Sustainable Development of Offshore Aquaculture in the Gulf of Mexico

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ABSTRACT

Within the Gulf of Mexico, no offshore aquaculture industry exists to provide a model for potential investors to adopt. The Gulf of Mexico Offshore Aquaculture Consortium (OAC) has initiated a planning and applied research process to develop a sustainable offshore aquaculture industry. An OAC research plan has been developed to provide a vision for the future of offshore aquaculture in the Gulf of Mexico.

Proper site selection is critical to the success of aquaculture. This is particularly true in the marine environment, either coastal or offshore, where minimal control over the ambient environmental conditions are possible. Future industry planning will require the OAC to select appropriate sites to assist governing agencies, as well as ensure success to investors.

The OAC has selected an experimental offshore aquaculture site in federal waters off the coast of Mississippi. This site, in the vicinity of a Chevron gas platform, will provide passive protection to the cage from vessel traffic and surveillance to storm damage and vandalism. Throughout OAC research and development, environmental issues associated with aquaculture impacts on the environment – eutrophication, biopollution and artificial reef effects – and environmental impacts on the aquaculture operation – biofouling, seasonal anoxia, sediment resuspension, episodic tropical storms – will be addressed. Legal research on the fragmented regulatory framework is being conducted, focussing on the current permitting process and determining the best Marine Aquaculture Zoning strategy for the Gulf of Mexico. Economic sustainability will be paramount, with careful observation of market situations, recording associated expenditures, and revenues from the conducted research. Finally, logistics of operating an aquaculture venture 40 kilometers from shore will require enormous engineering ingenuity.

KEY WORDS: Offshore aquaculture, Gulf of Mexico, regulatory framework

BACKGROUND AND RATIONALE

It is the goal of the Gulf of Mexico Offshore Aquaculture Consortium (OAC) to develop a sustainable offshore aquaculture industry. "Sustainable development" has numerous working definitions that, depending on ignorance or misuse, have been modified to fit user needs. The Food and Agriculture Organization of the United Nations (FAO) defines "sustainable development", in their *Code of Conduct for Responsible Fisheries* (1997), as:

> "...the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the agriculture, forestry, and fisheries sectors) conserves land, water, plant, and animal resources, is environmentally non-degrading, technically appropriate, economically viable, and socially acceptable."

By using this FAO definition, sustainable fisheries requires the natural fish stock to be harvested at a rate equal to the regenerative rate of that stock. However, due to poor fish harvesting management, increased perturbations to fish habitat and an increased demand for fisheries products, sustainable fisheries have rarely existed, providing the impetus for increased aquaculture production, or "cultivated natural capital" (Goodland and Daly 1996). Goodland and Daly (1996) describe input-output rules required for environmental sustainability of renewable and nonrenewable resources. This concept should be applied for the sustainable development of aquaculture to ensure the industry will exist for future generations (Costa-Pierce 2001).

However, negative environmental impacts associated with marine cage aquaculture have become a global phenomenon (Pullin et al. 1993, Black 2000). The areal holding capacity for aquaculture operations may be determined from the total possible area available to site grow-out cages. However, an areal stocking method may result in overstocking the environment where the biological carrying capacity is much lower than the required area for grow-out. Overestimation may occur as the industry neglects to account for flushing rate, naturally occurring organic input, additional anthropogenic nutrient inputs, and numerous temporal oceanographic or hydrographic parameters that may limit total allowable nutrient input from aquaculture. Using Goodland and Daly (1996) input-output rules for sustainable aquaculture development requires that farm effluents - excess feed and metabolic wastes - "should be within the assimilative capacity of the local environment to absorb without unacceptable degradation of its future waste-absorptive capacity or other important service" (Goodland and Daly 1996). Hence, "assimilative capacity" is warranted and necessary to describe allowable aquaculture farm effort accepted in a given area. Further, Goodland and Daly (1996) separate sustainability into social, economic and environmental categories. This classification scheme is central to OAC research to ensure a sustainable offshore aquaculture industry will develop within the region.

AQUACULTURE SITE SELECTION CRITERIA

Appropriate site selection of aquaculture facilities must take into account biological, physical and social criteria to ensure success. It is generally recognized that fish are distributed within the acceptable zone of tolerance of numerous complex, interrelated parameters comprising its ambient environment. Fish habitat may be defined as an area "where they [fish] may feed, rest, breed and find shelter from both predators and inhospitable environmental intrusions" (Ryder and Kerr 1989). Quite often this habitat is not optimal for growth but must remain within the zone of tolerance for each ambient environmental parameter (e.g. temperature, salinity, dissolved oxygen) to allow survival.

Wild fish, in an open-ocean environment, must either tolerate changes to these parameters or display an avoidance behavior to environmental perturbation. Within an aquaculture setting, fish are contained in a given spatial environment and; therefore, the fish have no choice but tolerate environmental change. It is for this reason that aquaculture development and operations ***must*** proceed in a sustainable manner to ensure the local natural environment has the assimilative capacity to absorb fish farm wastes without unacceptable degradation of the environment. Aquaculture is the ***only*** user-industry of the oceans that ***require*** a constant, clean supply of water for success, and often times aquaculture operations may enhance the form and function of the natural environment by providing habitat to natural systems (Costa-Pierce and Bridger 2001).

GULF OF MEXICO OFFSHORE AQUACULTURE CONSORTIUM

In 1999, the OAC was formed to create a collaborative, Gulf-wide, university-based interdisciplinary research program to address social, environmental and technological issues that have plagued offshore aquaculture endeavors in the Gulf of Mexico (Table 1). By developing university/industry partnerships and seeking broad public/commercial input, the Consortium's goal is to develop socially and environmentally acceptable offshore aquaculture models that are appropriate to all stakeholders in the Gulf of Mexico region.

OAC Aquaculture Site

A site was chosen in 26 m of water approximately 40 km off the coast of Mississippi, in federal waters (29° 58.649'N, 88° 36.297'W) (Figure 1). This site is adjacent to a Chevron gas platform and within the Chevron minerals lease. Placing the cage in close proximity to a gas platform has provided the OAC cage passive protection from numerous user groups currently present in the Gulf of Mexico and some surveillance to cage damage resulting from storm events and vandalism. Although there has been much debate in the past regarding the integration of the oil and gas industry with offshore aquaculture (Stickney 1999), a recent analysis of aquaculture-oil/gas integration has shown that such an industry marriage may not be feasible (Bridger et al. submitted).

Table 1. The Gulf of Mexico Offshore Aquaculture Consortium (OAC), outlining the holistic development approach by member institutions.

Expertise Area	Institution
Legal/Regulatory Research · Permitting · Aquaculture Zonation · Operation Regulations	· MS-AL Sea Grant Legal Program, MS · LA Sea Grant Legal Program, LA · TX Sea Grant College Program, TX
Engineering Design and Monitoring	· MIT Sea Grant College Program, MA · Ocean Spar Technologies LLC, WA · Good Streak Marine Inc., LA
Site Selection with GIS	· Auburn University, AL · C-FAST Inc., NC
Hatchery Systems	· Texas Parks and Wildlife · The University of Southern Mississippi · Virginia Institute of Marine Sciences
Fish Husbandry/Grow-out	· The University of Southern Mississippi · MS-AL Sea Grant Consortium · Texas Sea Grant College Program
Fish Health	· Texas A & M University · The University of Southern Mississippi
Fish Nutrition	· Land O'Lakes Farmland Feed, AR
Fish Genetics	· Texas A & M University · The University of Southern Mississippi · Florida Marine Research Institute
Environmental Monitoring	· The University of Southern Mississippi · Mississippi-Alabama Sea Grant Consortium · National Marine Fisheries Service, Pascagoula, MS · Louisiana State University
Economics/Marketing	· Mississippi State University
Social Research	· Auburn University, AL
Education/Outreach	· Auburn University · Mississippi-Alabama Sea Grant Consortium

Cage and Mooring System

Typically, coastal aquaculture cages may be classified as gravity cages or Class 1 cages according to Loverich and Gace (1998). This cage configuration often experiences deformation and loss of internal cage volume associated with water movements due to wind, wave and current action. Up to 80% of the expected growing volume, used to base stocking density calculations, may be lost in currents of 1 m/s (Aarsnes et al. 1990). Gravity cages also have all their buoyancy located at the water surface and cannot sink to avoid storm surges. To sustain the high energy environment expected in the Gulf of Mexico and allow cage sinking to decrease hurricane damage while maintaining possession of the fish stock, an Ocean Spar Sea Station (OSSS) was chosen for OAC research (Figure 2; Loverich and Gace 1998). OSSS cage design is based on the floating spar buoy concept to shape the net enclosure and provide rigidity to the netting (Loverich and Croker 1993).

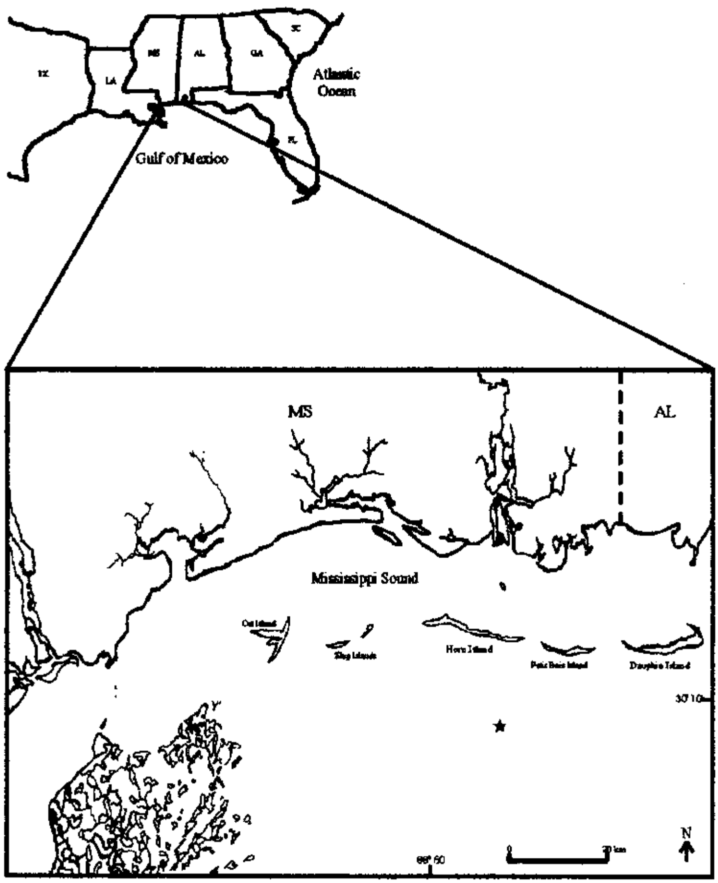

Figure 1. OAC offshore aquaculture experimental site (H) located in 26 m of water approximately 40 km off the coast of Mississippi, in federal waters (29° 58.649'N, 88° 36.297'W), near a Chevron gas platform.

The OSSS has a 600 m^3 volume, that is retained by its semi-rigid structure and netting. In contrast to the Ocean Spar Sea Cage, utilizing anchor tension to retain a constant shape and volume, the OSSS is self-supporting and will hold its shape and volume in the absence of both gravity and tensioned anchors (Loverich and Goudey 1996). The OSSS has a double-cone shape that is considered optimal for raising pelagic fish species, providing increased internal volume. To maintain constant volume and shape, the OSSS netting remains taut between a central spar buoy, approximately 1 m diameter and 9 m long, and an octagonal rim, located in the middle of the double-cone configuration and having an approximate 15 m diameter. The octagonal rim is composed of eight flanged sections of steel pipe that are individually pressurized and sealed to allow floatation of the central rim on the water surface. The central spar buoy has a lower variable buoyancy chamber that allows the OSSS to be submerged during harsh environmental conditions at a rate of approximately 25 m in a 15 minute period. For OSSS submergence, the spar buoy is ballasted with water that enters from the bottom of the spar when a valve in the top of the spar buoy is opened to release the air. Raising the OSSS simply requires displacing the ballast water in the spar buoy with air introduced from a SCUBA tank by divers.

Recent open ocean aquaculture projects have opted for the more commonly used submerged grid mooring system (Fredriksson et al. 2000). To decrease mooring costs, system complexity and potential environmental impact, the OAC OSSS is moored to the Outer Continental Shelf (OCS) on a single-point mooring (SPM) (Figure 2; Goudey et al. in press). An OSSS/SPM configuration will also decrease potential impacts of offshore aquaculture to marine mammal species by eliminating the need for a predator net surrounding the cage.

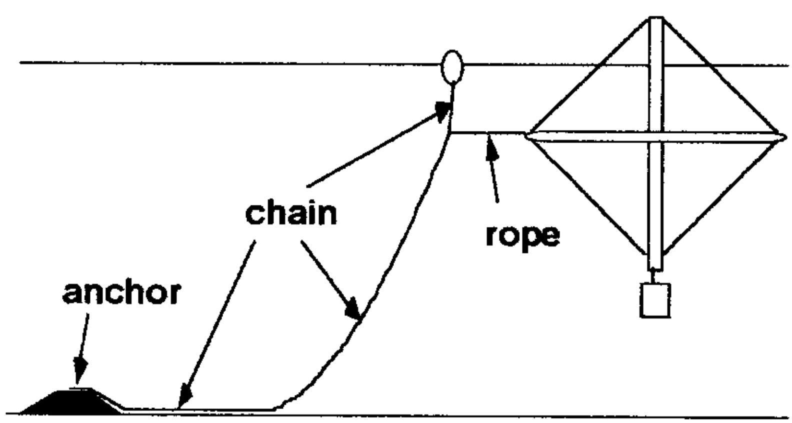

Figure 2. Representation of the Gulf of Mexico Offshore Aquaculture Consortium single-point mooring (SPM) system and Ocean Spar Sea Station cage.

Cage and Mooring Deployment

Although deploying any cage and mooring is site and environment specific, siting a cage and mooring it in a distant offshore location poses new challenges to overcome. Perhaps the most efficient mode of deploying the cage and mooring 40 km from shore would have involved carrying the assembled rim, central spar buoy, ballast weight and single-point mooring components to the site on a barge. This strategy would have decreased the necessary travel time associated with towing system components, similar to other project deployment strategies (Baldwin et al. 2000). Further, the OAC research team expected use of a lift-boat, with sufficient working deck space, would have created the safest and optimal deployment conditions by jacking the lift-boat out of the water and creating a stable work platform, offshore. However, just days prior to the scheduled cage deployment, the northern Gulf of Mexico experienced approximately 2.5 m waves which delayed access to a lift-boat, creating the necessity to explore alternative methods for cage and mooring deployment. At this time, The University of Southern Mississippi research vessel IX 508 was chosen for towing the cage and mooring block to the site and subsequent system deployment following careful consideration and discussion.

Prior to towing the cage components to the permitted aquaculture site, the rim sections were assembled at the NOAA National Marine Fisheries Service dock in Pascagoula, Mississippi. This dock provided sufficient workspace to assemble the 15 m octagonal rim and stage the various cage and mooring components, near the water, for efficient transfer to the water surface. On October 28, 2000, a crane was contracted to lift the 12,275 kg (27,000 lbs) mooring block in position, approximately three meters below the IX 508 wash and rutters, and secure it to the IX 508 A-frame to ease deployment. This mooring block was previously attached and welded to the assembled single-point mooring chain, and lifted to the stern of the IX 508. The central spar buoy was hoisted to the water surface and allowed to float in a horizontal position during the towing operation. The assembled octagonal rim was hoisted to the water surface and positioned in such a manner to enclose the central spar buoy to ease towing and cage assembly. Finally, the ballast weight, harvest ring, work platform and netting were all lifted to the IX 508 deck, prior to departing Pascagoula.

To ensure site arrival at sunrise, towing began at approximately 1800 hours. At a maximum towing speed of three knots, the IX 508 arrived on station at approximately 0400 hours, at which time the vessel remained in the vicinity of the Chevron gas platform until sunrise.

Mooring deployment commenced at sunrise, October 29, 2000. The octagonal rim and central spar buoy components were released from the IX 508 prior to lowering the mooring block to the sea floor to increase safety and maneuverability of the vessel. The mooring block and single-point mooring chain were slowly lowered to the desired location, followed by divers descending to inspect the block on the seafloor and release the lowering IX 508 rope. The octagonal rim and central spar buoy were then retrieved and connected to the single-point mooring line.

The central spar buoy had to be in a vertical position to create the taut netting, double-cone configuration of the OSSS. The ballast weight, a circular concrete block weighing approximately 3,181 kg with a toggle through its middle to attach it to the bottom of the spar buoy, was lowered to the water surface, attached to the bottom of the spar buoy, and further lowered until the spar buoy was vertical by receiving the tension of the ballast weight from the IX 508 crane cable. Divers disconnected the crane cable from the ballast weight. Once in a vertical position, the harvest ring was lowered over the spar buoy. The netting was attached to this harvest ring, which will later facilitate fish harvesting by raising it up the central spar buoy and effectively decreasing the internal cage volume. The netting was further lowered over the spar buoy and attached to the top of the spar buoy, followed by the work platform, positioned on the top of the spar buoy.

The spar buoy was then floated to the central portion of the octagonal rim. The netting was stretched to each flanged region of the octagonal rim and shackled to the inside corner of the rim section. This completed formation of the upper-cone section of the OSSS and created a very taut net. The lower portion of the net was attached to the harvest ring and tightened as much as possible. The cage and netting were secured for the night and the vessel departed the site.

The following morning the deployment team returned to the aquaculture site in a smaller research vessel (RV Tom McIlwain) and completed cage assembly. The net was further tightened over the central spar buoy and the netting, mooring shackles and connections were inspected.

Cage and Environmental Monitoring

No fish will be stocked within the aquaculture cage during the first year of OAC research. The novel OSSS/SPM configuration will be monitored to determine the degree of motion resultant from the ambient oceanographic conditions. Specific environmental monitoring of the cage and environment will determine the potential seasonal influence of the nepheloid layer and hypoxic layer to stocked fish, and the impact of hurricanes and storm surges on sediment resuspension. Baseline benthic environmental data will be collected to determine the impact of offshore aquaculture operations on the environment.

FUTURE DIRECTION OF OAC RESEARCH

Following Year 1 research, one of the candidate species summarized in Table 2 will be stocked in the cage and grown to a market size. These species each have excellent grow-out and market potential characteristics. Numerous criteria are used to select candidate species for aquaculture including required growth rate to a market size. Calculated growth performance indices (ϕ'; Longhurst and Pauly 1987), using L_{∞} and K values from wild stock literature, for candidate northern Gulf of Mexico species provide favorable growth attributes to attain economically feasible grow-out (Table 2). Throughout candidate species grow-out trials, careful notes will be taken regarding grow-out inputs and outputs to determine economic feasibility of offshore aquaculture operations in the Gulf of Mexico.

Table 2. Growth performance index (Φ')[a] calculated from cited L_∞ (cm) and K values for potential aquaculture species indigenous to the northern Gulf of Mexico. Values shown in parentheses are standard errors. (Taken from Bridger et al. submitted)

Species	Sex	L_∞ (cm)	K	Φ'	Source
Rachycentron canadum	male	117.07 (2.808)	0.432 (0.046)	3.77	Franks *et al.* (1999)[b]
	female	155.50 (3.514)	0.272 (0.017)	3.82	
Lutjanus campechanus	combined	95.0 (1.35)	0.175 (0.005)	3.20	Nelson and Manooch (1982)[c]
Sciaenops ocellatus	combined	91.8 (2.1)	0.422 (0.023)	3.55	Doerzbacher *et al.* (1988)[d]
Seriola dumerili	combined	127.2 (N.P)[e]	0.227 (N.P.)	3.57	Manooch and Potts (1997)[f]

[a] $\Phi' = \log_{10}K + 2\log_{10}L_\infty$ (Longhurst and Pauly 1987)
[b] Cobia were caught from northeastern Gulf of Mexico within the recreational hook-and-line fishery and aged with sagittal otoliths (male N=170; female N=395).
[c] Red snapper were caught in the commercial hook-and-line fishery off Louisiana and aged with scales (N=403).
[d] Tagged red drum returns from recreational and commercial fishery off Texas and growth determined from tag and release measures (N=2010).
[e] N.P. = not provided
[f] Greater amberjack captured from headboats operating in the Gulf of Mexico from Naples, Florida, to Port Aransas, Texas and aged with sagittal otoliths (N=340).

Further engineering research will focus on mooring redundancy while maintaining a SPM configuration, optimization of aquaculture operational procedures with the OSSS, and the design and subsequent manufacture of a lift-boat strategy specifically for offshore aquaculture in the Gulf of Mexico (Bridger *et al.* submitted). Genetics research will be conducted to develop a genetic marker specific to each candidate species and broodstock to distinguish harvested aquaculture product from wild conspecifics. Disease monitoring will occur to document the extent of poor fish health throughout grow-out cycles. Careful planning for a future offshore aquaculture industry will also be conducted using GIS to select favorable aquaculture sites with minimal user conflicts. Finally, it is a priority for the OAC to educate the public of the project's operations and economic potential of offshore aquaculture to Gulf of Mexico fishery-based communities.

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