entities seeking entrepreneurial opportunities. Additionally, production records and financial statements from the farms in the Philippines show excellent return on investment. Sea Station can be easily arrayed to work well in conjunction with decommissioned oil rigs. The Sea Station is submersible and even when floating, tests suggest it is the best heavy weather sea cage available, again indicating good potential for deployments in the Gulf of Mexico.

Offshore Aquaculture from the Perspective of a State Regulatory Agency

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Austin, Texas

Introduction

Welcome to this beautiful part of the state. I hope that you have enjoyed the conference so far. Longer ago than I care to remember, I had a dream and a life's ambition of being involved in open ocean aquaculture. This was back in the days of graduate studies in the school of Oceanography at Texas A&M University. I shared this dream with Granvil last fall and sure enough here I am standing before you today. Guess I could consider this presentation a fulfillment of a dream. However, my purpose today is to give you some ideas on how best to deal with the state regulatory environment primarily from a Texas purview. My life took some interesting turns since those early days. For twelve years I worked for the domestic shrimp harvesting industry in their trade association and then for the past 8 _ years in the Texas Parks and Wildlife Department, first as the Chief of Coastal [marine] Fisheries and most recently as Director of Intergovernmental Affairs. I hope this gives me a somewhat useful perspective to share with you in this conference.

The topic "Offshore Aquaculture from the Perspective of a State Regulatory Agency" is meant to give you a focus and a feel as to what might be some significant issues in the process of a state's relationship to open ocean aquaculture as well as some background as to how the current statutory environment was established.

My presentation will cover:

1. Mission, organization, and possible points of interface between the Parks and Wildlife Department and firms attempting to initiate open ocean aquaculture;
2. Texas' attention to aquaculture both through legislative and agency actions; and
3. Issues that need to be considered in working with Texas Government on possible open ocean aquaculture operations.

Texas Parks and Wildlife Department Overview

The Texas Parks and Wildlife Department is the state agency given the challenge to manage, protect and conserve the states' wildlife resources [including fishery resources] as well as the state parks system. It is directed by nine commissioners appointed by the Governor for periods of six years. The commission hires an executive director who is the chief executive officer of the Department. Internally the department is divided up into ten divisions to include the Law Enforcement Division, Coastal Fisheries Division, Resource Protection Divisions, and Inland Fisheries Division. These are probably the divisions that would be most likely to interface with the offshore aquaculture industry. A senior member of the Coastal Fisheries Division staff represents the state on the Gulf of Mexico Fishery Management Council as well as the Gulf State Marine Fisheries Commission. The first serves as an advisory group to the Regional Administrator of the Southeast Region of the National Marine Fisheries Service, and the latter is an interstate compact between the five U.S. states bordering the Gulf of Mexico. While neither of these entities have a direct regulatory role, they are looked to by policy makers for advice on issues of a fishery management nature in the Gulf of Mexico. Later in this presentation I will cover in more details what may be the issues in offshore aquaculture that would be handled by these various divisions.

State Attention to Aquaculture

Legislative Actions

While I am not aware of any active policy that the state has concerning offshore aquaculture I think that a brief review of some legislative activity in the past ten to fifteen years might be instructive in determining future plans for industry development.

In 1981 under extreme controversy, the state legislature placed red drum [*Sciaenops ocellatus*] and spotted sea trout [*Cynoscion nebulosus*] in the category of game fish/protected species and took them off the commercial market. Prior to that time these were the most popular commercially harvested finfish. As a result of the void created, fish less well known to the consumer were brought into the market and were accepted.

Texas leadership was proactive in this area and it was several years before other Gulf states took similar actions to protect these same fish. During this period the market continued to prosper in the Gulf region, creating problems for enforcement of the Texas laws against commercial harvesting of protected fish. In due course a body of law was established to

require a detailed paper trail for seafood products sold or transported into Texas. The elements of the law were even more detailed when protected finfish were involved.

The success of the catfish aquaculture industry in the central Gulf states during the 1980's caught the attention of the state leaders. In addition researchers at Texas A&M University had received worldwide attention in development of shrimp aquaculture techniques. These efforts were making the headlines and attracting attention as well. These industries seemed to provide an opportunity to take advantage of a decline in finfish availability.

In 1989, the state legislature considered and passed the "Fish Farming Act of 1989." Prior to passage of this act, the Parks and Wildlife was the principal state agency involved with the aquaculture industry. The department was attempting to carry out a regulatory, wild stock protection, and promotion role. The legislature viewing that the full opportunity was not being realized by aquaculture under this regime, transferred the focus of the aquaculture industry to the Texas Department of Agriculture. The Parks and Wildlife was basically left with a mandate to permit non-indigenous species brought into the state for aquaculture purpose. There was also an Aquaculture Executive Committee established in state government consisting of the Chairman of the Parks and Wildlife Commission, the Commissioner of the Agriculture [a state-wide elected official] and the Commissioner of the General Land Office [also a state-wide elected official]. This group was meant to bring a higher profile to the aquaculture industry to insure its development was not hindered by the state bureaucracy. Provisions were also made in the legislation for the position of an "Aquaculture Liaison Officer" to coordinate activities of the Executive Committee and be the single point of contact for the industry within state government. The solitary focus in 1989 was land-based aquaculture.

Also in 1989, the Legislature considered and passed the Artificial Reef Bill for the purpose of establishing a series of reefs off the coast to attract both recreational fishermen and divers to the Texas coast. An earlier presentation to the conference reflected on this program. In short, provisions would allow owners of oil or gas production platforms to donate these to the Parks and Wildlife Department along with half the savings that the owners would accrue compared to removal options. This continues to be a very successful program.

In 1991, the next legislature [the Texas Legislature meets in regular sessions every two years for 140 days] modified some of the changes made by the Fish Farming Act of 1989, by eliminating the Aquaculture Liaison Officer and the power of the Aquaculture Executive Committee to adopt

rules over fish farming operations. While perhaps cosmetic, the bill did change the language in the appropriate sections from "fish farm" to "aquaculture." In addition, language between Parks and Wildlife statutes and laws of the Department of Agriculture dealing with commercially protected fish were brought into harmony. This completed the effort begun in 1989 to transfer the licensing of aquaculture facilities to the Department of Agriculture.

In 1995 to further protect against illegal harvest, the legislature took action to require that any fish defined as "protected" brought into the state for sale must have been raised continuously on a prepared feed containing 20% or more of plant protein or grain by-products and must be in marked containers as required by law. Marine fish listed by the Legislature as being protected include blue marlin, jewfish, longbill spearfish, red drum, sailfish, snook, spotted sea trout, striped bass, tarpon, white marlin, and any hybrids of these fish.

In the session of 1995, attempts were made to transfer more of the authority for aquaculture back to the Parks and Wildlife Department. This issue which originally was generated by the Texas Department of Agriculture was met with fairly broad support from the industry. It became embroiled; however, with issues dealing with effluent from the currently operated shrimp farms in coastal locations and eventually failed.

Between the 1995 and the 1997 Legislative sessions, the Natural Resources Committee of the State Senate conducted a study of the Aquaculture Industry in the state and presented to the legislature a proposal that would expand the Parks and Wildlife role in the aquaculture industry as well as incorporate other elements of state government into an oversight/regulatory role on aquaculture to deal with the increased concern for diseases being transmitted from aquaculture facilities to wild stocks. Again the primary concern was from shrimp aquaculture.

Departmental Actions

With the statutory fluctuations noted above, the role and involvement of the Parks and Wildlife Department in aquaculture have been fluid and evolving. The best description of the Department's responsibilities in aquaculture can be described as multi-faceted. Since the evolution of marine aquaculture, the agency has been interested in protecting native stocks of fish and other aquatic resources. The tension has increased over the past five to ten years when shrimp aquaculture began development along the coastal areas of Texas utilizing non-indigenous species. The impacts from such operations both from water quality as well as a disease transmission has become alarming to the public and that alarm has been transmitted to state leaders.

With its long coastline, Texas is closely tied to the marine environment. The seafood industry traditionally has contributed some half billion dollars annually to the state's economy. By far the largest sector of seafood industry is made up of shrimp harvesting. The harvest of oysters, blue crabs and finfish make up a substantially lesser portion of the overall. In view of statutory and regulatory actions, a general perception may be that the state leaders oppose the seafood industry. This is not the case nor has it been shown to be the case with the aquaculture industry. Unfortunately the overall responsibilities of the Department to protect the wild stocks have required greater restrictions on both the traditional seafood harvesters as well as the aquaculture industry. It should not be perceived that any seafood operation whether traditional or innovative such as open ocean aquaculture will be view in an adversarial relation by the Department.

Fishery managers represented in the Department are confronted every day with issues reflected as a greater number of harvesters on a smaller fishery resource base. In that regard it would seem that efforts to enhance the native harvesting capacity, support the citizens of the state interested in an economical and plentiful seafood supply and stimulation of economic development along the coast of Texas would be met with a positive response, if properly approached. The latest annual assessment of U.S. marine fish stocks by the National Marine Fisheries Service found that nearly a third (96 of 279 identified species) are over fished or are approaching an over fished condition. With the heavy involvement of the federal government in fishery management for more than 20 years, this finding is significant and compounded by the increased the demand for seafood products. These factors obviously cause a critical problem for government.

In the aquaculture arena, the Department's principal efforts have been directed by its statutes for permitting non-native species for aquaculture application, enforcing regulations on finfish marketing especially as related to protected species of finfish, and reviewing aquaculture facilities water discharge permits. More recently the Department was been involved with the issue of disease in aquaculture facilities and the possibility of any pathogens being passed to the wild stock. While not fully equipped to handle this new problem area, authority for quarantining diseased ponds have been enacted.

Issues

Issues that I suggest require review in conjunction with any effort to conduct open ocean aquaculture operations off the coast of Texas are the following:

1. Consider the jurisdiction—Due to the process by which the Republic of Texas joined the United States the state retained its 9 nautical mile territorial sea. All other states except for Florida, along its West Coast, have a 3-mile territorial sea. Of course inside of state jurisdictions, logistics might be advantageous, but should ensure that the state climate for this activity is properly prepared. There will also be similar considerations if the facility falls under Federal jurisdiction.
2. Consider the state regulations of importation of fish—This may not be a problem in other Gulf states, but could prose problems in Texas if not anticipated. As mentioned above, in order to protect against illegal harvesting of protected species, the Texas Legislature established a detailed scheme for marketing seafood by ensuring the proper license, documentation and in the case of protected species, the proper packaging is present with each shipment of seafood entering the state. In determining market strategy, it is important to know any requirements for importation into the targeted state seafood market. When the marketing strategy is being developed, consideration should be given to discussion of plans with the Department's Law Enforcement Division or counterpart agencies in other states. Of course Federal authorities will also be involved if operations are in the Exclusive Economic Zone.
3. Consideration of impact on native stocks—The protection of native stocks and the ecosystem that supports them is critical to any fishery management regime whether at the state or federal level. In that regard, it would be useful to work with the agency having either a direct or an indirect role in protection of wild stocks in the area of the operations. If land based aquaculture can be any yardstick in this regard, being considered a "good neighbor" can become a full time job. In the unpredictability of harvesting from the wild, any perception of degradation of the native population can cause significant problems with traditional fisheries.
4. Use of state liability protection—a key to the success of the artificial reef program is the state's acceptance of liability for platforms in the program. Efforts to use that umbrella of protection in support of a commercial venture may pose some significant problems for state leaders with a responsibility to minimize state liability whenever possible. If the thought of using offshore oil and gas platforms as foundations for an open ocean aquaculture operations are implemented a clear understanding of liability issues, long term maintenance issues, and final disposition issues, must be fully explored and resolved.

The bottom line from a regulatory agency's standpoint is that constructive communication at the initiation of the project development and operation will save time and dollars overall. I feel that the Department and the state would welcome review of a sound program to conduct open ocean

aquaculture off the Texas coast; however, the issues I have addressed here as well as possibly other developed during the course of project design will need to be considered and resolved.

In closing let me say that in blissful ignorance I admire the pioneering spirit that brought this conference together and offer my assistance at the state level in helping to better focus the state issues that would arise with such a venture.

Session 5: Biological Candidates for Culture and On-shore Hatchery Support

Overview of a Modern, Shore-Based Hatchery for Offshore Mariculture Support

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Abstract

The first critical hurdle facing the development of an offshore mariculture industry is the availability of high quality seed required to stock the pens or cages. First estimates for the requirement of seed based on the possible offshore sites discussed so far are staggering (≅9,000,000,000 by 2000). In fact, the main flaw in most business plans concerning offshore mariculture is the absence of a real plan concerning seed availability, including the realistic costs. The shortage of seed is due mainly to the difficulty in culturing the early life stages of marine species. Most marine fish hatch at a small size, requiring some form of micro-invertebrate prey initially and marine crustaceans go through multiple metamorphic stages, requiring many different food types (algae and micro-invertebrates). These food requirements mean that in order to culture the desired commercially valuable species, one must also culture or supply larger quantities of required prey species. While it may be possible to site a component of the hatchery offshore on larger platforms, it may be more cost-effective to site the food production, hatchery and maturation systems onshore. This, of course, reintroduces the specter of competition for coastal resources and coastal zone management, something that offshore aquaculture was supposed to eliminate. This represents the second hurdle to the development of mariculture because there are some real disadvantages to location on the coast, e.g. nearshore pollution, lack of biosecurity, competition with industry and recreation and environmental fluctuations. However, the advent of commercial closed, recirculating aquaculture systems should ameliorate these disadvantages by reducing both the need for influent water supply and the dis-

charge of effluent. The improved control needed for initial life stages will be easier to maintain in recirculating systems, especially biosecurity. Many new technologies for the automated culture of algae and micro-invertebrates are being developed. The Japanese, world leaders in offshore mariculture, have until recently based their production on the availability of wild seed. Recent developments in Japan (e.g. new government facilities, regulations and research) suggest that they realize that a dependable source of cultured seed is essential for the future success and growth of aquaculture in Japan. Other recent developments suggest that they are diversifying their industry to include onshore recirculating aquaculture systems. A similar pattern appears also to be occurring in Europe. A comprehensive plan for mariculture development in North America should recognize the strengths and shortcomings of each type of production system while focusing resources and energy on the development of appropriate commercial technology.

Introduction

Global aquaculture production has risen at a rate of 10.9 percent over the last decade. In fact, 25.6 percent of the world's fishery production is now attributed to aquaculture (Tacon 1997a). Looking at the latest production statistics (Figure 1), it is clear that marine finfish and shellfish are minor contributors to the actual aquaculture production, 2.1 percent and 4.1 percent, respectively (Rana 1997). However, due to their greater relative market value, they contribute more (a factor of 4 times) to the value of aquaculture products, 8 percent and 17.3 percent, respectively. The marine finfish culture industry produced 573,332 mt in 1995 up from 209,684 in 1984 at a growth rate of 9.6 percent/yr during the 11-year period and at 13.2 percent/yr during the last five years (FAO 1997; Pedini and Shehadeh 1997). Much of the finfish mariculture production is achieved using nearshore cages and offshore cages and net pens (Pedini and Shehadeh 1997).

There are many critical issues facing the development of offshore mariculture and most are described in detail in this volume. One group of critical issues can be considered to be societal and technological constraints concerning facility siting (e.g. pen design, mooring systems, navigation and environmental concerns) (Hayden, 1998; Helsley 1998; McElwee this volume; Kruse this volume; Conforti this volume; Rayburn this volume). These constraints result from our lack of technology or lack of adequate governmental policy and procedure. They frequently impede progress but rarely cause the complete failure of a project unless mismanagement has occurred. The next grouping of critical issues is that of economics; it is expensive to build and operate facilities offshore (Belle this volume; Johnson and Breed

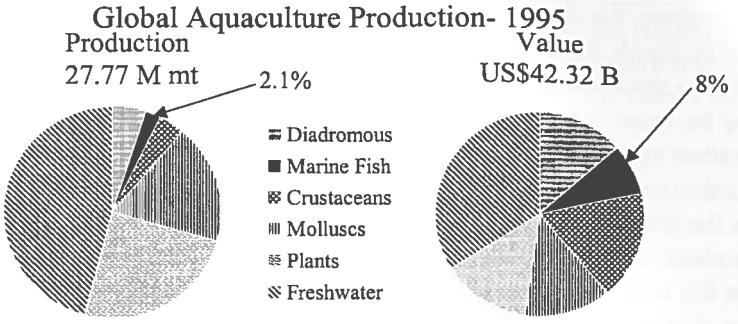

Fig. 1. Global aquaculture production by class in 1995 (Rana 1997). The pie chart on the left is a breakdown by millions (M) of metric tons produced and the pie chart on the right is by value in billions (B) of US dollars.

this volume; Wilson and Stanley this volume; Thomson this volume; Loverich this volume). These expenses include construction and other capital costs, labor and management, operating costs (e.g. feed, repairs and marketing) and transportation. Once again these costs rarely cause the failure of a project unless one or more costs have been significantly underestimated or price of the product drops significantly in response to increased supply. For example, the value per mt of salmon and sea bass/sea bream decreased over 29 percent from 1984 to 1995 (unadjusted for inflation) and 50 percent and 1990 to 1995 (adjusted for inflation), respectively, due to increased production and market saturation (Bartley 1997a; Lem and Shehadeh 1997). The last of critical issues concerns the biology of the cultured species and exposes gaps in our knowledge and technology. These biological constraints include the supply and biosecurity of broodstock and seedstock- the subject of this review.

Of all the critical issues facing offshore mariculture, the most constraining at present is the availability of high quality seed required to stock the pens or cages (Fukusho 1996: Savage et al. 1998; Johnson and Breed this volume). You cannot start an industry unless you have the raw resources on which to base production- in aquaculture that is the seedstock. First estimates for the requirement of seed based on the possible offshore sites discussed in this volume are staggering. In fact, the main flaw in most business plans concerning offshore mariculture is the absence of a real plan concerning seedstock availability, including the realistic costs. The shortage of seedstock is due mainly to the difficulty in culturing the early life stages of marine species. Most marine fish hatch at a small size (halibut eggs are 0.9 mm compared to salmon at 6 mm, Wray 1998), requiring some form of micro-invertebrate prey initially. These food requirements mean that in or-

der to culture the desired commercially valuable species, one must also culture or supply larger quantities of required prey species. While it may be possible to site a component of the hatchery offshore on larger platforms, it may be more cost-effective to site the food production, hatchery and maturation systems onshore. As a result, even in cases when seedstock production technology appears to be adequate, seedstock availability rarely meets the demands of the industry (Pedini and Shehadeh 1997). The need for modern onshore hatchery and food production facilities and their design is the topic of this review. Furthermore, recommendations will focus on the development of offshore mariculture in North America while most of the industry experiences that will be reviewed are taken from the Japanese and Mediterranean mariculture industries.

Status of the Industry

Mariculture is an international business but most of the production is centered in the Orient (FAO 1997). The Japanese account for 5.1 percent of total world aquaculture production, ranking third in the world (Rana 1997) and they culture >50 percent of the marine finfish (FAO 1997). The Japanese consider food a strategic resource just as most Americans consider oil a strategic resource. Being an island nation, food from the sea is particularly valuable (per capita consumption is 67.8 kg in Japan compared to a global average of 13.4 kg) and government and industry have worked in a partnership to develop this resource (Bartley 1997b). The best example of the investment that the Japanese have put into mariculture is the chain of fisherman association and prefectural aquaculture facilities that dot their coastline (49 prefectural, 21 city and 53 fisherman associations; Fukusho 1996). Currently, there are more than 50 major facilities, each of which cost between 2-7 Billion Yen (US$750,000,000-2,400,000,000 total cost). These facilities house research programs that focus on the hatchery production of finfish fry, mollusc larvae and crustacean larvae while a few also include grow-out systems. They require extensive food culture systems for algae and micro-invertebrates that are fed to the fry and mollusc and crustacean larvae. At the present time, most of the production is used for stock enhancement and offshore mariculture.

The Japanese are world leaders in nearshore and offshore mariculture because most of the population prefers marine finfish to freshwater finfish-eels being the exception. The mariculture of food fish is based on the net pen culture of sea bream and yellowtail, 72,185 and 169,765 mt in 1995, respectively (FAO 1997). The Japanese have until recently based their production almost solely on the availability of wild fry. Recent developments in

Table 1. Projected production levels of seedstock at the Nagasaki Prefecture Marine Laboratory. This modern hatchery and fisheries research station is estimated to cost 10 Billion Yen or US$86,000,000 (Anonymous 1997b).

Yellowtail	500,000
Bartail	300,000
Abalone	500,000
Urchins	500,000
R&D- tilefish, grouper, rockfish, whelk, sea cucumber	

Japan (e.g. new government facilities, regulations and research) suggest that the industry realizes that a dependable source of hatchery cultured fry is essential for the future success and growth of mariculture in Japan. The largest mariculture facility in the world, the new Nagasaki Prefecture Marine Laboratory (Table I), has recently been constructed by the prefecture government and industry at a cost of 10 Billion Yen (US$86,000,000). It contains a hatchery, maturation facility, larval food production systems, net pens and processing plant (Anonymous 1997b). The financial goal of this facility is to add 40 Billion Yen per year from fisheries products to the local economy by 2011. Despite their heavy investment in mariculture facilities (>US$1,000,000,000), few of the Japanese facilities produce more than 10 Million fry and larvae per year for a total of 500 Million/yr (≅$2/fry or larvae). The figures speak for themselves; mariculture is big business in Japan and inspires heavy investment.

A similar pattern appears also to be evolving in Europe, especially southern Europe (Tacon 1997b). Production of sea bass, sea bream, mullet and flatfish in the Mediterranean has risen to over 54,000 mt in 1994 and 60,000 in 1996 from a level of ≅5,000 mt in 1984, a rise of >1000 percent in a decade (Table II; Pedini 1996). Production of sea bass and sea bream is projected to increase to >100,000 mt by 2000 and will require 1.1 billion fry (Hjul 1997). This increase in production is attributable to the increased trade opportunities created by the formation of the European Union (EU), generous financing of infrastructure by the EU, mastering of fry production techniques, development of better formulated feeds and use of sea cages as the favored production system (Pedini 1996). Figure 2 shows the current production levels by country and year, respectively. The greatest increase is in sea bass and sea bream production where the fry are produced in hatcheries and the potential for increase is limited only by the

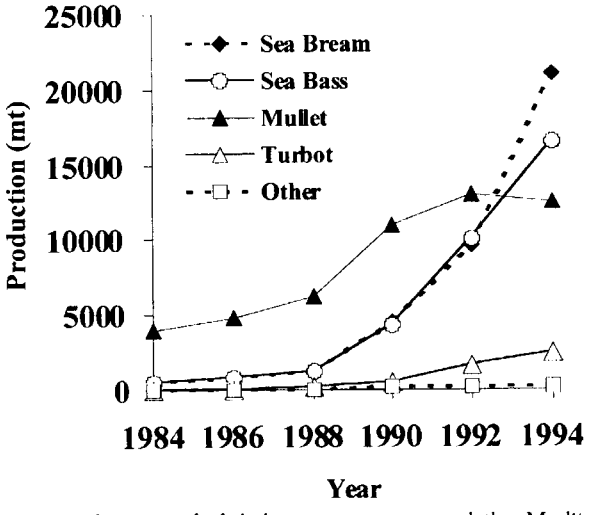

Fig. 2. Production of marine finfish by countries around the Mediterranean Sea during the period of 1984-1994 (Lem and Shehadeh 1997).

Table 2. European marine finfish production in metric tons (mt) of food fish and hatchery production of fry in millions M (10^6) (Bauce 1997; Anonymous 1997a; Hjul 1997; Wray 1997a, 1997b, 1998; FEAP 1998).

- Mediterranean sea bass and sea bream production was 54,570 mt and 236 M fry in 1996 and 70,000 mt and 310 M fry in 1997. Production is predicted to be >100,000 mt by 2000.
- Greece produced 21,000 mt (40 percent of total) and 95 M fry in 1996.
- Turkey produced 12,000 mt in 1996.
- Italy produced 6,500 mt and >60 M fry in 1996.
- Spain produced 5,600 mt and 6,000 mt in 1996 and 1997, respectively and one hatchery produced 1.2 M fry in 1996.
- Flatfish production was ≅3,200 mt in 1997.
- Norway produced 70 mt of halibut in 1994 and 138 mt in 1996.
- France produced 852 and 950 mt of turbot in 1996 and 1997, respectively.
- Spain produced 1,890 and 2,225 mt of turbot in 1996 and 1997, respectively. They are projected to grow more than 3000 mt and 2 M fry in 1998.

market (Lem and Shehadeh 1997). Most recently, similar hatchery techniques are being applied to flatfish, especially the turbot (Wray 1997a, 1997b). The production of mullet, on the other hand, appears have been stable for the last five years, apparently due to the fact that production is dependent on wild fry. This represents a reasonable comparison of the expected sustainable growth rates for finfish production when one is dependent on wild fry and the other is not (Pedini 1996).

Current Needs

The US Department of the Interior and Department of Commerce do operate large, modern freshwater hatcheries for sport fishing and salmon stocking programs that approach the scale of investment seen in Japan and Europe (National Science and Technology Council, 1996). Together these hatcheries had a yearly operating budget of ≅US$60.5 M in 1994, over half of the total amount that the US government spent on aquaculture-related activities that year. In comparison, the US has yet to establish a single fisheries development facility of this scale for mariculture. There are several university, government and private research facilities scattered around the country that have developed strong programs in mariculture of fish, molluscs and crustaceans. However, none could come close to producing the quantity of seedstock needed to support even a pilot-scale, offshore mariculture project much less a large-scale operation. This is a major impediment to the development of an offshore mariculture industry (Katz 1996).

In terms of immediate research focus, the US aquaculture industry and research community must select a few appropriate target species or genera for screening and then standardize protocols between laboratories for their commercial evaluation. This is the one biological issue which has been at least partially addressed on a research basis; many scientific publications on spawning of marine finfish are available. Several of the later chapters in this volume and the previous volume review the characteristics of many potential target species (Drawbridge and Kent 1998; Ostrowski 1998; Benetti et al. this volume; Davis et al. this volume; Ostrowski and Chambers this volume). However, the list is far too long and we can only afford to develop methodologies for a few initial target species with current research funding. Moreover, the commercial scale spawning of North American marine finfish species is lacking. The only truly commercial-scale marine finfish hatcheries in North America are for redfish restocking programs. However, redfish may not be the optimal species for offshore mariculture, especially in terms of market demand but they may provide the best candidate species for proving the technology.

The issue for discussion in this chapter is the selection of these species based on our current and potential future hatchery technologies. The growth of offshore mariculture will require massive amounts of fry and it will be expensive at first to produce them. Several hatchery facilities should be created immediately at existing laboratories and their efforts coordinated. A typical pilot-scale facility would require 10 to 25-5 mt hatchery tank systems for fry production in order to evaluate multiple species and/or compare rearing techniques over a 24 month time period. Concurrent with the initial target species selection process, facilities and methods for the commercial-scale production of algae and micro-invertebrate must be developed (Rusch and Malone 1991, 1993; Morizane 1991; Kanamaki and Shirojo 1994). The production of fry will require ever greater amounts of natural larval foods; this production is space and labor intensive, often requiring a magnitude of effort greater than maintaining the fry culture system itself. If the industry could then select 2 or 3 initial target species or genera with the highest probability of success based on market potential as well as biological characteristics (e.g. growth, feed conversion and fecundity), progress toward commercial scale production would accelerate.

Future Needs

Using the examples provided by the history of offshore mariculture in the Orient and the Mediterranean, several future goals for development in North America can be identified. The construction of and stable funding for several (2 to 4) world-class research hatchery facilities (cost >US$20,000,000) at appropriate locations along the temperate and subtropical coasts of North America is a top priority for the development of an offshore mariculture industry. These facilities would include programs in genetics, disease management, nutrition and reproduction and demonstrate commercial scale hatchery production of marine fish fry and invertebrate larvae. These facilities would also house flexible arrays of hatchery tank systems, large automated algae and micro-invertebrate culture systems (Fujita et al. 1982; Rusch and Malone 1991, 1993; Kanamaki and Shirojo 1994) and biosecure, closed, recirculating systems for broodstock maturation and spawning (Turk et al. 1997). Ideally, the facilities would be managed through a collaboration of government and industry and would pioneer technology that industry alone would not typically support (e.g. genetics improvement of stocks, basic nutrition research and disease management) but from which they would ultimately derive great economic benefit (Katz 1996).

The future goal should be to meet the demand for marine finfish fry created by a mariculture industry that is estimated to grow at a double-digit

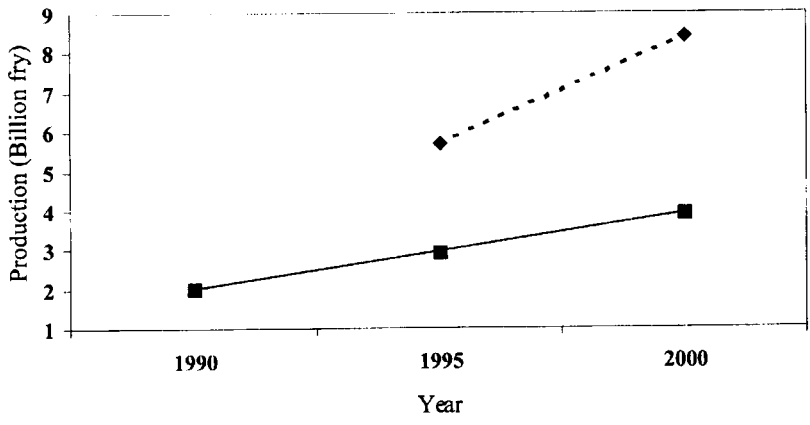

Fig. 3. Estimated world production of marine fish fry for the last 1ten years. The solid line represents the actual current production of ≅50% of the total needed fry and the dashed line represents the total estimated number of fry needed for all marine finfish production in the years from 1995 to 2000.

growth rate for the next ten years (Pedini and Shehadeh 1997). Hatchery production of marine finfish in 1990 was estimated to produce ≅2.7 B fry to support a final harvest of 225,000 mt and hatchery production in 2000 is projected to be ≅3.9 B fry to support a projected harvest of 350,000 mt (Figure 3). These production estimates equal approximately half of the world's total production from finfish mariculture (573,332 mt in 1995; FAO 1997) such that wild fry are still being used at nearly the same rate as hatchery spawned fry. This being the case, nearly ≅8.4 B fry would have to be produced in 2000 to supply the entire demand for finfish mariculture worldwide (Figure 3). To satisfy the need for this 8.4 B fry, it would require 1,000 hatcheries operating 365 d a year, each producing ≅100,000 fry/d (≅33,500,000 fry/yr each), estimating a 25 percent survival rate to the juvenile stocking size. Currently, the best hatcheries produce between 1-10,000,000 fry/yr with only 15 percent survival to stocking sizes (Fukoshu 1996; Wray 1997b).

Progress toward meeting the demand for marine finfish fry and shellfish larvae can be divided into two issues, one is the development of technology to produce the fry and larvae while the second is the cost-effective employment of the technology. The costs of the fry and larvae are as much a concern as their availability. One of the ways that the cost can be trimmed is through the use of automated systems that reduce the labor intensity of seedstock culture. The most commonly automated components of aquaculture systems are environmental systems (e.g. temperature, pH, dissolved

oxygen and photoperiod); feed management systems (e.g. input and cleaning); financial and inventory systems (e.g. accounting and maintenance); and filtration systems (e.g. exchange rate, backwashing and special filtration). The use of process control and artificial intelligence systems will make it possible for aquaculturists to reduce the operating costs and labor costs of aquaculture production systems (Lee 1991, 1993, 1995; Whitson et al. 1997), including hatchery and maturation systems needed for offshore mariculture. Aquaculture control systems result in: (1) increased process efficiency; (2) reduced production costs; (3) improved understanding of process; (4) reduced energy and water losses; (5) reduced stress and disease; (6) improved accounting (Lee 1995). Process control technology will undoubtedly be useful for the operation of offshore mariculture systems. too. These systems can be used to automate feeding, sense changing weather and sea conditions, sense stresses to sea cages and observe fish behavior (McCoy 1993; Whitsell and Lee 1994; Whitsell et al. 1997; Benetti et al. this volume).

Another critical goal for the future development of offshore mariculture is the identification of ideal candidate species (Katz 1996; Benetti et al. this volume; Davis this volume; Ostrowski this volume). Regardless of the market potential or price per kg (i.e. demand) for a particular fish species, its availability through culture will affect the supply and hence the commercial value of a cultured species. The first issues to be addressed are the control parameters (e.g. environmental and nutritional) for out-of-season spawning. This will require the development of regulated spawning techniques for each species and the advent of genetic selection/stock improvement programs (Bartley 1997a). It must be relatively easy to spawn in captivity and culture the fry to the stage at which they can be weaned to artificial feeds; the key is that few marine species are easy to culture. Their smaller egg size and resulting small hatching size as compared to freshwater fish is certainly one major obstacle but their very carnivorous life style is another major obstacle resulting in the need for large volumes of micro-invertebrate prey. The ideal marine species would be one in which large well developed fry hatch and feed immediately on standard cultured micro-invertebrate prey such as brine shrimp or rotifers. The fry should then be capable of being weaned quickly (<14 d) to artificial feeds; feed conversion should be excellent during most growth stages. There must also be a focus on the development of artificial larval feeds for marine fry (Fukusho 1996). This research can be coordinated with the research on production of natural larval foods so that partial replacement will be the first objective, followed by complete substitution. The ideal species would be tolerant of crowding and of a wide

range of temperature and salinity, allowing its use to be spread through the temperate and sub-tropical areas of North America. This species would also be one that could be spawned on cue so that production could be maintained out-of-season. No one species appears to possess all these ideal characteristics at this time but marine bass and flatfish species appear to hold the best promise.

A final area of future research centers on health related issues and biosecurity. Establishment of best management practices for each ideal species, especially disease management, will be essential to the success of fry culture (Katz 1996). The acceptance of standards for biosecurity in all hatcheries will act to insure the industry against catastrophic disease outbreaks. The biosecurity of broodstock systems will also be necessary to insure the health of the fry produced in biosecure hatcheries. Use of wild broodstock would eventually cause the same types of coastal zone conflicts as the collection of wild fry; we must develop dependable sources of healthy broodstock for each of these ideal species. Maturation feeds must also be improved before cultured broodstock can be used to sustain the demand for seedstock created by a growing offshore mariculture industry. The use of biosecure closed, recirculation systems will increase as the number of cultured broodstock increase and our dependency on natural waters will decrease (Lee 1995; Turk et al. 1997). These biosecure broodstock systems will also enable genetic selection programs that will lead to improved, domesticated stocks. The ability to environmentally isolate the broodstock lines and develop inbred families from which a variety of family crosses can be made is a requirement before growth of a mariculture industry can be sustained. The best evidence for increased emphasis on domestication and genetic improvement of marine finfish has been the >20-fold increase in scientific publications on mariculture genetics from 1980 to 1994 (Bartley 1997a). This pattern of development (e.g. improved biosecurity, improved nutrition and domestication) mimics the development of commercial broiler coops and feedlots in developed countries (Allison et al. 1991; Mottram and Street 1991), ensuring offshore mariculture will meet its future market potential.

Recommendations

A comprehensive plan for mariculture development in the US should recognize the strengths and shortcomings of each type of production system (e.g. recirculating tank, pond, nearshore cage and offshore cage and net pens) while focusing resources and energy on the development of appropriate commercial technologies. The most critical issues facing the development of on-shore hatchery and maturation facilities for the support of offshore mariculture are:

1. Construction and funding of a government/industry network of mariculture hatcheries (2-4) located on the temperate and sub-tropical coast of North America, focusing on applied research and commercial hatchery demonstration. This effort can be modeled on the prefectural aquaculture stations found in Japan.
2. Development and application of improved hatchery technologies, especially for large scale production of algae and micro-invertebrate prey. Automation of as many hatchery functions as is possible is considered advantageous.
3. Identification of ideal species for culture, focusing first on egg and hatching size and second on prey/food selection. Those species that hatch at a larger size will be much easier to provide with prey of appropriate size. These species must also be amenable to out-of-season spawning techniques.
4. Once optimal candidate species are identified, genetic selection programs must be instituted to develop biosecure, domesticated stocks, optimizing hatching size, disease resistance, conversion efficiencies and growth rate. Special facilities will be required to house these valuable stocks in biosecurity.

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Feasibility of Selected Candidate Species of Marine Fish for Cage Aquaculture Development in the Gulf of Mexico with Novel Remote Sensing Techniques for Improved Offshore Systems Monitoring

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Abstract

This paper is divided in two sections: (1) Biological and market criteria were evaluated to rank several pelagic, demersal, reef and coastal fish species into *experimental, technological* and/or *economical feasibility levels*, according to their respective prospects for commercial aquaculture development using offshore floating net cages in the Gulf of Mexico. Dolphin fish (*Coryphaena hippurus*), greater amberjack (*Seriola dumerili*), pompano (*Trachinotus carolinus*), yellowfin tuna (*Thunnus albacares*), bluefin tuna (*Thunnus thynnus*), Southern flounder (*Paralichthys lethostigma*), Gulf flounder (*P. albigutta*), mutton snapper (*Lutjanus analis*), red snapper (*L. campechanus*), gray or mangrove snapper (*L. griseus*), yellowtail snapper (*Ocyurus chrysurus*), groupers (*Epinephelus spp*), and red drum (*Sciaenops ocellatus*) are among the native candidate species whose potential for commercial aquaculture development in offshore systems in the Gulf of Mexico is evaluated in this paper. (2) Several methods exhibiting potential for solving some of the problems of large offshore aquaculture production systems are presented and discussed in this paper. These include a number of novel underwater imaging, detection, measurement systems and monitoring devices employing either optics, acoustics or a combination of both. Specifically, there is a need to monitor, in real time, the existing fish biomass in net pens. Coupled with a system that can monitor the volume of uneaten feed, this technology could be instrumental in minimizing feed losses, production costs and environmental degradation in and around the fish farming area. In addition, these remote sensing techniques

lend themselves to fast and accurate counting devices to monitor the transfer of stock from one system to another. Other useful applications of these methods range from *in situ* plankton counting and identification to detection of large potential predators and vessels. An optical system patented by HBOI provides a real time 3D laser generated "movie" of fish, displaying their movements (x,y,z) in a volume. Finally, environmental and legal issues associated with offshore platforms and their use for marine finfish aquaculture are briefly discussed in this paper.

Introduction

Marine finfish aquaculture production worldwide has been increasing exponentially during the 1990s (F.A.O., 1997). In 1995, total marine fish production was 532,000 metric tons (MT). Assuming a conservative steady annual percentage rate (APR) of 5 percent, total production by the year 2,000 will be 700,000 MT (Tacon, 1998).

Inshore and offshore net cages are the most widely used systems for commercial aquaculture of marine finfish in Asia (Ikenoue and Kafuku, 1992; Aoki, 1995; Chou *et al.*, 1995; Li, 1995; Liao *et al.*, 1995), producing more than 90 percent of the 7.5 million MT of high-value marine finfish worldwide between 1992 and 1995 (Main and Rosenfeld, 1995). Cage culture of marine fish has grown rapidly over the last decade in Europe, particularly in Greece and Spain with the gilthead sea bream (*Sparus aurata*) and the Mediterranean sea bass (*Dicentrarchus labrax*). Production of sea bream and sea bass in Europe increased from 1,000 MT in 1985 to 35,000 MT in 1994 and is expected to rise to 60,000-100,000 MT by the year 2,000 (New, 1997). Cage culture is also developing very fast in Australia, where southern bluefin tuna (*Thunnus maccoyii*) ranching has already become a multimillion dollar industry. Indeed, tuna ranching in Australia began in 1990 and is presemtly the largest bluefin aquaculture industry, with production of approximately 3,000 tonnes in 1997 (Smart *et al.*, 1998).

The most comprehensive review on cage aquaculture worldwide was made by Beveridge (1996), who compared the use of net cages with other growout systems such as ponds, embankments and tanks used for farming marine fish. Miget (1995) suggested that the marine fish industry in the U.S. could be developed in association with offshore oil rigs in the Gulf of Mexico. Indeed, the available infrastructure of thousands of inactive oil and gas platforms, combined with ideal year round water quality parameters, make the Gulf of Mexico an attractive option for the development of offshore cage systems for marine fish farming. Due to stringent regulations restricting the use of water and coastal areas for aquaculture, offshore sys-

tems represent the best alternative for the development of commercial fish farming operations in the U.S.. However, with the exception of salmonids and a few research projects, the production of high-value marine fish in inshore and offshore net cages in the U.S., Latin America and the Caribbean regions has been negligible and restricted to pilot scale operations (Benetti *et al.*, 1995a; Benetti *et al.*, in press).

Among the most important problems to be resolved before developing large scale cage culture systems in the Gulf of Mexico for are those related to liability, bonding, insurance and other legal issues associated with offshore platforms. Environmental issues must also be addressed. Poorly managed cage aquaculture systems can be detrimental not only to the ecosystem and biodiversity, but also to the sustainability and commercial viability of the operations. There have been problems related to environmental degradation associated with cage culture in the coastal areas of several countries (e.g. The Philippines, Norway and Scotland). However, environmental impact generally associated with cage culture in coastal areas should be insignificant at deep water platform locations. For instance, contamination of the sediments and benthos by pesticides and metals (mainly *copper* from copper-based paints used as antifouling agents and *zinc*, which is a component of fish feeds and is used in galvanized cage structures) would be negligible in an offshore environment due to the greater depth, strong water currents and distance from the shore. Proper cage farming management techniques include avoiding the use of chemical pollutants while improving rates of growth and food conversion, therefore minimizing wastes due to excessive excretion, uneaten feeds and feces. A limited amount of nutrients and solids will inevitably be released from the cage farming operations, but, eutrophication is not a threat in areas surrounding offshore cage systems. Even though the natural productivity of the water may be expected to increase to a certain extent, limited amounts of organic and inorganic pollutants can be assimilated by the carrying capacity of the offshore environment. Nevertheless, controls, such as the requirement of periodic environmental assessments of cage sites prior to and during project development, should be effected.

Feasibility levels

The criteria used for establishing the feasibility of each species are somehow subjective and restricted to the *level of control* and *results to date* related to the following aspects:

- *maturation*: broodstock availability and management;
- *spawning*: natural, environmentally conditioned and/or hormone induced;

- *larval rearing*: larval husbandry techniques;
- *survival rates*: during the larval rearing, nursery and growout stages

Experimental feasibility: *Research level.* The species is generally difficult to raise, with little or no control over maturation, spawning, and larval rearing. Survival rates from fry to harvest size are low (between 0-1 percent). The species has been and can be experimentally raised but results cannot be consistently repeated. Research at this level is generally conducted at universities or research institutions and is funded by government grants.

Technological feasibility: *Research and development level.* Control over maturation, spawning, and larval rearing vary greatly among the species. Survival rates are generally low to medium (between 1-20%). The species has been and can be raised but not yet at a profit. Results can be repeated consistently. R&D is generally conducted in private companies, universities and research institutions using both private and government funds.

Commercial feasibility: *Economic feasibility level.* Total control over maturation, spawning and larval rearing. Survival rates are generally medium to high (20-70%). The species has been and is being commercially cultured at a profit by the private sector.

Brief Overview of Selected Candidate Species

Biological and market considerations were evaluated to rank the following pelagic, demersal, reef and coastal fish species into the feasibility levels previously described. The species were ranked according to their prospects for offshore aquaculture using net cages in the Gulf of Mexico. Results are shown in Table 1, along with a brief overview of a few selected candidate species.

Bothidae

Paralichthys lethostigma, **Southern flounder**

The southern flounder, *Paralichthys lethostigma,* is a lefteye flatfish found along the U.S. east coast and Gulf of Mexico from North Carolina to Texas, but is absent from southern Florida (Robins *et al.*, 1986). Adults reach 60-91 cm (review by Pattillo *et al.*, 1997). The southern flounder is considered one of the top candidate species for commercial aquaculture development in the United States because it tolerates higher temperatures and lower salinities than most other flatfish species and can be therefore reared in a wider variety of environments. In addition, flounder have excellent market demand and price. A similar species, the Japanese flounder

Table 1. Feasibility levels of selected candidate marine fish species for cage aquaculture in the Gulf of Mexico.

Common Name	**Species**	**Feasibility**	**Potential**
Dolphin fish	*Coryphaena hippurus*	technological	good
Greater amberjack	*Seriola dumerili*	experimental	excellent
Pompano	*Trachinotus carolinus*	experimental	good
Yellowfin tuna	*Thunnus albacares*	experimental	very good
Bluefin tuna	*Thunnus thynnus*	experimental	very good
Southern flounder	*Paralichthys lethostigma*	technological	very good
Gulf flounder	*Paralichthys albigutta*	experimental	very good
Mutton snapper	*Lutjanus analis*	technological	excellent
Red snapper	*Lutjanus campechanus*	technological	excellent
Mangrove snapper	*Lutjanus griseus*	experimental	good
Yellowtail snapper	*Ocyurus chrysurus*	experimental	good
Red drum (red fish)	*Sciaenops ocellatus*	commercial	excellent
Orangemouth corvina	*Cynoscion xanthulus*	experimental	good
Nassau + other groupers	*Epinephelus spp*	experimental	very good
Red + other porgies	*Pagrus spp*	experimental	good

hirame (*Paralichthys olivaceus*) has been commercially raised in cages in Japan and Korea. According to the National Fisheries Institute, annual profits from farmed flounder in 1997 exceeded $100 million in Japan. For growing out flatfish in cages, it will be necessary to modify the bottom of the cage to some extent (Jeon *et al.*, 1992). It appears that Southern flounder has great potential for cage culture in the Gulf of Mexico.

Paralichthys albigutta, Gulf flounder

The gulf flounder, *Paralichthys albigutta*, is a lefteye flounder (Bothidae) found throughout the Gulf of Mexico to North Carolina, including southern Florida and the Bahamas (Robins *et al.*, 1986). Very similar to the southern flounder in appearance and general ecology, gulf flounder prefer higher salinities and are smaller, reaching a maximum size of 71 cm and 5 kg (review by Pattillo, 1997). The gulf flounder is another excellent candidate species for aquaculture development in the Gulf of Mexico. However, further research should be conducted with this species before an evaluation of its aquaculture potential is made.

Carangidae

Seriola dumerili, Greater amberjack

The greater amberjack, *Seriola dumerili*, is distributed worldwide in tropical waters. The jacks are among the most commercially important family of marine fish in the Indian and Pacific Oceans (Robins, 1986). Commercial culture of a similar species, the Japanese hamachi or yellowtail (*Seriola quinqueradiata*) has been conducted in other countries for several decades. Wild caught fingerlings of this species have been cultured in floating net cages in Japan since 1965 and adults are marketed worldwide for sashimi or sushi (Ikenoue and Kafuku, 1992). Recently, R&D work in Japan and Australia has been concentrated on another similar species, *Seriola lalandi*, whose pilot scale production has demonstrated excellent potential for expansion to commercial scale. The technological feasibility of maturation, spawning and larval rearing of another related *Seriola* species (*S. mazatlana*) has already been proven (Benetti *et al.*, 1995b; Benetti et al. *in press*). The establishment of a economic and commercial hatchery operation for greater amberjack, *S. dumerili*, will make this species a logical choice for offshore cage culture in the Gulf of Mexico.

Trachinotus carolinus, Florida pompano

The Florida pompano, *Trachinotus carolinus*, occurs in estuarine and coastal waters of the Gulf of Mexico and from the southeastern U.S. to

Brazil, but is most abundant along the Florida coast (review by Pattillo *et al.*, 1997). It is considered a good candidate for marine aquaculture and received considerable attention in the U.S. during the 1960's and 1970's (Moe *et al.*, 1968; Watanabe, 1995), but research has been discontinued. The Florida pompano would be suitable for cage aquaculture if the species is proven to be technologically feasible at the hatchery level. Adults prefer higher oceanic salinities (Pattillo *et al.*, 1997) and maximum growth rates occur at stable temperatures above 25°C (Finucane, 1969). Studies on Florida pompano in floating net cages suggest that using large offshore cages in areas such as the Gulf of Mexico may provide a favorable growout system (Watanabe, 1995). Wild caught fingerlings of Florida pompano have been experimentally reared in cages and ponds in Venezuela, Mexico and Ecuador.

Coryphaenidae

Coryphaena hippurus, **Dolphin Fish or mahimahi**

Dolphin (mahimahi), *Coryphaena hippurus,* are predatory pelagic fish distributed throughout the tropics and subtropics (Palko *et al.*, 1982). This species has considerable potential for cage aquaculture due to very fast growth rates and high fecundity. In flow-through seawater systems, captive reared fish fed artificial diets had growth rates that were among the fastest ever recorded for teleosts (Benetti *et al.*, 1995a). All technological aspects of dolphin fish aquaculture are controlled, but the economic feasibility of their aquaculture has not been realized yet.

Lutjanidae

Lutjanus campechanus, **Red snapper**

The red snapper, *Lutjanus campechanus*, inhabits coastal waters along the eastern U.S. from North Carolina to the Yucatan in the Gulf of Mexico (Robins *et al.*, 1986). Natural stocks have been overfished and the commercial fishery was closed in 1991 (Bennett, 1993). Spawning and larval rearing of this lutjanid is currently in the experimental stage (Phelps *et al.*, 1996). In Taiwan, the intensive culture of *L. argentimaculatus,* a species closely related to *L. campechanus,* is already well established with growout taking place in culture ponds and cages (Liao *et al.* 1995). Another similar species native to the Pacific ocean, *Lutjanus guttatus*, has been successfully spawned and experimentally raised in cages in Costa Rica and in Mexico. The red snapper is an excellent candidate for cage culture in the Gulf of Mexico, once larval rearing and fingerling production protocols are established.

Lutjanus analis, **Mutton snapper**

The mutton snapper, *Lutjanus analis*, is a popular native game fish and a promising candidate for cage aquaculture development in the Gulf of Mexico. The mutton snapper exhibits fast growth and survival rates, is resistant to diseases and has a high market value. Wild caught mutton snapper have been spawned and larvae reared in captivity by Watanabe *et al.* (1998) and Benetti and Feeley (in prep.). Hatchery reared 4-month-old juveniles would be suitable for stocking in offshore cages for growout. Watanabe *et al.* (1998) reported that juveniles grew from a mean weight of 10.5 g to 140.8 g after 71 days in recirculation seawater tanks (48 fish/m^3). With financial support, the aquaculture of this species could be rapidly expanded from the R&D stage to commercial production.

Lutjanus griseus, **Gray (mangrove) snapper**

The gray snapper, *Lutjanus griseus*, is a ubiquitous resident of the Gulf of Mexico and the western tropical and subtropical Atlantic inhabiting estuaries, riverine, mangrove, shallow bay and offshore coral reef environments. The gray snapper has good potential for cage aquaculture because it tolerates a wider range of temperatures and salinities than most snapper species and is a commercially important high quality food fish. Gray snapper has been successfully spawned and their larvae reared through metamorphosis (Benetti and Feeley, unpublished), however the viability of sustained spawning and larval rearing needs to be further investigated.

Ocyurus chrysurus, **Yellowtail snapper**

The yellowtail snapper, *Ocyurus chrysurus*, is another important Lutjanid native to the Gulf of Mexico and western Atlantic ocean. Some experimental trials on their spawning and larval rearing have been conducted with limited success in Texas (Riley *et al.*, 1995; A. Davis, University of Texas Mar. Sci. Inst., pers. comm.) and in Florida (T. Capo, University of Miami, pers. comm.). Survival rates during the larval rearing are still very low and laboratory reared fingerlings exhibit slow growth and high food conversion rates. A considerable amount of R&D work must be conducted before evaluating the commercial aquaculture potential of the yellowtail snapper.

Sciaenidae

Sciaenops ocellatus, **Red drum**

The red drum, *Sciaenops ocellatus*, is an important estuarine and coastal gamefish of the Gulf of Mexico and eastern United States. Since 1990, commercial harvest of red drum has been closed in the Gulf of Mexico due to overfishing pressure driven by the popularized Cajun style "blackened

redfish" recipe (review by Pattillo, 1997). However, the sale of farm raised fish is legal and the Florida Department of Agriculture has proposed guidelines to lipid test farmed fish to distinguish them from their wild caught counterparts. Red drum are one of the few marine species whose culture is commercially established and exhibits very good growth and survival rates. Maturation, spawning, larval rearing, fingerling production and growout technology is readily available. It is an excellent candidate species for cage culture in an offshore environment. Red drum has been introduced from the U.S. to several countries throughout the world. This species is commercially cultured in cages in Asia (Taiwan) and experimentally in Ecuador. Red drum juveniles and adults prefer high salinities with maximum growth occurring at 35 ppt and are eurythermal, with adult fish moving offshore to avoid cooler temperatures (review by Pattillo, 1997). Other Sciaenidae species with potential for cage culture in the Gulf of Mexico is the orangemouth corvina (*Cynoscion xanthulus*).

Scombridae

Thunnus albacares; **Yellowtail tuna;** *T. Thynnus,* **Bluefin tuna**

Found worldwide in temperate, subtropical and tropical waters, the bluefin tuna, *Thunnus thynnus*, and yellowfin tuna, *T. albacares* are commercially important fish species whose aquaculture potential have been recently partially developed. Ranching wild caught tuna in cages is a common practice in the Mediterranean and in the Pacific. In Australia, 8-12 kg juvenile northern bluefin tuna are caught offshore, stocked in cages for growout until they reach market size of 20-30 kg. Growout period is only approximately 3 months; specific growth rates (SGR) are 5% of their body weight per day. However, spawning, larval rearing and fingerling production of tuna is only at the R&D stage in Japan (bluefin) and in Panama (yellowfin). In the U.S., the fishery is based solely on wild caught fish. When tuna hatchery operations are technologically feasible, then the U.S. can begin to consider offshore cage culture of *Thunnus spp.* in the Gulf of Mexico.

Serranidae

Epinephelus spp., **Groupers**

The *Epinephelus* genus is a large subgroup of the Serranidae family consisting of medium to large tropical and subtropical species that are recognized for their commercial value as food and ornamental fish. A considerable amount of information is available in regards to grouper aquaculture (Tucker, 1994). Floating cage growout of grouper is practiced in Thailand (Ruangpanit and Yasiro, 1995) and other Asian countries. Groupers are

recognized as the most commercially important cultured commodity in Hong Kong, Taiwan and the Southeast Asian region (Kuo *et al.*, 1988). It takes approximately a year to get 9-10 cm fingerlings to reach a market size of 1 kg. However, the larvae are extremely delicate and survival rates to the fingerling stage are still low. Nevertheless, several species of groupers of the genus Epinephelus are commercially raised in many countries in Asia, particularly Singapore, Japan and Taiwan. If fingerlings are available, native Gulf of Mexico species (*E. striatus*, *E. morio*) are very good candidates for cage aquaculture based on reported growth rates and commercial feasibility of other species in the Asian Pacific *Epinephelus sp.* (Kuo *et al.*, 1988).

Sparidae

Pagrus spp., **Porgies**

The sea bream, *Pagrus major*, has been cultured in Japan since 1965 and today, 90% of production is supported by hatchery reared fingerlings with growout being conducted in floating net cages (Kumai, 1995; Main and Rosenfeld, 1995). The red porgy, *Pagrus pagrus*, is the only *Pagrus* species of the porgy family that is native to the Gulf of Mexico (Robins *et al.*, 1986). Although other Sparidae of the genus *Pagrus* and *Sparus* have been commercially cultured in Asia and in Europe, respectively, no reports of aquaculture of porgies are avialable for the U.S..

Adapting novel optical and acoustics technologies to offshore aquaculture

Harbor Branch Oceanographic Institution's Engineering Division has developed a wide array of subsea sampling and data acquisition systems for oceanographic research, exploration and defense applications. These include a number of underwater imaging, detection, measurement systems and monitoring devices employing either optics, acoustics or a combination of both. Some of these technologies may have direct applicability to both onshore and offshore aquaculture endeavors.

3-D Laser Scanner

A unique 3-D, high resolution underwater laser scanner that may have application in commercial offshore aquaculture has been developed by HBOI'. The first system was developed under contract to the US Navy for military purposes. Subsequently, others have been refined and built for marine science applications. Rather than relying on underwater lights and a conventional video camera (subject to back scatter in turbid water) this system

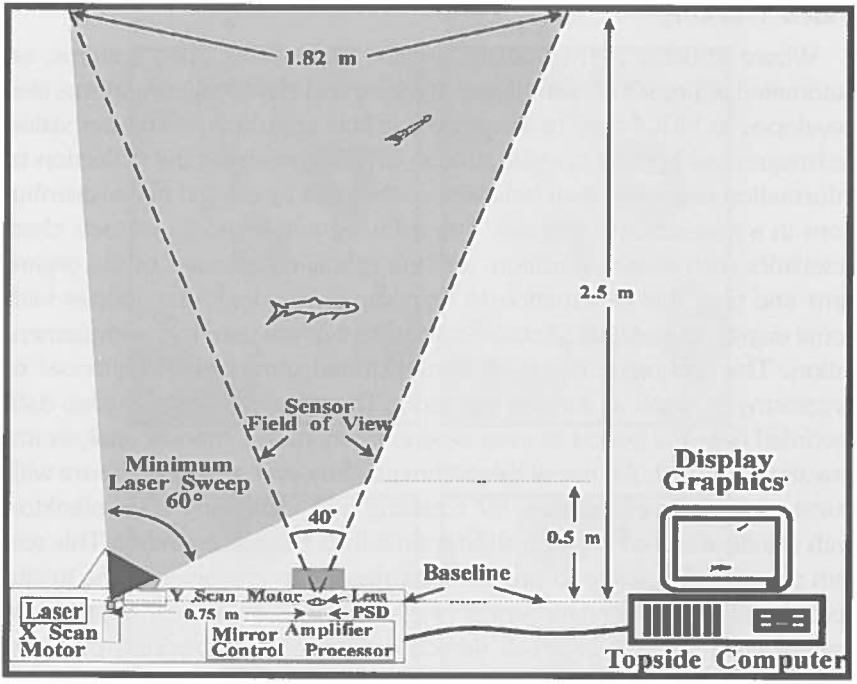

Fig. 1. 3-D laser scanner may have application in offshore net cage systems.

rapidly "paints" a scene in a given volume with a laser beam that is repeatedly and rapidly scanned in a "raster fashion" by a pair of computer-controlled mirrors.

The trajectory of the incident light is always known from the instantaneous position of the computer-controlled mirrors. The laser beam is emitted through a glass port in the underwater housing. Behind a second port is a ìPosition Sensitive Detectorî (PSD) that provides the ìxî and ìyî coordinates of the centroid of the reflected light. Knowing the angle of incidence, also know is the where expected the point at which the reflected light strikes the PSD had it reflected off a flat surface at a given range. Should it land anywhere else, something (for example a fish passing by) has interrupted the ìz path.î Through simple physics, geometry and trigonometry a high-speed microprocessor runs algorithms to process these ìinterruptionsî into a high-resolution 3-D map of the volume before the device. Figure 1 depicts the theory of operation of the apparatus. This system is capable of imaging 20 frames per second (very nearly video rates). High resolution laser generated ìmoviesî have been produced of small (1-2 cm) nearly transparent fish that accurately quantify their size as well as their instantaneous location, speed and direction in a given volume of water.

Video Tracking

Where turbidity permits imaging using underwater video systems, an automated approach to quantifying, tracking and identifying organisms also developed at HBOI may be employed. In this approach, computer vision techniques are applied to video images of biota, enabling the collection of information regarding their behavior, mobility and local and global distributions in a non-intrusive manner. The software automatically extracts characteristics such as size, duration, and the spatial coordinates of the organisms and uses this information to taxonomically classify the species with some degree of certainty. Active contour models are used in the implementation. This technique has been demonstrated using video sequences of organisms as small as marine plankton. The sheer volume of video data recorded over the period of even several hours makes manual analysis impractical. Through the use of this technique, however, results compare with human expert level accuracy for counting and identifying even plankton with results achieved in much shorter time than manual counting. This system provides the ability to process data needed to characterize the in situ spatial and temporal relationships of almost any organism or object in its natural environment. Figure 2 depicts an example of tracking plankton size, type and position with time.

Acoustic Sensing of Larger Fish, Mammals or other Large Animals or Objects

Another system designed by Harbor Branch engineers for a different problem may have application in offshore aquaculture, particularly for monitoring, measuring or counting larger fauna. The system is depicted in Figure 3 in its intended purpose, which is to prevent manatees (an endangered species) from getting crushed by closing navigation locks in very turbid water. It is an acoustic system, but far less expensive and many times more rugged and robust than commercial imaging sonar systems. A row of "emitters," each placed approximately 10 cm from the next in a cartridge strip is mounted to one gate. An identical cartridge is mounted to the other gate, where it is being utilized as a row of "receivers."

This "either/or" functionality of the cartridges is the result of one of its unique features. Rather than using expensive and delicate ceramic acoustic elements, each component is simply a "tube" of rolled piezo-electric film. When excited mechanically, the piezo-electric film generates an electric charge. Conversely, when given an electric charge, it vibrates. Thus, two identical cartridges are usedæthe emitter is provided electrical pulses causing it to vibrate at a very high (over 700 kHz) frequency in structured syn-

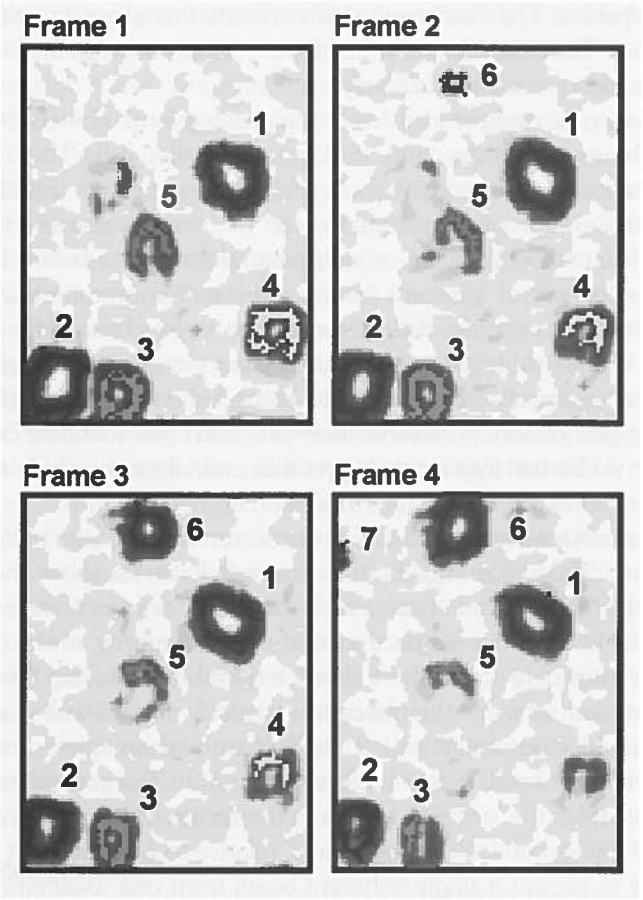

Fig. 2. Example of tracking plankton outlines over four sequential frames.

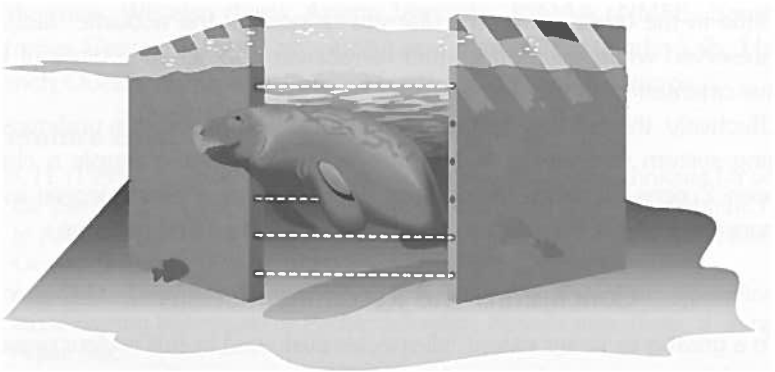

Fig. 3. Low cost, low power acoustic detector for large fish, mammals and large objects.

chronous pulses. The "receiver" side converts this acoustic energy back into a signal. The elements are spaced every 10 cm from surface to bottom creating a sort of acoustic "ladder."

The system is designed to detect the passing large objects or animals such as sharks, manatees, etc., and ignore smaller fish. Thus, anything passing between the acoustic "rungs" goes undetected. Similarly, the microcontroller is programmed not to react to a single beam interruption as would be the case of a mullet or crab passing through a beam. However, when two (or more) adjacent beams are broken simultaneously, the microcontroller recognizes the presence of a large object. The length of time that beams are interrupted may be interpreted as the length of the object passing through. In addition to being linked directly to the motor controlling gate closure (to reverse their direction upon manatee detection), the system is also tied into a data logger that provides a valuable data set for biologists monitoring the animals migration and behavior.

Two important features of this acoustic system are: (a) The frequency (greater than 700 kHz) is high both to assure that it is far above the hearing range of this endangered species and, therefore, does not annoy or "harass" them; but also to assure that the acoustic energy is absorbed and attenuated after only a very short distance (essentially the gap between the closing gates)æthis keeps the concrete and steel, parallel walled-lock form simply becoming saturated and ensonified with meaningless acoustic reverberations that would defeat the system; and (b) The second salient feature that enables the system to work is the shape of each piezo-film element. The navigation lock doors "swing" relative to each other. It would be impossible to project a single coherent beam from one fixed emitter to its corresponding fixed receiver when they're mounted on these swinging doors. However, by forming the acoustic beam into a 160∝ "fan" that diverges very little in the other plane, the discrete "rungs" of the acoustic "ladder" are preserved while assuring emitter-to-receiver contact regardless of the relative orientation of the two doors.

Effectively, this is a low cost, rugged, controllable-resolution underwater imaging system that works in a controlled volume (for example a chute between 2 pens or tanks) to monitor, count and to a lesser degree even measure the objects passing through - all in an automated manner.

Conclusions and Recommendations

To a greater or lesser extent, all species evaluated in this review present potential for commercial aquaculture development in offshore systems in the Gulf of Mexico. We recommend that the private industry use native

species which have been ranked at the economic and/or technological feasibility levels for project development. Universities and research institutions should focus on those candidate species ranked at the experimental feasibility level. The technology available for offshore net cages systems can support the development of the industry. Methods for improved monitoring, surveillance, security and safety of offshore systems are also available and could be easily adapted for use in cage aquaculture. From the technological viewpoint, sustainable mass production of fingerlings of commercially important marine finfish species for stocking the cages constitutes a limiting factor for industry development. Although most species evaluated were ranked at the experimental and/or technological feasibility levels, the technology for their commercial aquaculture development is available in the U.S., and closely related species are commercially raised in other countries. Even though the offshore environment would be subject to minimal environmental impact caused by fish farming in cages, we recommend to carry out rigorous environmental assessment simultaneously with the development of the commercial operations. By monitoring and minimizing any potential environmental impact, offshore aquaculture operations in the Gulf of Mexico can be sustainable in the long run. Finally, problems related to liability, bonding, insurance and other legal issues associated with offshore platforms must be resolved before this resource can be fully exploited. The offshore area of the Gulf of Mexico exhibits extraordinary potential for the development of a sustainable marine fish cage aquaculture industry.

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Research Summary on Potential Mariculture Species for the Gulf of Mexico

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Abstract

The Gulf of Mexico is one of the US's most economically productive marine habitats supporting a wide variety of industries including a highly productive fishery. In 1996, Texas landings of marine species were valued at 9.5 million dollars and included a diverse group of fish species ranging from highly pelagic to reef fish. Given the established fishing infrastructure, diverse selection of native species and relatively warm waters, the Gulf of Mexico provides an excellent opportunity for mariculture development. To support a commercial mariculture industry, the target species must be biologically compatible with the culture conditions, have a controllable reproductive cycle, and larval development suitable for the mass culture of juveniles. Additionally, suitable markets must be identifiable that will support the price structure necessary for a commercial operation. Our laboratory has been evaluating and developing native fish species such as Florida pompano, various snappers, groupers, drums, jacks and the cobia as mariculture species. This paper is a brief overview of research at the University of Texas at Austin, Marine Science Institute, Fisheries and Mariculture Laboratory with emphasis on species of potential commercial interest. Examples of controlled maturation, larval development and growth rates will be discussed. Growth rates and culture potential for various gulf species such as Florida pompano, grey snapper, yellowtail snapper, ling and greater amberjack are presented.

Introduction

Ocean fishing, the largest source of fish production, is producing about 90 million metric tons annually and can no longer sustain the over fishing and pollution pressures man has placed on it (Willinsky and Champ, 1993).

At the same time, the world's demand for seafood is rapidly increasing and is expected to reach 110 to 120 million tons by the year 2010. In response to this demand aquaculture has developed into the fastest growing food production system in the world and is expected to produce 39 million tons by 2010 (FAO 1996). As the world's second largest importing nation of fisheries products, the continued expansion of U.S. seafood production will diversify agriculture, reduce the nation's balance of trade, relieve fishing pressures on native species, diversify the supply of products for seafood processing, provide fry and fingerlings for conservation projects, and provide high quality seafood grown under conditions that control the use of antibiotics, steroids and other additives used elsewhere.

The Southeast Region of the United States (Texas to North Carolina, Puerto Rico and the U.S. Virgin Islands) supports a diverse fishing and processing industry that was valued in 1994 at about 1 billion dollars (NOAA 1996). Associated with the wild fisheries, are established processing and distribution channels for a wide variety of species. With an established infrastructure for seafood processing and suitable coastal and oceanic sites for mariculture operations, this area has considerable potential for the continued development of commercial mariculture operations.

Although commercial shrimp and fish farming operations have experienced some difficulties, mariculture operations are slowly becoming established. In Texas, the red drum, *Sciaenops ocellatus*, and pacific white shrimp *Penaeus vannamei* are the primary mariculture species. Each contributing about 3 million pounds to local production. This production is relatively small, yet it has allowed the expansion of infra structural support such as feed mills and hatcheries.

In addition to a small but established mariculture industry, Texas has an active marine enhancement program. This program was established, in part, due to declining stocks of red drum in the 1970's. The enhancement program has specialized in the spawning and rearing of sciaenid species such as red drum (*Sciaenops ocellatus*) and spotted seatrout (*Cynoscion nebulosus*). Utilizing spawning technologies developed by Arnold et al. (1979, 1988) and extensive pond larval rearing techniques, this program has been extremely successful. It has developed into an active marine enhancement program that includes three hatcheries capable of producing 30 million red drum and 5 million seatrout fingerlings anually.

These examples of mariculture and stock enhancement operations clearly demonstrate that commercial operations and large scale hatcheries are viable entities in the United States. In addition to the well established production technology for the red drum there are a wide variety of native species

occupying a variety of habitats that could be developed for commercial production. In fact, several species that are native to US coastal waters, such as the greater amberjack and cobia are being commercially cultured in other countries. Hence, it could be argued that it is not a lack of technical knowledge, but a lack of market incentives as well as regulatory hurdles that has kept the mariculture industry from growing at a pace equal to that seen in the world market. As the demand for high quality fisheries products continues to increase, the incentives to expand mariculture operations in the US will continue to grow. If mariculture expansion is to be encouraged, it is essential that we develop culture techniques for native species and adapt these techniques to meet our social and economic constraints. The use of native species will not only avoid the introduction of non native species, but it will also support the development of techniques that can be applied to both mariculture and remediation projects to enhance both sport and commercial fisheries.

One of the primary goals of the The University of Texas at Austin, Marine Science Institute, Fisheries and Mariculture Laboratory (FAML) is to facilitate the development of sustainable mariculture through research and education. This program applies a multi-disciplinary approach to the study of natural history combined with laboratory determinations of physiological and environmental requirements as well as the development of production technologies. The objective of this paper is to summarize observations and research results that have been obtained at FAML for native species in the areas of maturation/reproduction, larval rearing and grow out.

Maturation/reproduction

The FAML has a long history in the field of maturation/reproduction where scientists have successfully spawned a number of marine species of commercial and scientific interest (Table 1). We currently have 12 spawning tanks that range in size from 10,000 to 30,000 l for large fish (1-50 kg) and 10 spawning tanks (< 400 l) for smaller fish and crustaceans. Each maturation tank is an independent closed recirculation system consisting of culture tank, settling area, biological filter and air lift pump. All of the fish species we currently work with are pelagic spawners. Consequently, once spawning is initiated we simply collect the eggs in a 250 micron filter bag connected to the effluent drain leading from the culture tank to the biological filter. The fertilized eggs are then quantified and utilized for research purposes.

Fish, like many other species, exhibit rhythmic physiological and behavioral patterns generally known as bio-rhythms. Fish reproduction (maturation, mating, and spawning) is often rhythmic and strongly correlated with

Table 1. Species that have been spawned or are currently being worked with at the Fisheries and Mariculture Laboratory

Food or bait species	**Ornamental species**	**Anticipated spawners**
Red drum *Sciaenops ocellatus*	Ling *Equatus umbrosus*	Ling *Rachycentron canadum*
Black drum *Pogonias cromis*	Spanish Hogfish *Bodianus pulchellus*	Florida pompano *Trachinotus carolinus*
Spotted seatrout *Cynoscion nebulosus*	Pygmy Angelfish *Centropyge argi*	Gray snapper *Lutjanus griseus*
Atlantic croaker *Micropoganias undulatus*	Harlequin Bass *Halichores maculipinna*	Foureye butterflyfish *Chaetodon capistratus*
Yellowtail snapper *Ocyurus chrysurus*	Bluehead wrass *Thalassoma bifasciatum*	Jacknife fish *Equetus lanceolatus*
Red snapper *Lutjanus campechanus*	Peppermint shrimp *Lysmata wurdimanni*	Camel Shrimp *Rhynchocinetes uritai*
Southern flounder *Paralichthys lethostigma*	Scarlet cleaner shrimp *Lysmata amboinensis*	
Pigfish *Orthopristis chrysoptera*	Fire shrimp *Lysmata debelius*	
Pacific white shrimp *Penaeus vannamei*		

the interrelated seasonal cycles of light, water temperature and food supply. This naturally leads to a period of the year that can be defined as the spawning season. The seasonal cycle can be either allowed to occur naturally in outdoor tanks and ponds or it may be induced artificially in the laboratory.

In the laboratory temperature and photo-period (day length) can be adjusted to mimic seasonal changes (Arnold 1988). If desired, these changes can be reduced to a 120 day cycle. As the fish pass though the artificial seasons, changing temperature and day lengths will result in the natural development of maturation and spawning. The red drum is an example of a fall spawner, who under fall conditions will spawn, releasing thousands of small floating eggs. Once spawning has initiated it will continue as long as the fish are held under these conditions. Similarly, the yellow tail snapper is a summer spawner and will initiate spawning once summer conditions are reached (Figure 1, page 134). With the advent of controlled spawning techniques, a fish can be spawned any time of the year, held in spawning conditions for a extended period of time, and the same fish can be utilized as brood stock year after year. If maturation and spawning does not occur under laboratory conditions using environmental ques, or laboratory facilities for the manipulation of temperature and photo-period are not available, spawning can be induced using hormone treatments. Hormone treatments have been shown to be reliable methods of inducing spawning of various species that do not respond predictably to environmental manipulations. The primary substances used for hormone-induced spawning are a) pituitary extracts and purified gonadotropins (e.g. Human Chorionic Gonadotropin, HCG) which are used to stimulate the ovaries and testes or b) Luteinizing Hormone-Releasing Hormone analogs (LHRHa) to stimulate the pituitary. Hormone treatments may be administered to fish with well developed oocytes either by direct injection, the utilization of a implant designed to slowly release the hormone or by oral administration (Thomas et al. 1995).

Larval Rearing

Current production technology for marine fish larvae requires the use of live feeds that can be expensive and unreliable. Consequently, a major focus of our research is to eliminate the live food requirement for marine fish larvae. Efficient use of artificial diets by marine fish larvae will have important implications for the economic viability of aquaculture. We have developed test tanks with a closed, recirculating design to evaluate nutrients and physical requirements of artificial diets (Holt ,1993). Previous to the development of this system, feeding artificial diets was difficult because of rapid

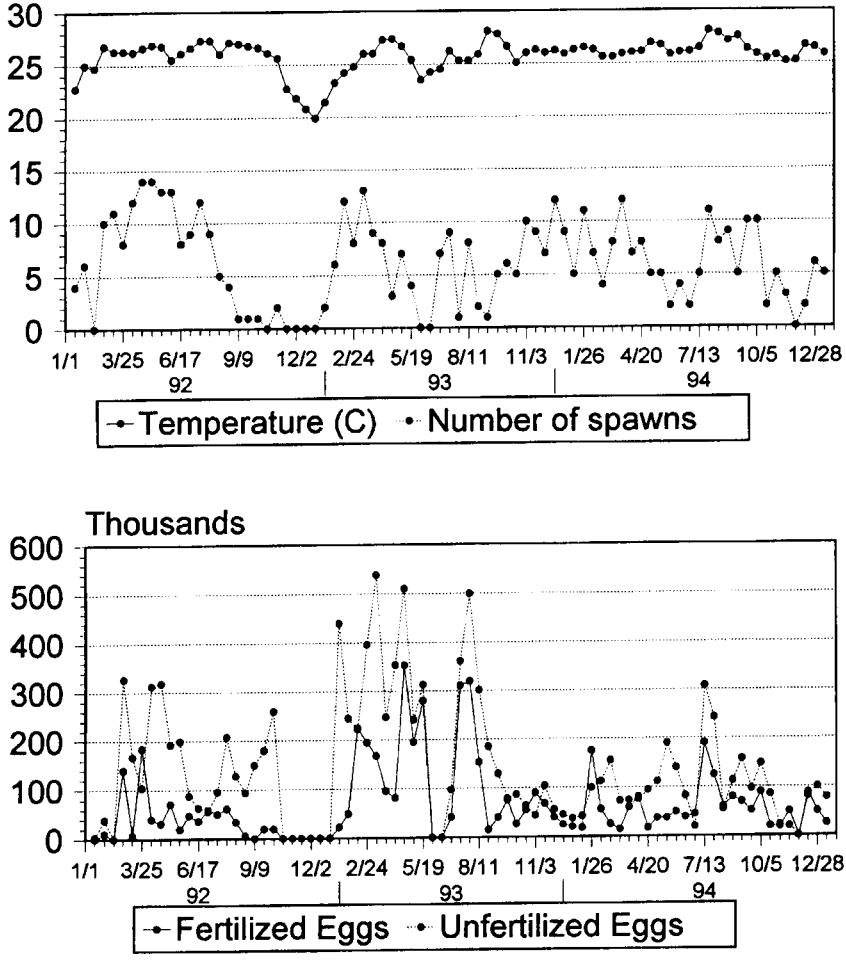

Fig. 1. Example of spawning data, averaged over 14-day intervals, from yellowtail snapper. Number of spawns represents the total number of spawn that were recorded over each interval.

deterioration of water quality. An added benefit gained by this closed culture system is the ability to rigorously control temperature and salinity. A feeding protocol was developed for red drum larvae based on combining a commercial microparticulate diet with live rotifers in the test tanks. In five feeding trials growth and survival were measured on larvae reared on a combination of live and artificial food for one to five days before being weaned to artificial diets. Results in each trial were compared to control larvae reared on the traditional diet of live rotifers and brine shrimp. The best results were feeding a combination of live and artificial food for five days and then completely discontinuing live prey. This meant that 8 day old larvae could be weaning, greatly reducing the need for live food. Survival and growth rates of larvae fed this combination were as good as larvae reared solely on live prey (Holt,1993). Both groups metamorphosed to the juvenile stage at less than one month. Survival rates of the early weaned fish was a remarkable 60% from egg to juvenile.

Successful weaning of red drum from live food after 7 days allowed us for the first time to evaluate specific nutrient requirements of larvae. We have developed a semi-purified diet to evaluate nutrient requirements for week old larvae. Microparticulate, semi-purified diets formulated with varying levels of total lipid from 13-28% of the dry weight were fed to larval red drum. The results indicate that 18% lipid in the diet produced the best growth in terms of length and any lower percentage lipid was associated with poor performance on stress tests (Brinkmeyer and Holt, 1995). Growth of larvae was depressed when offered diets with very low (0.2%) or very high (5.0) levels of (n-3) highly unsaturate fatty acids (HUFA). We found an optimum value for the ratio of two important (n-3) HUFA (DHA/EPA >2.5) in the diet as measured by increase in length, weight and protein content (Brinkmeyer and Holt, in press). Research designed to evaluate optimal sources (phospholipids vs triglycerides) of HUFA and their effect on lipid requirements is underway.

We have learned some things about the nutrition of weaned larvae but we have not solved the first feeding problem. Live food is still critical for the first week of feeding. Currently, we are investigating the role of endogenous and exogenous digestive enzymes on rates of digestion and growth during development of the digestive system. Our goal is to eliminate the live food requirement for larvae perhaps through additions of digestive enzymes directly into the diets or through the incorporation of selected microbes to enhance the utilization of nutrients in artificial diets.

The larvae of some fish species, e.g. red drum, can be successfully reared using extensive pond production techniques. However, many other marine

species require a more carefully controlled environment. Based on our laboratory scale red drum production protocol, the growout of larvae on a large scale has been demonstrated and we are currently optimizing our production protocol. Through the use of an intensive semi-closed recirculating system and minimal reliance on live feeds, the production of juvenile fish can be carried out year round. Once additional species are spawned and eggs are made available, the protocols developed for red drum will be adapted for the mass production of other marine species.

Species of interest

The Gulf of Mexico supports a diverse group of fish species that inhabit a variety of habitats ranging from freshwater to open ocean conditions. Atlantic coastal migratory pelagic fishes (e.g. cobia, and dolphin), reef fish (e.g. snappers and jacks) and pompanos represent an important resource of potential mariculture species for cage and closed system culture where "oceanic conditions" can be maintained. Cobia and dolphin sport fisheries produce more than 90% of the total annual yield of Atlantic coastal pelagic species (NOAA 1991) and are a component of a key recreational fishery. Additionally, there are over 100 reef fishes important to commercial or sport fishermen for which markets are established, having an estimated dockside value of $48 million (NOAA 1991). Concern has been expressed over the future of many of our marine fish stocks which are vulnerable to overfishing owing to various factors such as long lives, ease of capture, large body size and delayed reproduction (NOAA 1991). Fish stocks which have been characterized as over-utilized would benefit from reduced fishing pressures and/or remediation projects. Consequently, the development of biological data required for the commercial culture of marine fish would benefit both the fisheries and the mariculture industry.

Two species of reef fish, the greater amberjack (*Seriola dumerili*) and yellow tail snapper (*Ocyunus chrysurus*), as well as the pelagic cobia (*Rachycentron canadum*) and the Florida pompano (*Trachinotus carolinus*), are highly-prized recreational species supporting key recreational and commercial fisheries for which fishing pressures have been increasing and stocks are thought to be low. These species also have characteristics that make them suitable candidates for culture and hence warrant continued research.

The snapper family consists of approximately 100 species that are found throughout the world in tropical and subtropical areas. Because of their wide acceptance as an excellent food fish as well as declines in commercial fisheries, there is considerable interest in culturing various snapper species. In fact several species are commercially cultured in Asia. Although literature is scarce, information on spawning and raising several species of snapper

(e.g. *Lutjanus argentimaculatus*) is available. When considering species of this family one must recognize that in general the larvae are relatively small and hence difficult to raise. Although, considerable effort has been invested in the development of larval rearing techniques for snappers, success has been limited and techniques are considerably behind those developed for other marine species. Additionally in the wild, juveniles have relatively slow growth rates. Manooch (1987) has summarized the growth rates of a number of snapper species. Four species that are currently being evaluated for their culture potential in the US are the yellowtail (*Ocyurus chrysurus*), red (*Lutjanus campechanus*), grey (*Lutjanus griseus*) and mutton snapper (*Lutjanus analis*). Based on predictive growth equations these species will only reach 200-300 g in two years in the wild. Despite there slow growth in the wild, results under culture conditions indicate an improvement in growth rates. Utilizing semi-closed recirculating systems, we have raised yellow tail snapper to 489g in 767 day that is similar to the results obtained by Thouard et al (1990) using cage culture techniques in Tahitii. Similarly, wild juvenile grey snapper (approximately 3g initial weight) raised in our laboratory have reached 500g after two years of culture. Despite improvements in growth rates under culture conditions, a two to three year production period will be required to produce a 0.5 to 1 kg fish.

The development of a supply of juveniles is one of the factors restricting the development of culture techniques for snapper. Several of the snapper species have been spawned either using hormone induction or environmental manipulations. Previously, we have spawned both the yellowtail and red snapper and are currently working on the development of techniques for the grey snapper. The yellowtail snapper appear to be a relatively easy species to work with in the maturation laboratory and we have had very good results. Additionally, we have had some success with raising the larvae and have closed the life cycle for this species. With the first generation of laboratory reared yellowtail snapper initiating spawning this year, we have a unique opportunity to develop larval rearing techniques for this important snapper species.

Another species of potential interest is the greater amberjack. Life history, abundance and ecological data for amberjack are restricted to relatively few publications concerning: anatomy of the digestive tract (Grau *et al.* 1992), descriptions of foods (Manooch and Haimovici 1983), evaluation of genetic variability as determined by mitochondrial DNA variation (Richardson and Gold 1993) and tagging studies (Mather 1962; Moe 1966). The development of larvae under culture conditions utilizing hormone induced spawning for this species have been described by Japanese scientists

(Tachihara *et al.* 1993), thus, confirming that larval and juvenile production is technically feasible. Unlike the snapper species, the growth rates are very impressive. Juveniles captured from the wild and raised at FAML have reached 2 kg in approximately one year. As with many of the marine fish this species has also been cultured (using wild seed stock) in cages with good success. Consequently, once maturation and larval rearing techniques are developed commercial culture for this species could develop relatively quickly.

Because of its acceptance as an excellent food fish, high market price (average commercial value of $ 6.6/kg), adaptability to intensive culture systems, ready acceptance of artificial feeds and relatively fast growth rate, the Florida pompano has been considered a suitable candidate species for commercial culture (Wiliams et al., 1985). Most research in captivity has been conducted in cages or pond polycultures systems utilizing wild juveniles (Tatum, 1972; Gomez and Scelzo, 1982; Gomez and Larez, 1983). Although feed conversion efficiencies are very poor in this species (generally around 50%), they have a good growth rate and readily adapt to culture conditions. Based on growth rates at our laboratory 1g juveniles collected from the wild can reach 0.8 kg in a year. Although, this species looks very promising for commercial culture, maturation and larval rearing techniques will need to be developed.

The final species that we feel has considerable culture potential is the ling or cobia. Although data on the cobia are extremely limited and generally restricted to ecological data (Ditty and Shaw 1992; Joseph *et al.* 1964; Dawson 1971; Richards 1967) and a report on preliminary techniques for raising larvae from eggs captured from the wild (Hassler and Rainville 1975), this species has excellent culture potential. The eggs from this species are relatively large (1.25 mm in diameter) and the larvae are relatively large at hatch (3 mm). Based on the work of Hassler and Rainville (1975), the development of larval rearing techniques should be very similar to those that have been developed for the red drum and other marine species. Consequently, once maturation technologies are developed, larval rearing techniques should be relatively easy to implement. Additionally, the juveniles grow at extremely fast growth rates and are relatively hardy. Juveniles (0.5 to 1g initial weights) collected from the wild have reached 4.5 kg in one year. This extremely fast growth rate, high quality flesh and tolerance of moderate to poor water quality conditions make this one of the most promising culture species that we have evaluated.

Summary

With the exception of salmonids, the mariculture industry has been slow to develop in the United States. This is probably due to a variety of factors that when combined have inhibited the development of this industry. Despite these difficulties the mariculture industry has been expanding it , adapting to US social and economic constraints, identifying native species with commercial potential and slowly expanding. As long as seafood prices continue to rise, mariculture operation will continue to expand. With expanded support for research and technology transfer programs coupled with government sponsored incentive programs for commercial operations, the U.S. could quickly develop mariculture into a highly competitive industry.

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Development of Bluefin Trevally (*Caranx melampygus*) and Greater Amberjack (*Seriola dumerili*) for Offshore Aquaculture

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Abstract

Marine finfish research at the Oceanic Institute is dedicated toward development of intensive hatchery techniques for mass production of fingerlings for stock enhancement and commercial growout purposes. Accumulated knowledge on the maturation, spawning, and larval rearing cycles of representative species within different ecological and environmental zones is applied to other selected marine finfish of economic importance. Techniques developed include broodstock management and quarantine, individual identification and health assessment, and routine assessment of maturation processes. Current results indicate both bluefin trevally and greater amberjack are highly amenable to offshore aquaculture development, exhibiting adaptability to intensive culture conditions and rapid growth. The maturation cycle of bluefin trevally has been identified, and experiments have been conducted to induce year-round maturation through environmental and hormonal control. Research on the maturation cycle of amberjack has recently been initiated. Comprehensive broodstock husbandry and maturation technology of these species are reviewed.

The Offshore Potential

The Oceanic Institute (OI) is located on the Island of Oahu in Hawaii and is part of a archipelago chain situated approximately 2500 miles from the western U.S. seaboard. The annual consumption of seafood in the state averages 49 lbs./person/year more than three times higher than the average 15 lbs./person/year consumption on the U.S. mainland. Many of the Islands' commercial fisheries have been greatly reduced leading to strict bag and size limits. As a result, the Pacific Marine Aquaculture Center (PMAC) was formed to combine marine finfish technologies and offshore containment systems and demonstrate the economic and environmental feasibility

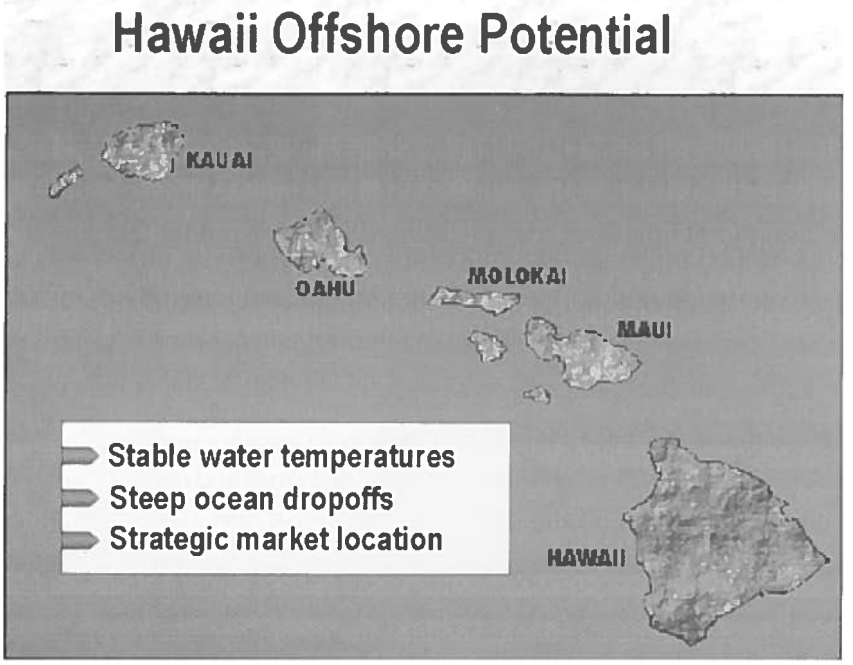

Fig. 1. Hawaii's beneficial characteristics for offshore mariculture.

of an offshore mariculture industry in Hawaii. The agencies involved include the University of Hawaii Sea Grant Program, the State of Hawaii's Aquaculture Development Program, and the Oceanic Institute. Hawaii maintains stable water temperatures year round ranging from 24-27°C, the waters are oligotrophic and its infrastructure is in place. The state is strategically located between markets in Asia and the U.S. (Figure 1).

Hawaiian Fisheries Development

The Institute has been developing comprehensive technologies through the Hawaiian Fisheries Development Program (HFD) utilizing representative species from a variety of ecological niches. The HFD program is funded by the National Oceanic and Atmospheric Administration (NOAA) through the National Marine Fisheries Service (NMFS) for the commercial development of technology for stock enhancement and farm production purposes. The technology serves as a model for standardized, yet flexible protocols for the collection and quarantine of broodstock, maturation and spawning of broodstock, and intensive hatchery and grow out. Species that have been successfully cultured at the Institute include striped mullet (*mugil cephalus* –Eda et al., 1990: Liu and Kelly, 1994a), milkfish (*Chanos chanos*– Lee, 1986: Lee et al., 1986, Liu and Kelly, 1994b), mahimahi (*Coryphaena*

hippurus – Kim et al., 1993), pacific threadfin (*polydactylus sexfilis* – Ostrowski et al.,1996) and the bluefin trevally (*Caranx melampygus*).

Quarantine and Growout

Fish species collected from the wild are placed into a rigorous quarantine program before they are allowed in growout areas at the Institute. The new fish are fresh water dipped to rid them of any external parasites and then placed into quarantine tanks for 4 weeks. These tanks consist of low volume (2000l), high water exchange rates (10+ turnover/day), and are isolated from maturation, hatchery, and growout areas. If problems occur during quarantine, different treatments are administered depending on the disease/parasite prognosis. These treatments include fresh water baths, tank exchanges, formalin baths, and Oxytetracylcine treatments. The fish are initially fed a diet consisting of squid, krill and smelt and are later weaned onto a dry 5.0 mm pellet (Moore Clarke Marine Grower) consisting of 50 percent protein and 14 percent lipid. Before growout, the fish are tested for tolerances to anesthetics such as MS222 and 2-Phenoxyethanol. Tolerances have been determined at 80-90ppm of MS 222 for both bluefin trevally and amberjack. After quarantine the fish are transferred to growout tanks and fed to satiation twice per day on the dry pellet and are measured and weighed monthly for growth performance. Survival rates and feed conversions are also calculated.

Pit Tagging

Once the fish near maturity, they are anesthetized and tagged for broodstock. Data acquisition is necessary for a long term breeding program and is facilitated through the use of a pit tag. The pit tag (14 mm long) has a 14 digit binary code and can be scanned up to 17.5mm intra-musculature. The tag is inserted into the left dorsal musculature at a 45-degree angle with a modified, spring loaded, syringe and data is retrieved via a Biomark -Avid Power Tracker 2 scanner (Figure 2). The pit tag identifies individual fish and allows for the collection of biological data regarding their size, length, sex, growth and maturity.

Broodstock Management

Proper management is the key to strong healthy broodstock. Feeding a complete diet (2 percent total body weight of fish/day) consisting of fish, crustacean, cephalopod and vitamins will enhance the growth and development of the broodstock. Maintaining a clean tank with high water quality is essential. This can be accomplished by periodic cleaning with a brush of algae and scum and maintaining adequate water exchanges for the amount

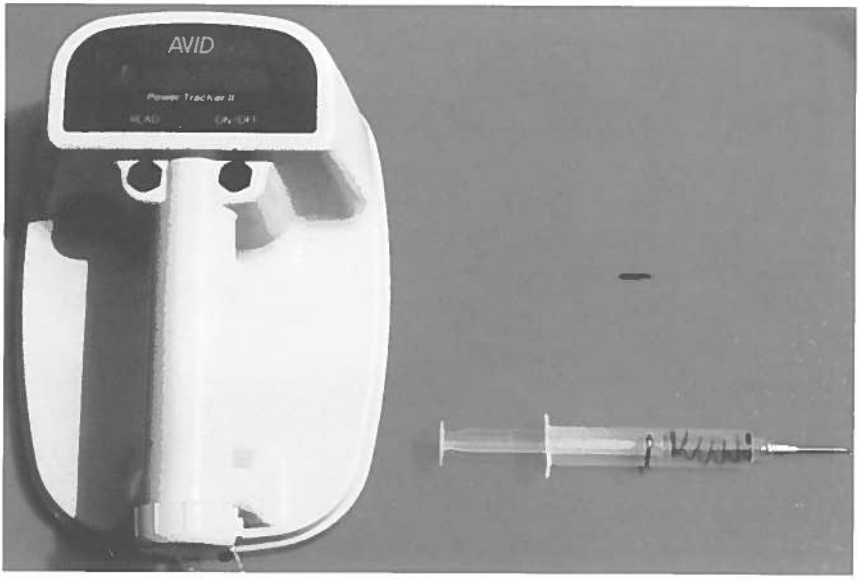

Fig. 2. Waterproof scanner, pit tag (14 mm), and pit tag syringe.

of fish in the tank. Disease prevention through close observation and strict operating procedures (i.e. not handling broodstock with a net from quarantine), will decrease the risk of disease within a culture system. Knowing your fish through behavioral observations is very important. Problems can be diverted by carefully observing feed amounts and swimming patterns. Noticing these problems early on will reduce disease outbreaks and decrease the recovery time of the fish.

Maturation

Broodstock fish are scanned once a month and examined for growth and maturation. The fish are corralled with a PVC crowder and netted with a perforated, plastic net and placed into a 150 l bath of MS 222 (90 ppm). The fish are then scanned with the Power Tracker for identification, weighed, measured, and cannulated for gonadal development. Cannulation is facilitated with the use of a 26 cm long polyethylene tube. The inside diameter is 0.8 mm and the outside diameter is 1.52 mm. The cannula is placed into the urogenital pore at an 80° angle, between 1-2.5 cm deep (Figure 3). The other end of the cannula is gently sucked upon to extract eggs/semen from the fish. Semen extracted from a male it is placed onto a slide with a drop of seawater and examined under a microscope for motility. Eggs collected from a female are placed into a test tube with 5 percent formalin and later checked in the laboratory for development. The eggs are staged for devel-

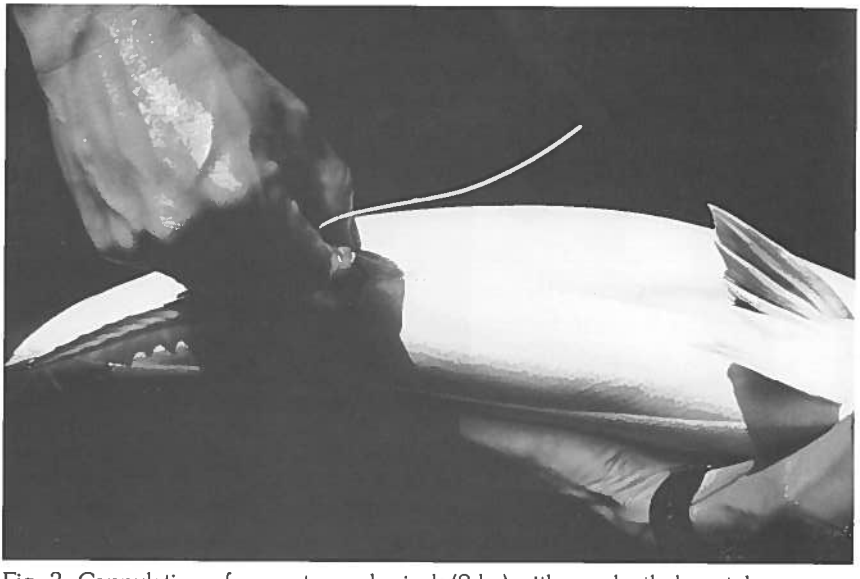

Fig. 3. Cannulation of a greater amberjack (8 kg) with a polyethylene tube.

opment under a microscope and fertilization rate is calculated. The development of oo cytes from a pre-vitellogenic through a cortical vesical (both immature) stage to a vitellogenic (mature) egg are important as to when the fish may spawn. An important aspect of our current broodstock research involves the determination of critical oo cyte diameters. The critical oo cyte diameter is the minimum size an egg will respond to a hormone implant or injection.

Spawning

Once the spawning season has been established, an egg collector is placed outside the tank to extract floating, fertilized eggs. The collector is built from a 55 gallon plastic barrel and with a 200 micron mesh bag suspended within. Surface water from the tank is skimmed and directed through the mesh bag and barrel outside the tank. Spawning generally takes place at night so collectors are set late in the afternoon and eggs collected the following morning.

Several ways that OI induces maturation is through photo period and temperature manipulation and hormone implant/injection. Protocol regarding the use of chronic releasing cholesterol pellets has been established at the Institute. The chronic releasing cholesterol pellet is made in the laboratory (200 micrograms each) from combining LHRH-a, cholesterol and cocoa butter in a mortar and pestle. The mixture is pressed into a plastic grid,

Fig. 4. The bluefin trevally (Caranx melampygus).

dried in an incubator, and then a hammer and nail is used to punch the pellets out. The finished product can than be implanted into the fish through a 3 cm incision (made with a scapula) along the right dorsal musculature. The pellet is inserted with a special syringe approximately 2 cm deep. The cholesterol pellet will slowly release LHRH-a for approximately 5-6 months and promote maturation, increase egg production and extend the spawning season of the fish.

The bluefin trevally has been successfully spawned year round at OI. Spawning has been natural and induced with most spawns occurring from May through September (Figure 4).

Species Potential

The characteristics of a good offshore species includes:

1. An established mass culture technique for consistent year round production of fry. In order for an offshore project to be economically feasible, cages must be stocked with thousands of fish for return on investment. It is essential that seed stock be produced or purchased in large amounts for year round stocking purposes.
2. Rapid growth rates (> 0.5 kg/year) and reliable feed conversions of 2:1 or less.
3. Adaptability to the rigorous offshore environment. A fish that can with stand currents greater than 2 knots and seas greater than 3 meters.
4. A species that is hardy, that can handle crowding, and is resistant to disease and parasites.
5. Marketability. A fish that is widely acceptable and can be sold for a profit.

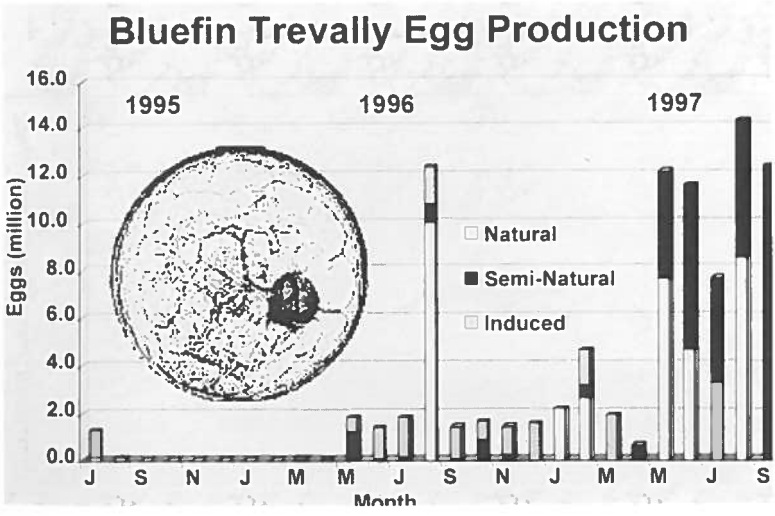

Fig. 5. Year round egg production of the bluefin trevally.

Blue Fin Trevally

Caranx melampygus is in the family Carangidae (Figure 4). It is a strong swimming predator fish that frequents open ocean drop offs and reefs. They are especially prized by fisherman for their spectacular fighting ability (Hoover 1993) and have been caught at 10 kg from the wild. Developmental work through the HFD program indicates the trevally to exhibit excellent offshore qualities. The trevally can be readily collected, domesticated, and trained onto a commercial diet. They can be cultured to .5 kg in 11 months at densities of 20 kg/m^3 on shore. Maturity of broodstock occurs between 1.5-2.0 kg. The broodstock can be spawned year round (naturally and/or induced) resulting in a constant production of eggs for a hatchery (Figure 5). Larvae culture has been successful on a research level but problems exist concerning first feed items on a commercial level. Currently, new feed studies are commencing at the institute to resolve these issues. New feed items such as copepods, trochaphores, and various larvae enrichments are being examined.

Greater Amberjack

Preliminary research at the Institute with the amberjack has been promising and indicates potential qualities for offshore culture. Captive juveniles collected from the wild (30mm) have taken to a dry feed within 36 hours and have grown to 2.8 kg in one year with a feed conversion of 1.2. This specie can obtain weights of over 50 kg in the wild (Figure 6). The amberjack has been considered an excellent aquaculture candidate because of

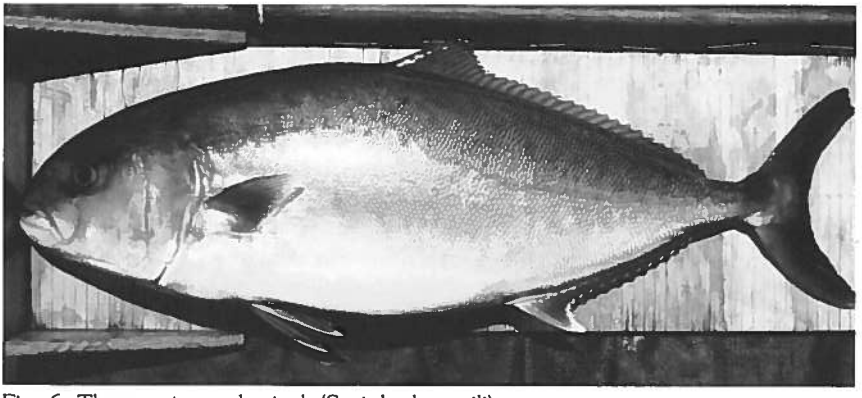

Fig. 6. The greater amberjack (Seriola dumerili)

their rapid growth rates, (Garcia et al. 1993; Greco et al, 1993; Porrello et al. 1993), their ability to adapt to confinements (Micale et al. 1993), high commercial value (Greco et al. 1993; Porrello et al. 1993), and tolerance to handling (Greco et al. 1993). *Seriola dumerili* are cultured intensively on land as well as in seacages in the Mediterranean (Greco et al. 1993; Garcia Gomez 1993; Grau et al. 1993), Japan (Masuma et al. 1990; Tachihara et al. 1993), and Hong Kong (Wong 1995).

Vitellogenic eggs (1.2mm) have been observed in captive broodstock at 6 kg. Mariculture facilities in the Mediterranean have been unsuccessful in larval development (Grau t et al. 1996). However, in Japan, fertilized eggs have been produced with intra-muscular hormonal injections (Tachihara et al. 1993; Masuma et al. 1990). The bulk of amberjack seedstock comes from the wild (Grau, et al. 1996: Garcia et al. 1993) and market size is 1 – 1.2 kg in 9 months (Grau et al. 1996). In 1994, Hong Kong exported an estimated 10 million juveniles to Japan which they cultured from wild caught fry (Wong 1995). In the Mediterranean, one of the major stumbling blocks is hatchery production (Grau et al. 1996). This is a major bottleneck for most marine finfish production (Figure 7) and needs immediate research and attention before an offshore industry can be successful.

Markets for the amberjack are excellent in Japan, Mexico, Mediterranean countries and, States bordering the Gulf of Mexico. In Hawaii, captive fisheries do not exist due to the potential problems associated with worms and ciguatera. If amberjack were produced from a hatchery and raised on a commercial diet, these problems could essentially be eliminated.

Conclusion

This is an overview of the Oceanic Institute's approach to broodstock husbandry, maturation and spawning for the hatchery development of marine fish species. The intent is to produce a protocol for the rapid develop-

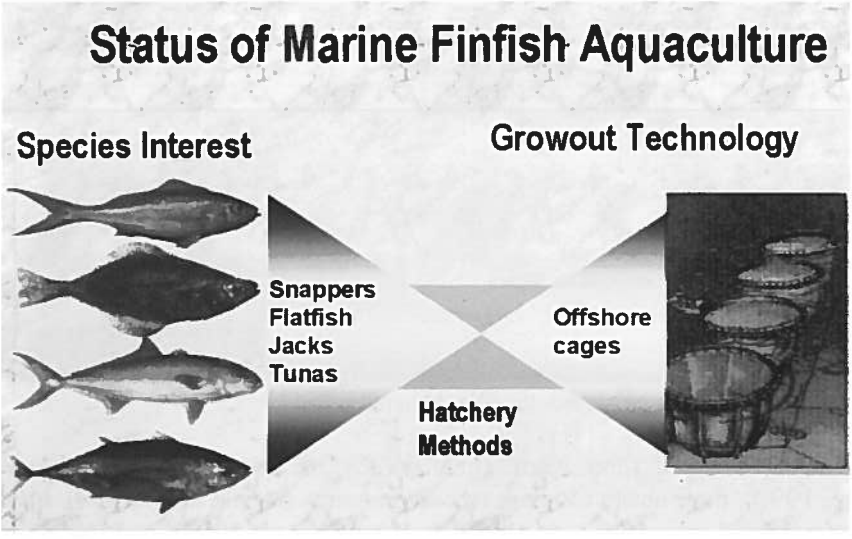

Fig. 7. A current bottleneck of marine fish culture is commercially viable hatchery methods for seedstock.

ment of techniques not only applicable to Hawaiian fish species but also to fish species in other regions of the world. These technologies have recently been applied to bluefin trevally and amberjack research, which indicate potential for offshore culture. The State of Hawaii is interested in offshore aquaculture to relieve fishing pressure of local stocks and to foster new business development. As a result, the Pacific Marine Aquaculture Center was formed to develop and implement offshore technologies for a mariculture industry. The world demand for seafood in the next 5 years will not be attainable by current culture methods onshore. Perhaps by utilizing the worlds oceans (comprising 71 percent earth's surface), we can economically grow and feed the worlds expanding population now and in the future.

Acknowledgments

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Summary Session

Abstract

The Status and Future Direction of the U.S. Department of Commerce/NOAA Aquaculture Plans and Programs

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The Department of Commerce and various NOAA agencies have been working together to develop a formal DOC/NOAA aquaculture policy. A Coordination/Steering Committee has been set up of those agencies that are involved, or should be involved, in focusing resources on the issues critical to the development of the aquaculture industry. A written policy was developed and a draft document presented at the World Aquaculture Society meetings in Las Vegas this past March. Previous to this joint DOC/NOAA document NOAA had developed its own aquaculture policy and the Strategic Plans for NOAA, Sea Grant, NMFS all contain sections relative to aquaculture.

As part of this focus on aquaculture NOAA has a budget initiative of $1.6 million that will become available in FY-99 which calls for regional consortia of interested funding partners meeting to develop regional plans and activities in what could be called a Virtual Institute. A Virtual Institute is one where the existing resources are combined and focused to accomplish agreed upon goals. The FY-99 initiative will build on investments made by the regional funding partners to help develop environmentally acceptable production systems including offshore aquaculture, marine recirculating systems and marine fish enhancement technologies.

The status and future directions of these plans and programs will be presented at the Offshore Aquaculture Workshop in Corpus Christi, Texas.

Joining Forces with Industry

James McVey
Aquaculture Program Leader
National Sea Grant Office
Silver Spring, Maryland
and
Granvil Treece
Aquaculture Specialist
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Participants from around the world assembled in Corpus Christi, Texas May 10-15, 1998 for the 3rd International Open Ocean Aquaculture Conference. The conference was sponsored by the Sea Grant Programs in Texas, Hawaii, Louisiana, New Hampshire and Virginia, the National Sea Grant Office, the National Coastal Resources Research and Development Institute, and Mr. Red Ewald. Pre-conference tours took participants to a shoreline finfish hatchery, a finfish research facility, a state aquarium and to offshore platforms, loading docks and other support facilities with potential for supporting open ocean aquaculture.

Summaries and updates of open ocean aquaculture projects were provided by presenters who have been working in various parts of the world, including the Atlantic Ocean off the Northeastern United States, The Gulf of Mexico, Ireland, Canada, New Zealand, Australia and the Philippines. Most reports were very positive. Gilbert Normand, the Secretary of State from Canada, spoke of strong support in his country for the offshore aquaculture industry, and stated that a report addressing how Canada will proceed with the industry will be completed within two years. He indicated that he would like to see reductions in rules and regulations, simplification of permitting and development of the industry similar to agriculture. Other governmental representatives from the United States presented the status and future directions of their departmental agencies and programs in relation to offshore aquaculture.

Since the major theme of the conference centered on offshore platforms, the merits and problems with using platforms in the Gulf of Mexico and other U.S. waters for aquaculture were discussed. Our summary in laymen's terms is: without a change in current laws, the real stumbling block to their use appears to be the U.S. Minerals Management Service

(MMS) requirements on liability and bonding for accident and lease abandonment. MMS requires 100 percent assurance that each structure will be removed once its use is terminated. Even though an aquaculture venture group may obtain a bond to assume responsibility, MMS still looks to the original petroleum company/owner for final assurance. Therefore, the petroleum companies are hesitant to release the platforms to venture groups if they continue to be held responsible for the platform. MMS states that a Surety Bond, US Treasury or Zero Coupon Bond, will work. Apparently those bonds stage payments based upon production. Other ways that an oil company can release liability are to turn rigs over to the "Rigs to Reefs" program[1] or to have a Federal agency take over the liability. A Department of Commerce (DOC) member said that he would check into the viability of the DOC assuming liability for one platform as a pilot for a multi-use effort (weather sensors, aquaculture, etc.).

There are presently two projects in the Gulf of Mexico off Texas. One has recently received a U.S. Army Corps permit and is proposing to grow fish in proximity to a platform, but the petroleum company has not released the platform. The other project is being conducted with a petroleum company and finfish have already been stocked at the platform. Results of a past project by an oil company were discussed in detail, and the conclusions were: 1) it appeared to be too expensive, but economics are yet unproven; 2) there was no liability relief under current law; 3) operations and engineering are unproven; and 4) to start a new industry requires new regulations.

One speaker discussed the costs associated with offshore aquaculture and indicated that a minimum production level of 200 tons of finfish per year must be reached for the venture to appear worthwhile and have a hatchery, with an estimate of 100 tons annually being the break-even point. It was stated that a minimum production of 18.5 kg of fish per cubic meter must be grown and a sales price of $US10/kg must be obtained. Production in Japan has reached 45.5 kg per square meter with flounder culture. The speaker stated that the minimum capital investment for a hatchery to support an offshore project would require $US 1.5 million. That same project would have a $US 2 million annual operating cost.

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[1]*The Rigs to Reef program exists in Texas and involves either dropping drilling platforms in place or moving them and dropping them into state water locations identified by the Texas Parks and Wildlife Department. The sunken platforms become fish attractions devices of interest to recreational fishermen [ed.]*

Another speaker suggested that an entire offshore project would cost $US 7.5 million, with a startup cost of $US 2 million for the base, $1.1 million for the hatchery, and $2.5 million for the offshore operation. Such a venture was estimated to employ 20 to 25 people, and to have a US$1 million/year payroll and US$2.2 million/year operational costs. Two large boats would be required to meet the needs of such a project.

Joint operations (petroleum and fish production) were not recommended because of space limitations on production platforms. It was suggested that the best depth for aquaculture is 35 to 70 m, and there were approximately 800 platforms in the Gulf within that optimum depth range. A full-time crew of three to four would be needed on each platform. There should be sufficient capacity to store a four to seven day supply of feed. A 15 to 20 ton crane for handling bulk feed containers and cleaning equipment would be required, and the use of video monitors and sonar was recommended to cut the cost of diving and safety/insurance requirements.

It was estimated that 2.5 to 5 percent of the feed used is wasted, and that a significant dispersion area is required for wastes. It was also estimated that a processing plant must process 5,000 tons annual to be economically viable. Currently, the U.S. Environmental Protection Agency will not allow processing in the Exclusive Economic Zone (EEZ), and probably will not allow it in state waters.

The finfish culture participants from countries other than the US suggested that the platforms carry too much baggage with them, and current technologies have developed such that the structures are not necessary for offshore aquaculture. Ireland uses large Bridgestone-type cages that are left alone for up to 50 days when the weather is bad and they have withstood waves up to 15 m in height. Moveable cage systems were discussed as options to facilitate the movement of fish farms into offshore exposed waters. Using bioeconomic-modeling techniques, new and improved cages are being developed. An adaptation of the Sea Station(tm) system, a free-floating, self-propelled system, was tested at the Massachusetts Institute of Technology. The motivating factors were: vast unexploited areas of the EEZ, limitations of current cage technologies, concerns over environmental impacts of nearshore sites, concerns over environmental impacts of fixed fish farms, costs and area requirements of anchor systems, and cost of harvest and delivery of conventional cages.

A well-known cage manufacturer reported on cage designs that have evolved for several applications, including a gravity cage system and a high current and exposed water environment cage system or Sea Station(tm) sea cage system. Commercial tests of the Sea Station(tm) sea cage system were

employed on three working farms: one farm growing summer flounder in Long Island Sound and two farms growing milkfish offshore in the Philippines. Apparently, the cages worked very well with production described in a single 3,000 cubic meter cage being at least 255 tons of milkfish per year. One innovative and progressive Filipino farmer has grown shrimp in a Sea Station(tm) with milkfish.

Sociological and environmental issues were discussed. An offshore aquaculture project off the Northeastern United States offers hope of reviving fisheries production in New England. Some countries such as Ireland have coastal communities that have been revived through the development of offshore aquaculture. They have streamlined the permitting process for open ocean ranching and only have a small number of permitting agencies, with a short turn-around time permit applications. Offshore aquaculture has developed into a $US80 million per year industry there, with most companies producing 5 tons or more annually. Having scientific information available through monitoring and measurement was critical to changing perceptions. The systems have actually increased crab and lobster populations near facilities.

Securing tenure is very important to the success of private aquaculture in the coastal zone. One speaker advised starting at the market and working backward and said the species selected should have a profit margin that allows for mistakes. The site is chosen to make you a low-cost producer. The most important thing on the farm relates to personnel. It takes the human management on a daily basis to make it work. You must have humility and be willing to change if you want to survive. You must develop a farming production plan with a sensitivity analysis to succeed. As investment in rearing volume goes up there is less profit. You should choose species and products where you have technical or natural resource advantage. Operate directly with the end user, and patent your product. You are only as good as your transportation cost. One finfish hatchery researcher stated that, in general, the slower growing finfish species have shown the highest feasibility for aquaculture.

Most of the researchers at the meeting shared the opinion that what is necessary now to implement a workable hatchery for offshore support is money. The biological research has been accomplished in many instances, but there has not been adequate funding for a commercial scale hatchery to support offshore aquaculture in the United States. Japan's new $100 million fish hatchery was cited as an example of the necessary support in another country.

Larval production is where most bottlenecks occur, and biologists have

the most trouble with mass fingerling production. Maturation and spawning are the keys to developing new species, and they can be done with hormonal induction using pituitary extracts.

One speaker listed the dolphin or Mahi mahi (*Coryphaena hippurus*), greater amberjack (*Seriola dumerili*), yellowtail amberjack (*S. lalandi*), Pacific yellowtail (*S. mazatlana*), yellowfin tuna (*Thunnus albacares*), bluefin tuna (*Thunnus thynnus*), pompano (*Trachinotus carolinus*), southern flounder (*Paralichthys lethostigma*), Gulf flounder (*P. albigutta*), mutton snapper (*Lutjanus analis*), red snapper (*L. campechanus*), gray or mangrove snapper (*L. griseus*), yellowtail snapper (*Ocyurus chrysurus*), groupers (*Epinephelus* spp.), and red drum (Sciaenops ocellatus) as being among the native and exotic candidate species with potential for commercial aquaculture development in offshore systems in the Gulf of Mexico. A summary of species research from Texas indicated that red drum is established but the market price is only moderate; pompano has good potential because of high market value; greater amberjack has good potential and is established elsewhere, but the market value is low; Ling or Cobia has excellent potential with moderate market value and is being grown in large ponds in Taiwan where they collect the eggs, but spawning has not been obtained elsewhere; snappers have moderate culture potential with a moderate market price, but the growth rate is slow and the food conversion ratio is poor; and the mutton snapper may be the best snapper candidate for offshore culture.

Grouper and the common snook have been assessed for culture in Florida; summer flounder, winter flounder, witch flounder, cod, haddock, oysters, scallops, urchins, and macrophytic algae are being assessed off New England; while development of the bluefin trevally (*Caranx melampygus*) and greater amberjack are being undertaken in Hawaii.

For more detailed information on the feasibility of offshore mariculture, see "Feasibility Study — Offshore Mariculture," A Report of Waldemar International Inc. to U.S. Department of Commerce, NOAA/NMFS, under award NA77FL0150, 1998.

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