A NATIONAL SEA GRANT INITIATIVE

Marine Aquaculture

Economic Opportunities for the 21st Century

Sea Grant SCIENCE FOR THE 21ST CENTURY

Contents

Marine Aquaculture: The Basis for Action

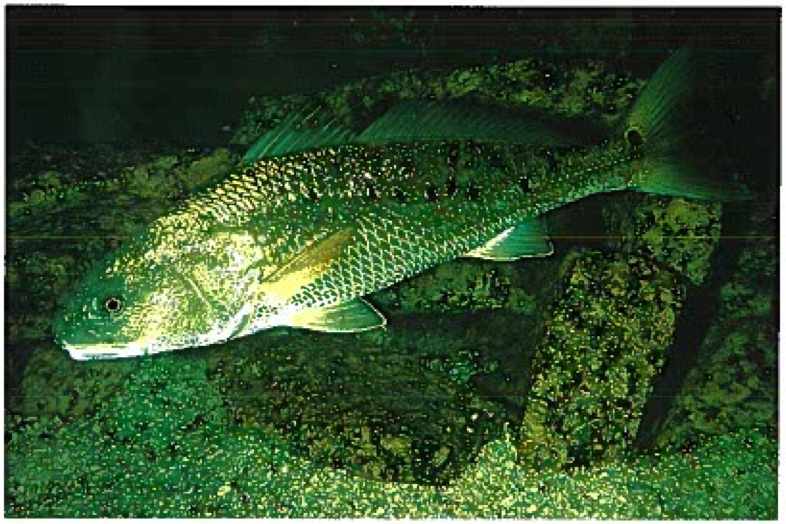
"The Sea Grant Program has supported research relevant to marine aquaculture; however, a major initiative should be undertaken in the context of environmental issues, the basic biology of candidate species, and competing use of resources. It is recommended that NOAA/Sea Grant be charged with leadership in support of research and extension programs on marine aquaculture-related topics focused on preservation of the marine environment, understanding the life history of candidate species, and multiple use of marine resources, including associated social, economic, and policy issues." (National Science Foundation 1992)

The problem

Scientific research, education, outreach and technology transfer

Worldwide consumer demand for wholesome seafood continues to increase; global seafood demand is expected to increase 70 percent by the year 2025. With harvests from capture fisheries stable or in decline, aquaculture would have to increase production by 700 percent to a total of 77 million metric tonnes annually to meet the projected demand. Aquaculture has the potential of supplying up to 25 percent of all the seafood consumed in the United States within the next 20 years. The United States finds itself on the short end of a seafood trade deficit, representing a total of $7 billion annually. More than 60 percent of the fish and shellfish consumed in the United States is imported. The United States exports large amounts of low value seafood, such as menhaden, that is worth billions of dollars less than the smaller amount of high value seafood, such as shrimp, that this country imports. Commercial fishermen and seafood processors are thus being forced out of business due to collapses of some of the country's more important fisheries. This results in the loss of economic opportunities and the traditional lifestyles for families that for generations made their living from the sea. Marine aquaculture will never replace the capture fisheries industry in providing seafood products to meet consumer demand. The commercial fishing industry is rapidly becoming more sophisticated worldwide, where science-based fisheries management techniques are being applied. Marine aquaculture will play an important role in rebuilding and restoration of marine fisheries, but at the same time, aquaculture products will ultimately compete in the marketplace with higher volumes of products from revitalized marine fisheries. Thus, price competition will drive the development of high value aquaculture products in the marine environment.

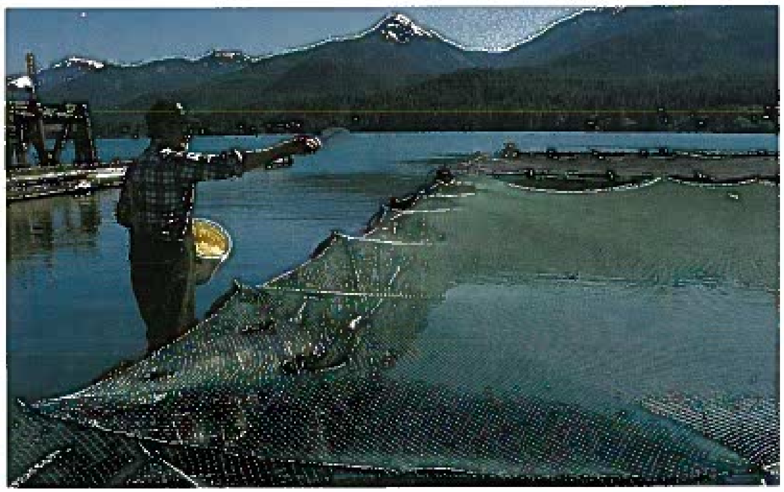
Nevertheless, in many nations, aquaculture has grown rapidly to help offset declines in natural fish populations, to provide jobs, and to enhance struggling national economies. Crops now farmed include seaweeds, molluscs, crustaceans, finfishes and other organisms. Much of the world's aquaculture production is for human food, but there are also culturists producing bait, ornamentals, and species for commercial and recreational stock enhancement.



The United States has a fairly well-developed freshwater aquaculture industry, but marine aquaculture has lagged far behind, accounting for only 15 percent of total domestic aquaculture production. The reasons that the growth of the U.S. marine aquaculture industry has been slow are largely non-technical. The non-technical barriers to expansion of nearshore marine aquaculture in the United States include its complex and diverse nature, its dependence on the use of public waters, multiple use conflicts, environmental concerns, and fragmented institutional and regulatory systems. These constraints have prevented traditional coastal aquaculture from reaching its full potential in the United States, and they may constrain the application of new and innovative approaches to aquaculture in the nearshore. Thus, the U.S. marine aquaculture industry can only expand if these non-technical barriers are addressed for the nearshore environment, and if new technologies can be applied to develop viable offshore and shore-based recirculating systems.

The opportunity

The United States, with its extensive marine and Great Lakes coastlines and vast Exclusive Economic Zone (EEZ) extending to 200 miles offshore, is positioned to greatly expand existing marine aquaculture production, and with it create jobs, boost local economies, and provide abundant, safe, and competitively priced seafood. Much of the technology being utilized abroad was developed in the United States, but growth of marine aquaculture in this country has been much slower than predicted. Part of the problem is the lack of a coordinated effort by government, academia, and industry working in concert to comprehensively address barriers to marine aquaculture development. Future efforts must focus on the short-term needs confronting coastal marine aquaculture as well as the long-term needs of closed system and offshore marine aquaculture and, in all cases, must incorporate sustainable practices and approaches.



A significant investment in research and technology transfer, leading to successful aquaculture enterprises in the U.S. coastal zone, has been made. Marine shrimp farms in Hawaii, South Carolina, and Texas; striped bass facilities in North Carolina and other eastern seaboard states; extensive mollusc farming activities along the east and west coasts; along with salmon ranching in Alaska and net pen salmon culture in Maine and Washington are examples of successful aquaculture enterprises that developed, in part, as a result of research and technology transfer activities conducted at U.S. universities and government laboratories. Successful coastal aquaculture enterprises have been established in protected bay or sound waters and in ponds. Because of competing interests along the nation's coastlines, the availability of suitable aquaculture sites is relatively small in many states. Nevertheless, marine aquaculture continues to be predominantly practiced in the coastal zone; expansion of existing and development of new coastal aquaculture operations will require further assistance from the research and outreach communities.

At the same time, aquaculturists are examining the potential that exists for development offshore and in closed culture systems on land.

Research and development emphasis has been on closed system aquaculture rather than on offshore facilities, yet after more than 20 years, the economic viability of closed system aquaculture remains elusive. The United States aquaculture community is only now exploring the potential for establishing facilities in unprotected offshore areas.

Considerable engineering and biological problems remain to be overcome with respect to closed system and offshore aquaculture. The two approaches may, in fact, end up working hand-in-hand. It is not difficult to visualize culture systems in which the broodstock are maintained in a closed culture system where spawning and rearing to stocking size occurs. Thereafter, the animals would be stocked in offshore facilities. Alternatively, the young animals could be reared in a hatchery and then stocked into natural waters where they could ultimately recruit to a commercial or recreational fishery and be subject to capture. That approach is called enhancement.

New approaches give rise to new problems and opportunities. High value species that can be reared economically in expensive facilities must be identified and the appropriate research associated with providing optimum rearing conditions needs to be conducted. Engineers will be required to develop closed and offshore systems that are dependable, cost-effective and in the case of offshore facilities, able to withstand adverse environmental conditions. State and federal agencies will need to develop policies and establish permitting requirements for these new aquaculture industries. Economists, sociologists, the insurance industry, and lending institutions will all become involved in a new activity. Manufacturers will need to respond with products and services to meet the technology needs of a new industry. Finally, entrepreneurs and venture capitalists will have to make risk capital available.

The prospects for growth of the marine aquaculture industry in the United States has also brought attention to its potential effects on the environment. Many of these concerns focus on the adverse impacts of disease, loss of genetic diversity, introduction of non-indigenous species, and potential habitat degradation. Future research and development efforts must incorporate these concerns and build into them efforts to obtain environmental data, conduct basic biological and ecological research, determine environmental effects, and offer environmentally compatible remedies.

As coastal, closed system, offshore and stock enhancement aquaculture expands, jobs will be created, cultured species will enter the seafood stream, and there will be less pressure on depleted wild stocks and a reduced need to import fishery products. All of this activity will require government support, stakeholder input, and a coordinated national effort.

The National Sea Grant College Program, a university-based, multidisciplinary research, education and extension network committed to the balanced use and conservation of marine resources, is poised to meet these challenges. Sea Grant programs in all coastal and Great Lakes states have spent the past 30 years building partnerships with local, state and federal governments, universities and research institutions across the country, and a wide variety of businesses and industries. The Sea Grant network is well-positioned to undertake the challenges and seize the opportunities presented by the needs of the marine aquaculture community through integrated aquaculture research and development efforts that team natural scientists, engineers, sociologists, market analysts, legal experts, and economists.

Sea Grant's investment in aquaculture

Aquaculture has been a major component of the National Sea Grant College Program's research and outreach activities since the program was established in 1968. Sea Grant has supported technology development for the existing U.S. industry in many areas, including offshore and recirculating marine systems, hormonal control of growth and reproduction, growout technology, feeds and nutrition, disease control, food processing, marketing, policy and regulation, and environmental technologies to meet water quality standards. Sea Grant research and outreach efforts on systems development, genetics, physiology and endocrinology, nutrition, disease, policy, and economics has contributed to the creation of several new aquaculture-based industries, including the Gulf of Mexico and South Atlantic soft shell crab industry, the Pacific Northwest oyster and clam industry, the hybrid striped bass industry, and the Mid-Atlantic hard clam industry. In addition, Sea Grant investments have helped with the establishment of scores of new businesses throughout the United States, and provided improved technologies to these businesses. The combined impact of Sea Grant-developed technology amounts to at least $100 million annually and supports thousands of jobs in the U.S. economy. The promise for future economic yield of research in this area far exceeds that amount.

The national Sea Grant network represents more than 300 universities and colleges, whose faculty and staff provide the talent and expertise necessary to generate and disseminate research information to the aquaculture industry. Sea Grant also works in partnership with the many other federal and state agencies, universities and industry organizations through its involvement, on behalf of the U.S. Department of Commerce, on the Joint Subcommittee on Aquaculture, a coordinating council established by the National Aquaculture Act of 1980 to help coordinate the many activities underway to assist the nation's aquaculture industry. Sea Grant efforts are conducted in concert and collaboration with federal agencies, such as the NOAA National Marine Fisheries Service and the U.S. Department of Agriculture and its Regional Aquaculture Centers, industry through the National Aquaculture Association and other national, state and local organizations, and academia through professional groups like the U.S. Chapter of the World Aquaculture Society and the National Shellfisheries Association.

The National Sea Grant College Program and its 29-member institutional network have generated a significant amount of information through research and technology transfer programs that is largely responsible for the limited marine aquaculture industry that exists in this country today, as the following examples demonstrate.

- As a result of Sea Grant research and extension efforts, hybrid striped bass culture in ponds expanded within a decade from the demonstration stage to an industry that produces 10 million pounds of fish valued at $25 million annually.
- Sea Grant researchers have developed sterile oysters that can be maintained in prime condition year-round and that now account for one-third of the $86 million U.S. oyster market.
- Since 1980, when no mussel culture industry existed in the northeastern United States and the wild harvest was valued at only about $35,000 annually, Sea Grant research and marketing efforts have increased landings of wild and cultured mussels in the region to an annual value of $6 million.
- In the western United States, Sea Grant research and outreach on Manila clams and blue mussels resulted in new industries worth $19 million annually.
- Guidelines developed by Sea Grant to reduce the risk of genetically engineered fish escaping into the wild were the first national environmental safety guidelines for aquatic

biotechnology and resulted in an award from the U.S. Department of Agriculture.

- Sea Grant specialists, working with watermen, researchers, students and others, provided seed oysters and expertise that are helping rebuild oyster reefs in Chesapeake Bay.
- Small, local soft-shell crab fisheries in New Jersey, Florida, South Carolina, and Texas grew, as a result of Sea Grant research and technology transfer, into multi-million dollar industries.
- Sea Grant research and outreach programs have been instrumental in the development of successful commercial culture of red drum and marine shrimp.

An impressive community of professionals with credentials in aquaculture research and outreach exists within the Sea Grant network. A considerable amount of credit for the rapid expansion of marine aquaculture around the globe can be traced to information and technology developed by this community. As the global economy continues to expand, there will be enhanced opportunities for bi-directional information and technology exchange between the U.S. and other countries.

Sea Grant has collaborated extensively in the international arena, creating opportunities for aquaculture technology exchange between the United States and Japan, China, Israel, France, Russia, and Ireland. NOAA, through Sea Grant, and Japan have been working together for more than 20 years to enhance the development of freshwater and marine aquaculture through the Aquaculture Panel of the U.S.-Japan Cooperative Program in Natural Resources (UJNR). Technology exchange between the U.S. and China on scallop and flounder aquaculture has been conducted by Sea Grant through a bilateral agreement. The U.S.-Israel Science and Technology Foundation has provided funds for aquaculture research with state Sea Grant programs. Sea Grant's efforts have been important in promoting the timely exchange of research information worldwide to foster development of the domestic industry.

Science and technology needs

The growth of marine aquaculture in the United States is hindered by problems that have yet to be solved and opportunities yet to be explored. Thus far, the strides Sea Grant has made in marine aquaculture have been confined to local and regional efforts. Sea Grant is now poised to attack the obstacles facing marine aquaculture through a comprehensive effort involving the enormous research, outreach, and partnering power of all 29 institutional Sea Grant programs and more than 300 colleges and universities nationwide.

It will take a concerted effort to solve the problems and explore the opportunities to support marine aquaculture development. Although many species most likely to be cultured have been studied to some extent, more research is required in the areas of developing larval feeds, breeding programs that maintain genetic diversity, and methods for early detection and treatment of diseases. There are also additional species with potential that have not been studied in any detail. Future opportunities exist for species for food production; great potential also exists in developing aquaculture technologies for the enhancement of natural fisheries and to produce ornamental fishes, invertebrates, and plants. Of even greater potential economic and social importance is the development of culture methods for marine organisms as sources of pharmaceutical products.

Research is also needed to improve closed system technology to make it more reliable, effective, economically efficient and environmentally sustainable. Closed recirculating systems are those that utilize little in the way of new water once the systems are filled and, consequently, produce little in the way of effluent. Water is constantly treated to remove solids, maintain dissolved oxygen and temperature levels within the optimum range and convert toxic compounds such as ammonia and nitrite into less toxic substances.

In 1992, the National Research Council of the National Academy of Sciences predicted that the best opportunities for future commercial aquaculture development are in recirculating systems on land and in confinement systems in the open ocean. Open ocean aquaculture presents a major technical challenge: engineering offshore farms so they can survive severe storms, such as hurricanes, without having the costs for facilities become economically prohibitive.

Finally, regardless of location and species cultured, all research, development and outreach efforts must incorporate studies that examine and address the myriad of environmental issues that marine aquaculture may present. If the U.S. aquaculture industry is to expand, it must incorporate environmental safeguards and practices, based on objective, science-based information, to ensure that both economic vitality and natural resource health are maintained.

Culture System Technology Development

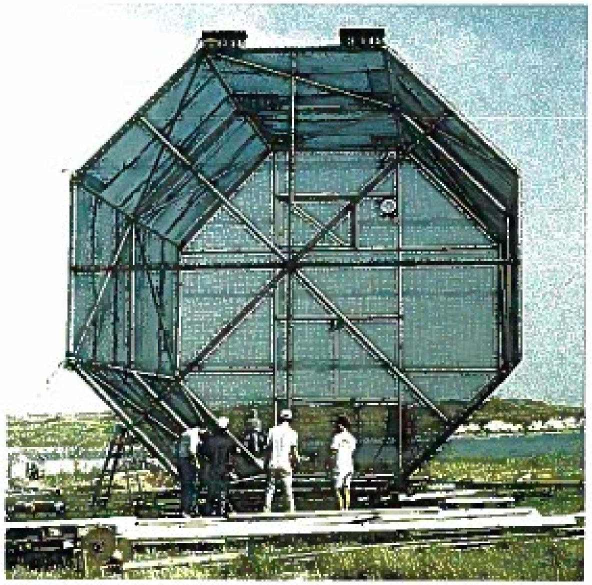
Marine aquaculture operations will in the future require the use of three distinct geographic environments: the nearshore/coastal region; the seafloor of the EEZ; and the surface and water column of the open ocean. Utilization of each of these environments presents its own separate set of engineering and technological challenges. Regardless of the geographical setting, however, is the practical need for constructing large enclosed volume containment systems that can be operated at low cost. While nearshore coastal aquaculture technologies have been developed over the last few decades and continue to be refined, innovation and the use of 'high tech' composite materials is required for offshore environments if system integrity, serviceability, and cost are to be appropriately balanced. Technology development and engineering research are needed for four such system approaches: surface cages for sheltered waters; subsurface cage systems; offshore "drifter" systems; and re-use of existing offshore structures.

Surface Cages for Sheltered Waters — Considerable experience has been gained in other parts of the world in cage and raft culture in relatively sheltered coastal waters. The dense arrays of salmon cages in Norwegian fjords, rafts for nori and net pens for yellowtail, sea bream, salmon and other species in Japan, and oyster and mussel rafts in Spain provide several good examples. Nevertheless, many of these systems have experienced severe damage from storms. Additionally, nearshore cages and rafts raise concerns by coastal property owners about aesthetics, and their location in high value coastal environments where many conflicting uses exist present major obstacles. However, more modern cage system designs can greatly reduce many of these problems and, in many cases, cage clusters can be made to be much less visually obtrusive. There is considerable room for improvement, however, and this Marine Aquaculture Initiative will explore design alternatives for more weather resistant and lower visibility surface cages in coastal waters.

Subsurface Cage Systems — The design of subsurface cage systems is in its infancy, yet it may be the system that is most suitable for many regions of the United States coast. Proper designs could result in an aquaculture system that would have the large volumes needed, be entirely out of sight and, other than its surface marker buoy, would provide few, if any, hazards to coastal navigation.

Before submerged systems can be deployed on a commercial scale, biologically-relevant technology suitable for fish with swim bladders must be developed. Fish do not tolerate large, rapid pressure changes without adverse health and growth impacts. Cage and feeding systems need to be developed that allow for bottom tending of the fish and the means of assuring slow and gradual changes in pressure built into the submerged cage system. Moreover, the system dynamics of such installations must be examined, and many engineering questions remain to be answered. For instance: How will submerged cages behave during severe storms and hurricanes? Will water pollution problems arise, and what can be done to minimize any such effects? Do submerged cages offer a cost-effective means of culturing fish?

Offshore 'Drifter' Systems — The open ocean is where the greatest challenge lies for marine aquaculture. One of the most promising ideas for utilization of this part of the ocean is the development of a new integrated technology wherein the cage and the tending ship are integrated into a simple single unit of sufficient size, stability, and endurance to stay at sea continuously during cage grow-out of the fish. The technology might be envisaged as a spar shaped vessel with living quarters, machinery, and operating space above water and a large circular cage below the surface. For example, the ship could be powered by thrusters at the base of the spar and on the upper ring of the cage. Diver access to the cage could be via a lock-out in the spar or through access ports in the upper part of the netting. Feeding could be done via a pump and tube system that supply either dry or wet food to the fish in the cage. Harvesting might be done via a fish pump to a tender vessel where the fish will be processed and transported to market. Resupply of the vessel could be accomplished via ship under calm or mild conditions and emergency supply can be achieved via helicopter landings on the deck above the living quarters. Such a concept is ideal for investigation by Sea Grant researchers and engineers.



Re-use of Existing Offshore Structures — A fourth approach to offshore confinement culture is the utilization of existing fixed structures for mooring and logistical support. Oil and gas platforms in the Gulf of Mexico are being made available by the petroleum companies to explore this possibility. These platforms can potentially serve as sites for logistical

support and for the deployment of cages that are located at the surface and/or submerged. The cages may be tethered to the production platforms or be located in close association but remain structurally independent. A variety of engineering and technological requirements will have to be developed. In addition, appropriate leasing policies and a suitable regulatory framework must be developed to allow commercial aquaculture to occur in conjunction with such platforms in state and EEZ waters.

The Challenge

Develop Appropriate Technologies and Engineering Solutions:

- Develop and test design alternatives for more weather resistant and lower visibility surface cages
- Develop and test design alternatives for subsurface cage systems
- Develop and test integrated offshore "drifter" system technologies
- Explore the technological and institutional issues for reuse of existing offshore structures as aquaculture platforms

Nutrition and Feeds

During the past decade, development of aquaculture feeds has focused on species-specific needs as well as the varying requirements of different life stages. In the United States, feed formulations primarily revolve around the culture of salmonids and channel catfish, as these represent the major domestic fish culture industries. Typically, other species that are cultured on a small scale or whose culture technology is under development must rely on use of these existing feeds, which often do not meet the optimal needs of the species being cultured.

Analyses of nutritional components of the diet of a species have matured to the point where most feed components can be readily identified. However, development of suitable formulated diets requires understanding nutritional component stability, contributions to palatability, and the nutritional requirements at all life stages of a target species.

Future research and development efforts should be directed at a number of needs. These include the evaluation of feed components in relation to quality of flesh and palatability for human consumption and the determination of optimal qualitative and quantitative levels of protein and lipid for target species. Further research is also needed to determine the stability of feed components in a formulated diet.

Defining the nutritional requirements of each species targeted for culture is a major task. However, in the process of producing formulated diets it is also necessary to consider product cost and environmental concerns. One of the main feed ingredients for most commercial feeds, fish meal, is already in short supply as indicated by its increase in price as well as the well-publicized decrease in world fishery catch over the past five years. Fish meal has largely been replaced by plant proteins in the diets of such species as channel catfish and tilapia. Significant reductions in the use of fish meal in salmonid diets have also been possible in some instances. One objective of the nutritional research associated with Sea Grant's Marine Aquaculture

Initiative will be to develop feeds that employ alternate proteins to spare fish meal for more traditional uses in the livestock industry where demand continues to increase, and to minimize fishing pressures on wild-caught fish.

Similarities in nutritional requirements provide the basis for generating "generic" feeds that can be fed to a variety of species. Alternately, many dietary components can be incorporated into a single "complete" diet for many species of fish. This alternate approach is substantially more expensive but has proven satisfactory for production of aquarium fish feeds.

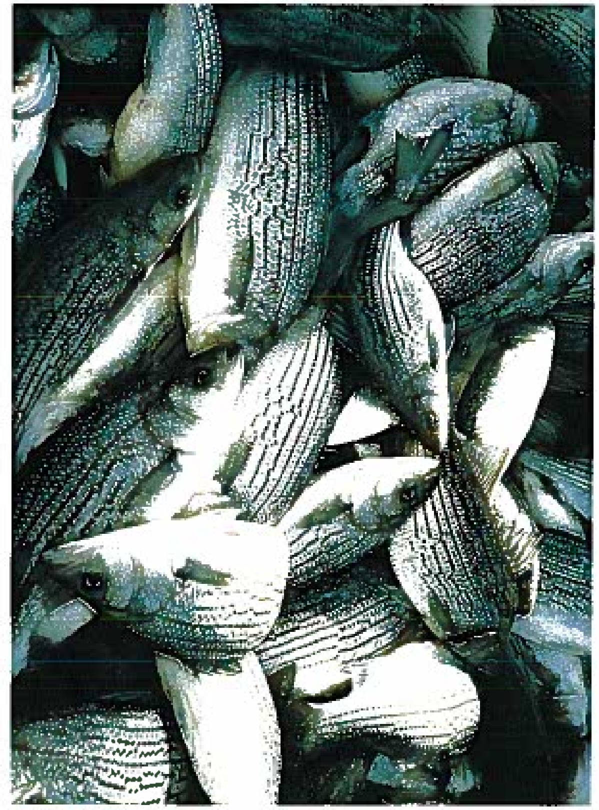
On the other hand, the nutritional requirements for each species may be discrete enough that development of a generic feed may not be practical. Currently, feeds manufactured in the United States are geared towards high volume production of a few feed types (channel catfish, salmon, shrimp, trout), and adjusting production schemes is often impractical and unjustifiable. Specialty feeds have been developed for new aquaculture species (e.g., hybrid striped bass and yellow perch), but production is limited to orders of sufficient product volume.

Identification of new aquaculture candidates will continue well into the 21st century. Future research and development efforts should include the development of technologies for mass production of feeds containing variable quantities of critical ingredients for specific species and culture systems, and the improvement in shelf life of feed components and feeds. The identification of lower cost and environmentally friendly nutritional alternatives for fish meal is also a high priority.

Larval nutrition is a major constraint to the culture of many marine fish species. Use of microencapsulation and other techniques for the production of homogenous feed particles of very small sizes has been very beneficial. Their use in addition to enrichment diets for rotifers and artemia has enabled culturists to rear new species of marine fish larvae. The use of recently developed feeds and feeding techniques will no doubt result in an expansion of possible aquaculture candidates.

The Challenge

- Identify the nutritional requirements of aquaculture candidates
- Develop cost-effective and environmentally friendly feeds for different life stages:
- Determine optimal qualitative and quantitative levels of protein and lipid for target species
- Develop stability of feed components in formulated diets
- Identify suitable alternate protein sources to reduce dependence on fish meal
- Develop technologies for mass production of feeds
- Improve the shelf life of feed components and formulated feeds
- Identify larval feeds that reduce dependence on live prey organisms
- Develop feeds that reduce water quality problems



Genetics of Culture Species

The geographic ranges of many fishes raise some obvious doubts as to the genetic continuity of each species. Examination of the genetic integrity of far-ranging fishes using state-of-the-art technologies (e.g., hypervariable nuclear DNA markers) have demonstrated that population substructures occur in a variety of marine species, including oysters, sciaenids (e.g., red drum), serranids (e.g., sea basses), and scombrids (e.g., certain tuna species). Some studies clearly demonstrate that certain species exhibit some degree of "biochemical" heterogeneity or have revealed that what was once thought of as a single cosmopolitan species is, in fact, a series of discrete populations or, in some cases, distinct species. The differences in the way that populations of a species are structured impacts directly on the issue of compatibility/incompatibility between a cultured stock and a wild one and how desirable traits in a local stock can be enhanced.

From a practical point of view the extensive variability within many fish species underscores the need to evaluate biological traits that may be of economic importance but are restricted to discrete populations. But it also emphasizes the need for additional information and understanding before introducing a 'foreign' variety of a species into a new area. Clearly, enhancement of desirable traits in a 'local' stock is a preferable solution to importation of a species that may harm other elements of the ecosystem if an accidental release were to take place. Equally important is whether individuals from different subpopulations are compatible in the sense of possessing similar or different adaptive gene complexes. Thus, research is needed to determine which genes in a species complex are of interest in aquaculture or stock enhancement efforts and to characterize those genes in the subpopulations. Modern genetic approaches to this challenge appear to hold great promise.

Future research on identifying gene complexes responsible for reproduction, gene expression, and other desirable traits will involve the use of state-of-the-art markers such as SNIPs (single nucleotide polymorphisms), RAPDs (randomly amplified polymorphic DNAs), AFLPs (essentially amplified RAPDs), and PINEs (paired interspersed nuclear elements). Thus, future research must identify appropriate stocks or substocks of targeted species for aquaculture production, evaluate the presence, absence and/or degree of expression of biological traits that are of economic benefit, adapt advanced genetic technologies already in use in the domesticated plant and animal sciences to aquatic systems, and develop and refine new state-of-the-art technologies for genetic manipulation for marine species.

The Challenge

Using state-of-the art genetic techniques and tools developed for domesticated terrestrial animals and plants:

- Identify target species for use in aquaculture production
- Characterize genetic population structure of target species in the wild
- Identify suites of target characteristics (traits) of critical importance to aquaculture
- Estimate heritabilities for the target traits
- Determine genetic factors controlling desirable traits in aquaculture species
- Incorporate enhancement performing alleles into selective breeding programs

Health and Disease

Any organism in captivity undergoes a certain degree of stress as a result of the artificial conditions (e.g., food, space, water quality) under which it lives. The task of the culturist is to alleviate these stressors in order to successfully propagate the target species. Accidental occurrences, such as power outages or malfunctioning of equipment, can cause acute stress (e.g., low dissolved oxygen levels, high ammonia, etc.). The organisms can die quickly and often in large numbers unless promptly relieved of the adverse conditions.

A more subtle and often undetectable health problem is low level chronic stress that can result from overstocking, less than ideal water quality, or the nature of the holding facility. Low level chronic stress results in poor cultured species performance (e.g., growth, survival, reproduction, etc.) during all phases of hatchery and grow-out operations.

Poor performance is not the only outcome of chronic stress. Such conditions, if not remedied, can lower the resistance of culture species and can set the stage for infection by pathogens. Even pathogens that are normally present at low levels may begin to flourish, which can ultimately result in major disease outbreaks. Prevention of an outbreak of disease is the best method of treatment, but when an outbreak occurs, the culturist is limited in the choices available for treatment. Even though therapeutic treatments are available, many often cannot be used because they have not been approved for use on fish intended for human consumption.

While significant strides have been made in utilizing new technologies for developing diagnostic techniques for diseases in the domestication of terrestrial organisms, progress in developing, adapting and applying these technologies to aquatic species has been slow. Additional effort is needed to understand the immune systems of marine organisms and the potential for the production of vaccines. An obvious area of future research is an increased effort to utilize all available technologies for the detection and treatment of diseases in finfish and shellfish. Thus, a great need exists to improve diagnostic capabilities for aquatic diseases and parasitic organisms, develop new therapeutants, and improve the approval process for use of therapeutants in cultured food fish.

The Challenge

Investigate Health and Disease Treatments:

- Determine the molecular basis of immune functions in marine organisms
- Investigate the defense mechanisms in marine systems for application in developing marine and human therapuetics
- Develop new diagnostic and therapeutic techniques
- Determine role of environmental stress on disease
- Develop new drugs and vaccines
- Determine the role of exotic species in disease transmission
- Explore the role of viruses as disease agents in cultured species

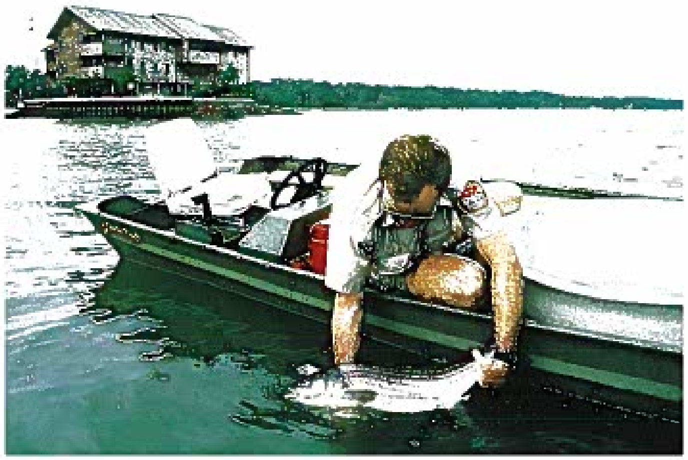
Public policy and law

One of the most often-cited reasons for the lack of growth of marine aquaculture in the United States is the complex and confusing policy and legal framework within which it must operate. There are a number of policy and legal issues facing marine aquaculture in state waters and in the EEZ that need to be addressed, such as: liability insurance; multiple use conflicts with navigation, fishing, boating, and the military; performance requirements; effluent requirements; use of exotic species; ecological response; and others. Many coastal and Great Lakes states have developed regulatory frameworks pursuant to aquaculture in state waters, but many policy issues remain to be solved. In many cases, natural resource agencies adopt a very conservative management approach to marine aquaculture because of the paucity of relevant research information on these issues.

In the EEZ, policy and legal issues have been addressed in only a few cases. As a result, there is no national policy or protocol for permitting aquaculture operations in the EEZ. An EEZ policy for aquaculture needs to be developed with the cooperation and collaboration of all involved agencies, including the NOAA National Marine Fisheries Service, U.S. Army Corps of Engineers, Department of the Interior's Minerals Management Service, U.S. Environmental Protection Agency, U.S. Coast Guard and others.

As a part of the Sea Grant Marine Aquaculture Initiative, agencies involved in developing, implementing and enforcing aquaculture policies will be involved in an overall effort to establish a viable coastal and offshore marine aquaculture industry. Information generated through scientific research and development efforts in new technologies, nutrition and feeds, genetics, health and disease and environmental studies must serve as the foundation for sound and balanced policy development. Topics that require agency attention include, but are not limited to:

- Multiple use conflicts — Guidelines must be established to accommodate traditional user groups in the coastal and offshore environment (e.g., commercial and recreational fishing, shipping, recreational boating, military activity).



- Environmental regulation — Siting and operation of coastal and offshore facilities should be done in an environmentally sensitive manner, and science-based guidelines for establishing baseline conditions and reasonable monitoring requirements during operation of these facilities need to be established.
- Use of exotic species — Policies concerning the use of exotic species, when necessary, in offshore waters need to be developed.
- Leasing requirements — Terms of leases need to be established and lease amounts need to be set at a level appropriate for such new business ventures.
- Navigational considerations — The siting of offshore facilities must include consideration of existing shipping lanes and the needs of navigation and safety.

The Challenge

Formulate Policy and Legal Guidelines for Marine Aquaculture:

- Synthesize policy and legal constraints to marine aquaculture development
- Develop model policy and legal frameworks for adaptation at the state and federal level, based on scientific information as it is developed
- Develop technological and engineering solutions to environmental issues

Socio-economic issues

Marine aquaculture, largely because of its lack of a proven track record, has been hampered by a paucity of venture capital and, perhaps as importantly, the lack of a coordinated effort among stakeholders to achieve successful commercial development in a socially and environmentally sensitive manner. The Marine Aquaculture Initiative will provide the foundation upon which such a coordinated effort will be developed. Integrating the expertise from various universities, agencies and the private sector to address these issues comprehensively will provide a new approach that has a better chance for success than past efforts to address the individual pieces of a very complex puzzle. Demonstration projects developed as a result of these partnerships can illustrate the potential for economic success and will help create a more positive climate for investors.

Sea Grant's comprehensive approach to marine aquaculture will:

- Address scientific, engineering, and socio-economic needs associated with the propagation of marine aquaculture species.
- Assess and propose mitigation technologies relating to the environmental impacts associated with marine aquaculture development.
- Form partnerships with private industry to transfer technology, design market strategies, and develop new industries.
- Provide marketing and technical expertise for new or prospective entrepreneurs.
- Enhance scientific literacy in the nation's schools by using examples from aquaculture as a teaching tool.

The Challenge

Develop Economically Viable Marine Aquaculture Businesses:

- Establish public-private partnerships to support offshore aquaculture R&D
- Provide market analysis of potential culture species
- Generate economic analyses for offshore aquaculture systems
- Create technical training opportunities for aquaculture workers
- Develop aquaculture-based science and math K-12 curricula

Sustainability

Applications

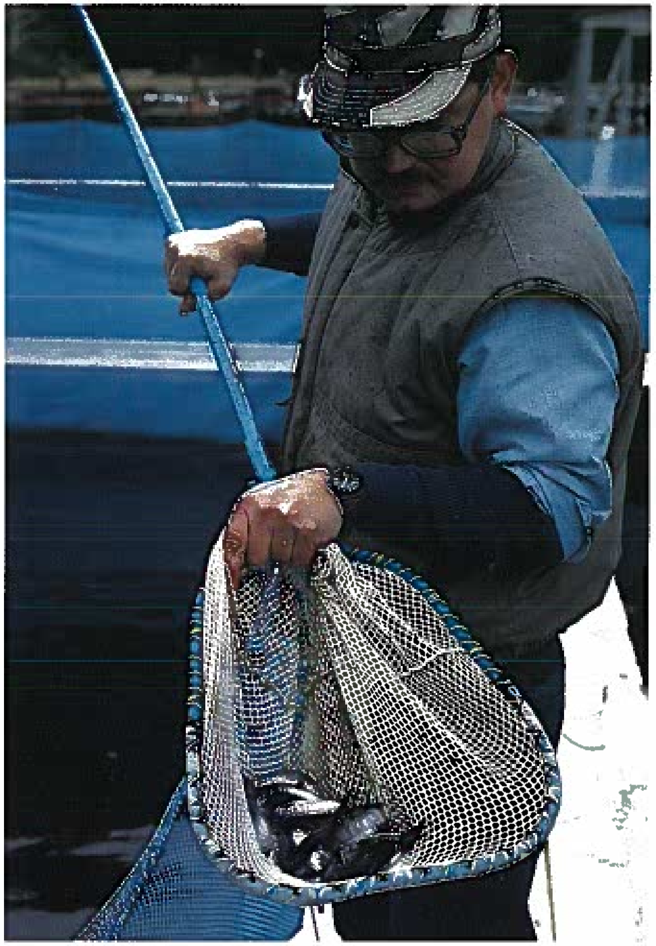
Marine aquaculture in U.S. waters must be developed with an eye toward sustainability, that is, with the goal of producing products while conserving natural resources. Its development must have a solid ecological perspective that is compatible with the social, economic, and environmental goals of coastal communities. Given that Sea Grant supports substantial research and outreach in this area, the proposed initiative will forge new linkages between aquaculturists and environmental scientists. Thus, Sea Grant research will focus on interdiciplinary efforts involving all stakeholders to minimize adverse impacts of marine aquaculture on the environment and wild stocks. Specifically, scientific efforts will provide the basis for the development of criteria for marine aquaculture operations, including determination of permissible discharges, optimal treatment of effluents, requirements for siting new operations, assessment of positive and negative ecological impacts, and necessary information for establishing siting protocols and standards to facilitate the permitting process. Topics to be addressed under the rubric of sustainability will include:

- Risk Assessment — Identifying potential detrimental impacts from aquaculture activity and the probability that the detrimental impacts will occur.
- Cost-Benefit Analysis — Assessing the economic and environmental consequences of activity associated with aquaculture ventures and determining potential economic and environmental benefits that might be gained by modifying certain activities.
- Best Management Practices — Employing management strategies that optimize production while maintaining environmental integrity.
- Education and Training — Developing educational materials and providing training opportunities on sustainable aquaculture for potential aquaculturists through formal training programs and demonstration projects.

The Challenge

Develop a Sustainable U.S. Aquaculture Industry

- Develop environmentally friendly feeds
- Engineer sustainable water and wastewater systems
- Develop water reuse and recycling protocols
- Evaluate nutrient and sludge management strategies
- Develop best management practices for marine aquaculture operations



Marine biotechnology

Aquaculture is the growth of aquatic organisms in a controlled environment. Such environments may be bioreactors, open or closed raceways, ponds or natural bodies of water. The aim of such culture is to be able to produce items of economic import such as pharmaceutical agents, feed additives, isotopically enriched chemicals, polymers, lipids with petroleum potential and foodstuffs. As was mentioned above, the United States has a significant annual trade deficit in seafood; increasing our nation's capability in aquaculture of food species would provide considerable economic benefit. There is also a growing market for production of ornamental fish, including captive breeding of tropical species now rare in their native countries, Economically viable aquaculture requires that the entire life cycle of a species be completed in captivity, yet many forms of potential importance do not reproduce under these conditions. Currently, foundational research in physiology and endocrinology is directed primarily at understanding reproduction and growth of cultured species, and developing means for its control.

Other major areas of activity include research on means to increase the productivity or food value of the cultured species; drugs and vaccines to enhance immunity to disease or other stresses; genetic improvement of strains and identification of deleterious or desirable genes within stocks; vaccines, drugs and feeds tailored to particular species and means to increase the palatability, quality and safety of cultured food products.

Sea Grant has supported — and continues to support — groundbreaking research in aquaculture. Among recent accomplishments have been:

- Development of a triploid oyster that makes possible a year-round rather than seasonal oyster production- this achievement has contributed greatly to the revival of the West Coast oyster industry.
- Use of DNA markers to differentiate between wild and hatchery-released stocks of fish, such

as salmon, steelhead and striped bass, particularly in areas where wild, genetically-diverse stocks are threatened by habitat loss, overharvesting or competition from non-native species.

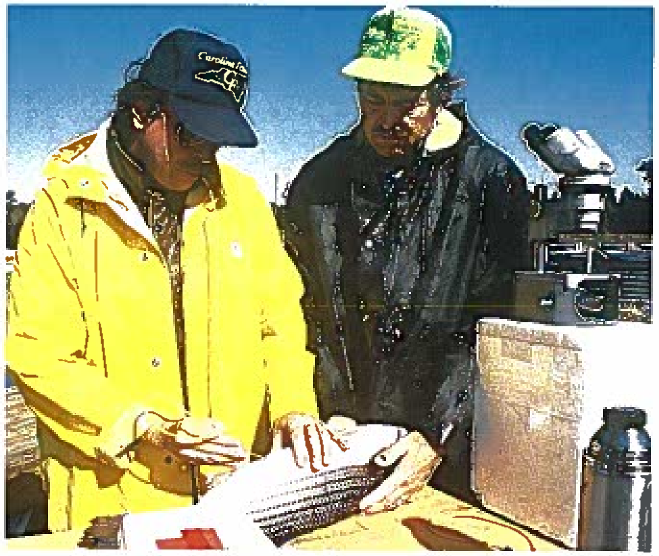
- Development of vaccines against two major diseases of salmon, IPN and IHN virus. This research set the stage for commercial development of improved vaccines to increase survival in cultured trout and salmon.

The Challenge

Produce More and Healthier Seafood:

- Enhance growth and productivity
- Control reproduction of cultured species
- Improve disease resistance and diagnosis
- Produce drugs and feeds tailored to each species
- Improve genetic makeup of strains

Stock enhancement



Aquaculture may be used to produce species for stock restoration and enhancement programs. Such programs are gaining increasing popularity as both recreational and commercial fisheries are being affected by decreasing population abundance; this is also true for endangered species, such as the shortnose sturgeon. Stock restoration and enhancement involves a complex set of components. If a depleted species could be replenished by stock enhancement in an environmentally sustainable way, the fishery could be rebuilt and economic return from coastal areas increased. Lack of knowledge about the ability of stocked fish to survive and reproduce in the wild and concerns about possible ecosystem impacts currently make stock enhancement an important area for further research.

A basic requirement for stock enhancement programs is that a suitable culture technology must be available for the target species. Organisms produced for release into natural systems must be healthy and genetically suitable. Further, there must be sufficient data to indicate what size of animal to stock, when and where to stock, and how many to stock. In pilot-scale programs, suitable tagging procedures must be identified to allow identification of stocked animals so that test parameters (size, timing, site, etc.) and overall impacts can be assessed. Information on a species' life history and how stocked organisms adapt to the natural system are needed for the effective use of suitable organisms in enhancement programs.

To have long-term acceptability, a stocking program must be conducted in an environmentally responsible manner. Fishery managers should be involved in the program so that the impacts of stocking are periodically assessed. Further, clear goals should be established to determine success. In some systems such as freshwater lakes and streams, put and take fisheries (e.g. trout, largemouth bass) may be the goal, while in marine systems establishing self-sustaining populations may be the goal. For anadromous salmonid species, stock enhancement programs are well-known and accepted. For example, enhancement activities through ocean ranching of salmon have been successful in Alaska, where the industry employs more than 30,000 people in salmon harvesting and another 20,000 in product processing. However, this is not the case for most estuarine and marine species. At the turn of the century, there were large scale stocking efforts to replenish over-exploited fisheries. However, no successes were demonstrated. In recent years, however, more controlled programs were undertaken and enhancement efforts in several states (e.g. Texas, Florida, South Carolina, Hawaii) have shown that stocking of coastal species can be successful under certain conditions.

Many species may be suitable candidates for stock enhancement/restoration programs (e.g. flounders, snappers, sturgeons), but basic research is needed in many areas. Such areas pose research challenges that will be a focus of Sea Grant's Marine Aquaculture Initiative.

The Challenge

- Identify candidate species for enhancement activities based on fisheries importance and biological information
- Identify life history characteristics of candidate species
- Develop basic biological requirements of candidate species
- Develop suitable culture technologies for broodstock development and spawning
- Identify the environmental suitability, food web dynamics, and carrying capacity of habitats for enhancement
- Characterize the genetic profiles of candidate species considered for stocking
- Perform pilot-scale testing to identify suitable stocking parameters
- Assess contributions to fisheries enhancement and to environmental effects of stocked species

Marine ornamental fishes and invertebrates

"Ornamental" fishes and invertebrates are freshwater or marine organisms held in home, office, commercial and public aquaria for display purposes. They are extremely popular throughout the U.S. and most developed nations. Marine aquaria, in particular, can be quite elaborate and may hold many different species. Continuing advances in aquarium technology have made it possible to maintain delicate arthropods (e.g. shrimp), mollusks (e.g. Tridacna), cnidarians (e.g. corals), and other taxa in long-term aquarium culture. Today's "mini-reef" aquaria are self-contained ecosystems, where many of the interactions between species can be observed.

The market for marine ornamentals is large and expanding vigorously; as the ease and techniques for maintaining healthy marine aquaria improve, it is expected that the demand for these organisms will accelerate even more rapidly. Virtually all of the present demand is met with wild-caught specimens, although there are small and active aquaculture enterprises culturing marine ornamentals in several states. For example, for coral reefs, the trade in ornamentals and live reef fish is proving to be a serious ecological threat. Cyanide and dynamite fishing methods have been used which cause high mortalities and serious threats to reef ecosystems.

Culture techniques have been successful for a few fish species, several invertebrate species, and many of the marine plants used in the trade. However, the methods for captive reproduction and husbandry of many species still need to be developed. With over 800 species of fish, and an unknown number of invertebrate species in the trade, aquaculture is not in a position to replace wild collection. However, aquaculture does provide an opportunity in the marine ornamentals industry.

Obtaining sound figures for the economic impact of the marine aquarium trade is difficult. Nonetheless, one five-year old economic estimate places the wholesale value of trade in aquarium fish and equipment (e.g., aquaria, filters, food, lighting, etc.) in excess of $400 million in the United States and the retail value at as much as $7 billion globally. The worldwide market for marine ornamentals alone is estimated at more than $100 million.

The Challenge

Explore Culture Opportunities for Marine Ornamentals

- Identify candidate species
- Define culture requirements
- Enhance growth and reproduction
- Examine market potential
- Reduce losses in shipping
- Identify economic opportunities

Reaching Out to the Industry

Sea Grant is known not only for its excellence in research in a wide variety of topic areas germane to this initiative; it also has an excellent reputation with respect to its education and outreach activities. Of course, Sea Grant programs encourage publication of results in the scientific literature, but information dissemination does not end there. Extension personnel in each Sea Grant program work closely with each other and constituent groups in translating scientific information into formats that can be used by interested parties. In the case of the Marine Aquaculture Initiative, extension experts will be involved at every step of the process to transfer information to all stakeholders. The needs of industry, the requirements of agencies and the design of research need to be integrated. Sea Grant extension agents and specialists are well-positioned to implement and maintain the required information transfer networks. Sea Grant communicators will develop publications, news releases, videos, interactive CD-ROMs and maintain web sites to distribute information to all interested parties. Much of the material developed by Sea Grant communicators is used in the nation's schools, and an important outcome of the Marine Aquaculture Initiative will be development of educational materials aimed at K-12 teachers and students.

Sea Grant and Marine Aquaculture: The Challenge

The Marine Aquaculture Initiative will provide the framework for meeting the needs of the fledgling marine aquaculture industry. Among the accomplishments that can be expected during the first five years of the initiative will be:

- Advances in the design and construction of sustainable commercial marine aquaculture facilities on-shore, near-shore and in the open ocean.
- Rapid expansion of marine food production from commercial aquaculture enterprises.
- Expansion of the modest existing enhancement efforts that are ongoing in conjunction with such species as red drum and striped bass.
- Acceleration of research on the culture of species that are sources of new pharmaceuticals.
- Expansion of the production of marine ornamental species to reduce dependence of the aquarium industry on wild-caught fishes and invertebrates taken from waters of the United States and foreign nations.
- Better understanding of and treatment methods for marine diseases that affect both cultured and wild stocks.
- Development of a constructive dialogue between aquaculture producers and environmental community leaders.

Sea Grant institutions

For information about the National Sea Grant College Program, contact:

National Sea Grant College Program
NOAA, Sea Grant, R/SG
1315 East-West Highway
Silver Spring, Maryland 20910-3282
(301) 713-2445

http://www.mdsg.umd.edu:80/NSGO/index.html

Alaska Sea Grant College Program
University of Alaska Fairbanks
P.O. Box 755040
Fairbanks, AL 99775-5040
(907) 474-7086

California Sea Grant College Program
University of California
9500 Gilman Drive
LaJolla, CA 92093-0232
(619) 534-4440

Southern California Sea Grant Program
University of Southern California
University Park
Los Angeles, CA 90089-0373
(213) 740-1961

Connecticut Sea Grant College Program
University of Connecticut
1084 Shennecossett Road
Groton, CT 06340-6097
(860) 405-9110

Delaware Sea Grant College Program
University of Delaware
Newark, DE 19716-3501
(302) 831-2841

Florida Sea Grant College
University of Florida
Box 110400
Gainesville, FL 32611-0400
(352) 392-5870

Georgia Sea Grant College Program
University of Georgia
Marine Sciences Building, Room 220
Athens, GA 30602-3636
(706) 542-5954

Hawaii Sea Grant College Program
University of Hawaii
2525 Correa Road, HIG 238
Honolulu, HI 96822
(808) 956-7031

Illinois-Indiana Sea Grant Program
University of Illinois
Purdue University, Department of Forestry and Natural Resources
1200 Forestry Building
West Lafayette, IN 47907-1200
(765) 494-3573

Louisiana Sea Grant College Program
Louisiana State University
128 Wetland Resources Building
Baton Rouge, LA 70803-7507
(225) 388-6710

Maine/New Hampshire Sea Grant College Program
University of Maine
5715 Coburn Hall, Room 22
Orono, ME 04469-5715
(207) 581-1435

University of New Hampshire
Kingman Farm
Durham, NH 03824-3512
(603) 862-0122

Maryland Sea Grant College Program
University of Maryland System
0112 Skinner Hall
College Park, MD 20742-7640
(301) 405-6371

Massachusetts Sea Grant College Program
Massachusetts Institute of Technology
E38-330/Kendall Square
292 Main Street
Cambridge, MA 02139-9910
(617) 253-7131

Michigan Sea Grant College Program
University of Michigan
2200 Bonisteel Boulevard
Ann Arbor, MI 48109-2099
(313) 763-1437

Minnesota Sea Grant Program
University of Minnesota
2305 E. 5th Street
Duluth, MN 55812-1445
(218) 726-8715

Mississippi/Alabama Sea Grant Consortium
703 East Beach Drive
P.O. Box 7000
Ocean Springs, MS 39566-7000
(228) 875-9341

New Jersey Marine Science Consortium
Rutgers University
Building #22
Fort Hancock, NJ 07732
(732) 872-1300

New York Sea Grant Institute
State University of New York at Stony Brook
121 Discovery Hall
Stony Brook, NY 11794-5001
(516) 632-6905

North Carolina Sea Grant College Program
North Carolina State University
100C 1911 Building
Box 8605
Raleigh, NC 27695-8605
(919) 515-2454

Ohio Sea Grant College Program
The Ohio State University
F.T. Stone Laboratory
1314 Kinnear Road, Room 1541
Columbus, OH 43212-1194
(614) 292-8949

Oregon Sea Grant College Program
Oregon State University
500 Kerr Administration Building
Corvallis, OR 97331-2131
(541) 737-2714

Puerto Rico Sea Grant College Program
University of Puerto Rico
P.O. Box 9011
Mayaguez, PR 00681-9011
(787) 832-3585

Rhode Island Sea Grant College Program
University of Rhode Island
Graduate School of Oceanography
South Ferry Road
Narragansett, RI 02882-1197
(401) 874-6800

South Carolina Sea Grant Consortium
287 Meeting Street
Charleston, SC 29401
(843) 727-2078

Texas Sea Grant College Program
Texas A&M University
1716 Briarcrest, Suite 702
Bryan, TX 77802
(409) 845-3854

Virginia Sea Grant College Program
University of Virginia
Madison House - 170 Rugby Road
Charlottesville, VA 22903
(804) 924-5965

Washington Sea Grant College Program
University of Washington
3716 Brooklyn Avenue N.E.
Seattle, WA 98105-6716
(206) 543-6600

Wisconsin Sea Grant Institute
University of Wisconsin
1975 Willow Drive, 2nd Floor
Madison, WI 53706-1103
(608) 262-0905

Woods Hole Oceanographic Institution Sea Grant Program
Woods Hole Oceanographic Institution
193 Oyster Pond Road, MS #2
Woods Hole, MA 02543-1525
(508) 289-2557

Developed by the Aquaculture Task Group of the Sea Grant Association for distribution through the National Sea Grant Network.
Task Group members—
William L. Rickards, Virginia Sea Grant College Program
M. Richard DeVoe, South Carolina Sea Grant Consortium
Robert R. Stickney, Texas Sea Grant College Program
Robert E. Malouf, Oregon Sea Grant College Program
Lee Stevens, Sea Grant Association

The Aquaculture Task Group would like to acknowledge the following individuals for their input and advice —
Robert W. Chapman, South Carolina Department of Natural Resources
Kenneth Chew, University of Washington
John Gold, Texas A&M University
Jane Lubchenco, Oregon State University
Theodore I.J. Smith, South Carolina Department of Natural Resources

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