Moving offshore
Sustainable offshore aquaculture development in the Gulf of Mexico

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United States population and seafood consumption is steadily increasing. If per capita consumption remained unchanged at 6.8 kg/yr, a 1 percent increase in the U.S. population would add more than 18 million kg of seafood. Domestic U.S. "wild caught" fisheries cannot meet these seafood demands without unsustainable harvests. U.S. seafood demand will therefore have to be met through increased imports or domestic aquaculture production. More than two-thirds of the seafood consumed in the U.S. is imported, resulting in more than a $7 billion seafood trade deficit. Aquaculture has been established in the U.S. for more than 100 years, but it remains relatively underdeveloped in comparison with the rest of the world. While aquaculture contributes more than 25 percent by weight to world seafood production, U.S. production is less than 5 percent of world aquaculture production. In recent years, however, U.S. aquaculture production has grown to more than 350,000 metric tons (USDC 2000). Development of an intensive aquaculture program in the U.S. will offset shortfalls in domestic seafood demand and reduce international import dependence.

Coastal aquaculture expansion is limited in the U.S. owing to the rapid increase of the nation's coastal population, creating increased human-induced pollution and stress to the marine environment and increasing user conflicts with existing industries and recreational groups. In addition, currently exploited coastal areas will eventually have environmental bottlenecks to future expansion of net pen aquaculture owing to threats of self-pollution by the aquaculture industry. As a result, it has been recognized that perhaps the most appropriate option for expansion of U.S. aquaculture production is in the exposed open ocean environment.

Department of Commerce Aquaculture Policy

In August, 1999 the U.S. Department of Commerce (DOC) approved an Aquaculture Policy to serve as a vision for national aquaculture development (http://www.nmfs.noaa.gov/trade/DOCAQpolicy.htm). The DOC aquaculture mission is to create sustainable economic opportunities in aquaculture while remaining environmentally sound and consistent with applicable laws and policies. Specific objectives outlined in the DOC Aquaculture Policy include increas-
The Gulf of Mexico Offshore Aquaculture Consortium

The Gulf of Mexico Offshore Aquaculture Consortium (OAC) was formed, "to develop a highly competitive, sustainable marine aquaculture industry that will meet growing consumer demand for aquatic foods and products that are of high quality, safe, competitively priced and are produced in an environmentally responsible manner." The OAC was created as a collaborative, Gulf-wide, university-based interdisciplinary research program with industry partnerships and broad public input. OAC research is focused on the development of a socially acceptable and environmentally-friendly offshore aquaculture industry in the Gulf of Mexico that is also economically feasible. Primary data collection and industry development will be performed using a proactive approach from the outset and in consultation with Gulf of Mexico stakeholders. The Texas Sea Grant College Program hosted an OAC workshop in February 2000 to facilitate input from the public, industry and OAC collaborators. A multidisciplinary research plan has since been implemented with research (legal/regulatory review, growout trials, engineering design, environmental and genetics research), demonstration (documenting offshore aquaculture operations, marketing/economics studies, disease monitoring) and education/outreach (public exhibits, internet, documentation/publisher, regional coordination, international collaboration).

Multidisciplinary Research for Offshore Aquaculture Development

Legal/Regulatory

Agency involvement and legal and regulatory requirements for offshore aquaculture permitting in both the state and federal waters of the Gulf of Mexico have been reviewed (Table 1; http://www.olemiss.edu/orgs/masglp/offshore.htm). As a result of this legal research, the OAC obtained permits to site and operate a marine aquaculture research facility in U.S. Federal waters approximately 40 km south of Mississippi, near a Chevron U.S.A. Production Company gas structure (29°58.64.9'N, 88°36.29.7'W). Further research will recommend a lead agency for permitting and regulation of offshore aquaculture and identify necessary elements for an offshore aquaculture zone. A Marine Aquaculture Zone (MAZ) dedicated to aquaculture can provide water column leasing with minimal user conflicts while securing capital investment and industry insurance. Continuing legal research will address issues regarding offshore aquaculture operations and sale of harvested products throughout OAC growout trials.

Husbandry

OAC research and demonstration will be conducted in a manner similar to a commercial-scale offshore aquaculture operation (i.e., feeding, net cleaning, mortality removal, fish size/health sampling). All farm chores will be documented with regard to cost and necessary man-hours to assist in determination of economic viability and to compile enterprise budgets needed to assemble a best management practices (BMP) workbook for offshore aquaculture.

Red drum (Sciaenops ocellatus) has been adopted as the OAC surrogate offshore aquaculture species for the initial growout cycle. Subsequent cycles will focus on cobia (Rachycentron canadum) and red snapper (Lutjanus campechanus), depending on juvenile availability. Red drum will be transported from the Texas Parks & Wildlife Department Perry R. Bass hatchery located near Palacios, Texas, to the Mississippi State University Coastal Aquaculture Unit (CAU) in Gulfport, Mississippi, where they will be grown in ponds to a size deemed appropriate for the offshore environment. Red drum fingerlings will be stocked (estimated final stocking density ~ 20 kg/m^3)

Table 1. The Legal and Regulatory Regime for Offshore Aquaculture

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<td>Rivers &amp; Harbors Act</td>
<td>Department of Agriculture</td>
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<td>National Environmental Policy Act</td>
<td>Environmental Protection Agency</td>
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<td>Ocean Dumping Act</td>
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<td>Coastal Zone Management Act</td>
<td>Regional Fishery Management Councils</td>
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<td>Endangered Species Act</td>
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<td>National Aquaculture Act</td>
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<td>Outer Continental Shelf Lands Act</td>
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<td>Clean Water Act</td>
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<td>Magnuson-Stevens Act</td>
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<td>Marine Mammal Protection Act</td>
<td>State Agencies</td>
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<td>Public Trust Doctrine</td>
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in the OAC 600 m³ Ocean Spar Sea Station† (OSSS) cage (manufactured by Ocean Spar Technologies (OST) of Bainbridge Island, Washington USA) to initiate the offshore growout trial. Throughout the growout cycle, red drum will be sampled monthly to measure weight and length. Average weight, length, Fulton's condition factor, and specific growth rate will subsequently be calculated. Quantity of feed given will be determined with time and feed amounts and rates recalculated from monthly growth data (feed from Land O'Lakes Farmland Feed). Food conversion ratio will be calculated. Monthly blood samples will be taken from red drum for stress response analyses in the offshore growout environment.

Pathogens in a culture facility can have disastrous consequences; therefore, early identification of potential problems is critical for minimizing mass mortality and producing healthy fish. Throughout the growout cycle, dead and moribund red drum will be removed from the OSSS and examined for the presence of serious pathogens. Examinations will be performed for external parasites and lesions on the gills and body surface. Internal organ swabs will be prepared for bacteriological analysis.

Environmental

Monitoring will determine the impact of the aquaculture operation on the environment. Regions of the Gulf of Mexico experience seasonal development of a “nepheloid layer” as a result of resuspension of fine seafloor sediments generated from bottom turbulence (Shideler, 1981). This fluid-like nepheloid layer, coupled with large volumes of water passing the OSSS increasing the dilution factor, may create difficulties in monitoring benthic and water quality impacts of offshore aquaculture operations in the Gulf of Mexico. Dynamic hydrographic and oceanographic conditions will not allow use of conventional methods to measure aquaculture impact on the environment. The OAC will suspend sediment traps from the OSSS to collect excess feed and solid metabolic wastes associated with farm operations. Organic material (fish feed and feces) will be quantified and analyzed with oceanographic data to allow modeling of the potential impact of offshore aquaculture in the Gulf of Mexico.

Deployed sediment traps will be used to collect resuspended sediments. Magnitude, particle size spectra, and height of sediment resuspension during various oceanographic and storm conditions will be determined. The Gulf of Mexico region is prone to large storms during the annual hurricane season (June 1-November 30). The OSSS has the ability to be lowered quickly to the sea floor in an attempt to protect it from potential storm damage. High current speeds, even at depth, can result in resuspension of substantial amounts of mud-silt bottom sediments in the water column that can adversely affect fish health through gill irritation and secondary bacterial infections. Increased concentrations of sediments could be lethal to fish resulting in economic losses.

The Gulf of Mexico has potential for occurrence of at least 14 harmful algal species (impacts range from environmental change, fish/invertebrate toxicity, and human toxicity). Algal bloom monitoring must be initiated by the OAC from the outset to adjust farming operations in a preventative manner (e.g., feeding rates and time) to protect the stocked fish. Water samples will be taken on a monthly basis - in the OSSS, outside of the OSSS and at control locations away from the OAC site - and analyzed for chlorophyll, algal densities and species composition.

Water and weather conditions (temperature, turbidity, dissolved oxygen, wind, sea state) will also be recorded at the time of water sampling.

High concentrations of wild fish can be observed in the vicinity of aquaculture cages (Carsi 1990). Fish communities associated with aquaculture facilities will enhance the ability of the “aquaculture ecosystem” to decrease environmental impacts of fish farming and enhance the productivity of the marine environment. Aquaculture facilities provide additional nutrients to the surrounding environment, through feed input and metabolic wastes from the growout fish. Nutrient input may influence the biofouling community structure and supplement the diets of attracted fish with excess aquaculture feed passing through the cages. The moored OAC OSSS cage will act as a large midwater artificial reef or Fish Attracting Device (FAD). Within nature, midwater structures can be extremely important to fisheries recruitment and have very complicated, self-sustained ecosystems associated with them (e.g., macroalgae). Fish aggregation to the OSSS will be evaluated on a monthly basis. Fish length will be estimated and used to calculate species biomass aggregating to the offshore cage structure with length-weight conversion equations for Gulf of Mexico fish species. A sample of fish aggregating to the OSSS will be collected during each season, measured (cm), weighed (g) and have otoliths removed for individual age and population structure determination. In addition, stomachs will be removed for stomach content analysis and to determine dependence of the fish community on excess aquaculture feed.

Engineering

Owing to the full exposure from all directions combined with the depth and soft sediments experienced at the OAC site, careful consideration of the cage mooring was required. To avoid the complexity and high cost associated with the common multi-point mooring array, a single point mooring (SPM) was chosen.

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Moving aquaculture to more exposed environments (unprotected with exposure experienced from a minimum of three sides) increases the logistics of the operation. Land may not be far away, but the degree of exposure increases the risk of storm damage to the cage infrastructure and complicates routine farming operations. The offshore aquaculturist, for example, must rely more heavily on mechanization to allow feeding at set times during the day. Routine operations - taken for granted in protected sites - now become a substantial chore. Unlike near shore exposed sites that enjoy the luxury of visual observation of the cages and stock (and quick response time to emergency situations), offshore aquaculture offers none of this. To address issues associated with extreme remote conditions, such as those in the Gulf of Mexico, the OAC will develop innovative technologies to allow appropriate levels of feeding, long-distance monitoring and communication and carefully planned responses to emergency situations. Feeding is the most expensive and arguably most important husbandry task. Development of an unmanned feeding capability is critical to the success of a research or commercial cage operation in the offshore environment. An autonomous feeding system, Robofeeder, which dispenses food pellets based on timed or remotely actuated controls is being developed at the Massachusetts Institute of Technology and will be employed. A means of observing fish during feeding will be developed using an underwater video camera and telemetry system to allow optimization of the distant offshore aquaculture operation.

The optimal model for cooperation between aquaculture and the oil and gas (O&G) industry may be in evidence at the OAC site. The benefits of proximity have been achieved without the liabilities of conflicting use of an active O&G platform or those associated with using an abandoned structure. Unlike the early visions of cages attached to and serviced by O&G platforms, the commercialization of aquaculture in the open ocean will require the development of specialized aquaculture support vessels (ASVs). These innovative craft or barges will be designed for efficient servicing of the cages, harvesting and hauling of fish and dealing with the routine tasks associated with the operation of an offshore fish farm. Based on a thorough review of ASV requirements, the OAC will identify an optimum concept from the variety of possible approaches. A detailed design for an ASV and estimate of construction and operational costs will be developed. Design of an ASV may become the focal point of an OAC MAZ established to continue this long-term research enterprise to develop and optimize offshore aquaculture and educate future operators and aquaculture students in the Gulf of Mexico region.

**Marketing/Economics**

Development of an offshore aquaculture industry is futile without economic viability. To profit from aquaculture; in both domestic and international markets; fish farmers, processors and distributors require adequate information about potential markets. Market trends and the factors influencing them will be analyzed. Market information will include domestic and foreign production; exports and imports; product forms (e.g. live, fresh, frozen, fillet, head-on-gutted); ex- vessel, farm-gate and wholesale prices; and processing and distribution costs. In anticipation of harvested OAC product, a Marketing Plan will be developed with emphasis on markets, product forms and seasonality to attain premium prices.

Standard farm production cost estimation procedures will be used to estimate operational and ownership costs for the offshore production system. Analytical procedures will require in-depth discussions with OAC collaborators and result in a set of operational and ownership budgets detailing expenditures and receipts.
Investment capital requirements to construct and equip offshore growout systems will be estimated for commercial-scale operations as designed by the OAC. Operational expenditures (e.g., feed, frequency of feeding and labor requirements) will be determined and overall cost of production documented and scaled for commercial ventures. Actual offshore aquaculture income will be attained from sales and utilized to complete the economic analysis (expenses vs. income) to determine economic viability and creation of a Model Business Plan for offshore aquaculture. Sensitivity and break-even (i.e., specifying the number of cages, fish biomass, feed requirements and fish loss) analyses of critical investment indicators (e.g., internal rate of return and payback period) will be conducted with respect to critical biological and economic variables.

**Disease**

Health management plays a vital role in the economic viability of aquaculture activities. Health management in fish culture operations differs from that associated with other animal production systems in a number of important respects. Some examples include: 1) fish are not readily observable in the aquaculture environment, therefore pre-clinical signs of disease or other adverse conditions are often not apparent until it is too late to take appropriate countermeasures; 2) disease conditions in fish, while similar in some respects to those conditions in other animals, are unique with regard to the nature of the host (fish are cold-blooded as opposed to the warm-blooded nature of most other animal production species), its response to challenge (inflammatory and immune responses of fish are generally more prolonged than other vertebrates) and etiology (infectious agents causing disease in fish are often unique to fish); 3) therapeutic approaches in the aquatic environment are often unique to that environment; and 4) even well-trained animal health professionals (e.g., veterinarians) frequently have minimal training in the area of aquatic animal medicine.

The OAC will develop a Gulf of Mexico Offshore Aquaculture Health Management Plan that will address the key issues of: 1) origin, maintenance and documentation of various features of parental stock, egg quality, fry, juvenile development and production facilities; 2) measures directed toward development and maintenance of high health parental stock; 3) monitoring and maintenance of optimum production conditions; 4) therapeutic and control measures; 5) food safety issues; and 6) training of personnel in principles of fish health management. Elements of the Offshore Aquaculture Health Management Plan will be based upon baseline clinical, behavioral and genetic data acquired relative to broodstock and various developmental stages of the production cycle. The Offshore Aquaculture Health Management Plan will be the result of coordinated activities of the various components of OAC offshore aquaculture research and demonstration.

**Genetics**

Offshore aquaculture marketing of game fish species such as red drum (Sciaenops ocellatus), red snapper (Lutjanus campechanus) and cobia (Rachycentron canadum) will require methods to identify or distinguish harvested products from wild stocks to ensure legal sale and alleviate potential conflicts. Genetic, specifically DNA, markers may be used to identify cultured fish origin. DNA remains essentially unchanged from parent to offspring, facilitating identification of progeny from known broodstock. A high number of hypervariable DNA regions exist, such as nuclear-encoded microsatellites and mitochondrial DNA that can be employed to generate identity profiles for hatchery-produced fish and probability estimates that a given fish was sampled from the wild population.

Statistical issues involved in DNA forensic testing to identify hatchery-produced fish from wild fish are straightforward. Assuming alleles (forms of genes) and genotypes (allele combinations or genetic constitution) of broodstock in the hatchery are known, genetic profiles can be established that would permit 100 percent certification that a given fish was not generated from that broodstock. The converse, proving that a given fish did not come from a wild stock, cannot be determined as confidently, but can be stated in terms of acceptable probability levels. Genetic data might indicate, for example, that there is a 100 percent probability that a given fish could have originated from known broodstock but that the probability that the same fish was sampled at random from a wild stock was less than one in a million. The OAC will target an acceptable probability level as less than one in 15-20 million.

**Project Output and Dissemination**

The OAC considers educating the public and fisheries communities in the Gulf of Mexico region about offshore aquaculture and its economic potential a major priority. Public education exhibits illustrating offshore aquaculture and its operations will be developed for marine education centers along the Gulf of Mexico coast. The first exhibit to be developed at the J.L. Scott Marine Education Center & Aquarium, Biloxi, MS. The OAC will maintain its internet site (http://www.org.usm.edu/~ooa) with novel methods (e.g., interactive internet displays) of enhancing user learning and enjoyment to serve as another outlet for effective dissemination of OAC research results. The OAC cage platform will also serve as an educational base to demonstrate offshore aquaculture operations to potential industry investors, and to instruct future offshore aquaculture operators and students.

Regional (Gulf-wide) workshops will be organized for individuals having interest and expertise to develop offshore aquaculture in the Gulf of Mexico. This will allow industry partners, scientists, engineers, legal experts, environmental NGOs, educators and regulatory agencies to meet and discuss OAC research and future directions. All aspects of OAC research will be discussed in an open forum among the interested groups attending. Workshops will conclude with a field trip to observe the OAC experimental cage location.

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