CHAPTER 2

THE GULF OF MEXICO OFFSHORE AQUACULTURE CONSORTIUM[1]

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ABSTRACT

Marine aquaculture may be classified into four categories according to the degree of protection afforded to the operation by the site characteristics: land-based operations; coastal, protected aquaculture; coastal, exposed aquaculture; and, offshore aquaculture. Offshore operations have all the logistical challenges of both remote coastal and exposed aquaculture but at an escalated scale. In 1999, the Gulf of Mexico Offshore Aquaculture Consortium (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, OAC research and development efforts were focused on legal/regulatory review, engineering and logistics mitigation, marketing, genetic forensic analysis, environmental impact monitoring, economic feasibility, disease assessment, and education/outreach.

DEFINITIONS OF MARINE AQUACULTURE

Marine aquaculture may be classified into four categories according to the degree of protection afforded to the operation by the site characteristics and resultant advantages/disadvantages (Table 1). Land-based operations pump the water to tanks, on-shore, thereby being protected from storm surges and adverse weather conditions. These operations require large capital investments in infrastructure and are restricted by coastal development to the extent that future land-based operations may be focused only on hatchery and processing facilities to complement open ocean grow-out. Similarly, coastal aquaculture sites are located in protected, remote bays or fjords, away from populated areas and presumably anthropogenic sources of pollution associated with coastal communities.

In coastal aquaculture, farm workers either make day trips to the near shore sites or may rotate in shifts, upwards of a week, living on-site for the duration if the site is a considerable distance from the homeport. Farm workers have their quarters in a cabin either floating on the water near the cages or on-shore in line-of-sight of the cage flotilla. This close proximity to the cages and fish stock provides security against losses to vandalism, theft, predators, or adverse weather. Most logistical issues have been overcome with

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Table 1. Comparison of marine aquaculture strategies as categorized by degree of exposure of the operation to natural oceanographic and storm events.

Location	Advantages	Disadvantages
Land-based Facility	- Control water quality - Isolation of operation from populated areas not required - Complete protection from storm surges	- Limited space - Expensive capital investment
Coastal Environments (protected bays and fjords)	- Less capital investment - Protected from much of the natural elements - Surveillance possible with minimal investment	- Possible self-pollution - Limited space for expansion - Isolation more desirable to be free of anthropogenic coastal pollution - User conflicts exist close to shore
Exposed Sites	- Utilizing environment previously unexploited - Consistent and high quantity water supply - Visual protection still possible from near by land	- Exposed to destructive natural elements - Limited space near shore - User conflicts exists close to shore - Increased infrastructure necessary with increased exposure - Rely more on automation
Offshore Sites	- Decreasing user conflicts with increasing distance from shore - Very consistent water supply - Large potential for industry expansion	- Truly exposed with no protection from either side - Increased capital costs associated with increased technology and mechanization - Large investments required to ensure economic feasibility - Complete isolation from shore bases with no land in sight

barges designed to hold large quantities of feed, regular site visits to change crew and replenish fuel and food, and constant communication maintained through VHF/UHF radios or cellular telephone. Site protection to the cages allows farm operators to perform necessary tasks, such as multiple daily feeding, net changing, size grading, and stock sampling. Although automation is becoming more of the norm owing to the large scale of some of these operations and operator desire to minimize fish stress through minimal direct handling, site protection allows for minimal dependence on automation.

A simple move of the farm to the open ocean environment increases the logistical demands of the operation. For exposed locations land is still not far away but the degree of exposure—from at least three directions—increases the risk of storm damage to the cage infrastructure and complicates routine farming operations. Rudi et al. (1996) consider the regularity of farm chores and the effect of operating in more exposed locations. The aquaculturist must now 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. Exposed sites, not far from a land base, still enjoy the luxury of visual observation of the cages and stock, and quick response time to emergency situations that are not present in the offshore environment.

Offshore aquaculture operations have all the logistical challenges of both remote coastal and exposed aquaculture but at an escalated scale. In such instances, the degree of exposure, from all directions, is substantial, with the farm being truly exposed to any and all natural elements and out of sight from shore bases. Operators will require large infrastructure to produce fish at the quantity necessary for economic feasibility. In addition, excellent husbandry practices are required to ensure a stress free, healthy stock that is growing in a uniform fashion. Routine operations such as net changing may be impermissible in this exposed offshore environment or certainly require appropriate selection of fair weather days and prioritization of farm chores. Due to the extreme remote conditions, offshore aquaculture will require innovative technologies to allow numerous chores that otherwise require much human intervention in existing farm operations.

Lack of, or decreased, human presence will require a substantial change in the mindset of both owners and managers, trusting more in technology to communicate with the farm site particularly during storm events. Indeed, as Muir (2000) points out "…a major challenge for future systems may be to overcome the psychological dependence on human-based management, allowing greater reliance to be placed on automatic monitoring, control and management systems." Such monitoring and control systems will be essential for functions requiring daily attention—appropriate levels of feeding at set times regardless of weather; monitoring ambient parameters such as oxygen, temperature, and current speeds; determination of fish stress that might alter feed quantities and time, and potential monitoring of depth in the water column to avoid energetic surface conditions; and, security sensors to inform of breaches due to structural damage, predators and poaching. Finally, owing to the distance and unpredictability of weather conditions, dependable forms of long-distance communication in the potential absence of cellular phone coverage and carefully planned emergency response need to be developed.

OPEN OCEAN AQUACULTURE AND THE UNITED STATES

The United States is presently confronted with an ever-increasing seafood trade deficit that is estimated to be approaching U.S. $9 billion annually. Some research investment has been made to offset this trade imbalance through domestic aquaculture production following creation of a Department of Commerce Aquaculture Policy signed August 10, 1999 "…to create sustainable economic opportunities in aquaculture in a manner that is environmentally sound and consistent with applicable laws and policy."

Specific DOC objectives, by 2025, are to:

- Increase the value of domestic aquaculture production from the present U.S. $900 million annually to U.S. $5 billion, which will help offset the U.S. $6 billion annual U.S. trade deficit in seafood.
- Increase the number of subsequent jobs in aquaculture from the present estimate of 180,000 to 600,000.
- Develop aquaculture technologies and methods both to improve production and safeguard the environment, emphasizing where possible, those technologies that employ pollution prevention rather than pollution control techniques.

- Develop a Code of Conduct for responsible aquaculture by the year 2025 and have 100 percent compliance with the Code in federal waters.

- Double the value of non-food products and services produced by aquaculture in order to increase industry diversification.

- Enhance depleted wild fish stocks through aquaculture, thereby increasing the value of both commercial and recreational landings and improving the health of our aquatic resources.

- Increase exports of U.S. aquaculture goods and services from the present value of U.S. $500 million annually to U.S. $2.5 billion.

Recognizing a presently overburdened coast with numerous user conflicts and substantial anthropogenic sources of pollution, this investment has been directed towards developing aquaculture technologies for the open ocean, including areas out of the sight of land within the U.S. Exclusive Economic Zone.

The pace of open ocean aquaculture development globally has been slow owing to the lack of suitable technology that allows efficient farm operations in high-energy exposed environments. Technology advancements have been more forthcoming over the past decade with industry expansion from coastal operations pushing the development of exposed sites. The impetus for moving further offshore has come from numerous sources:

- Environmental degradation issues associated with overstocking near shore sites that have low rates of flushing and subsequent lower carrying capacity than more exposed sites.

- Numerous user conflicts for coastal regions with traditional fisheries, coastal developers, recreational users, and environmental advocacy organizations that limit further industry expansion near shore.

- Lower health management risks associated with well flushed open ocean environments having more stable water columns than near shore sites thereby decreasing stress to the stock.

- Realization of the vast opportunities present in the underutilized open ocean environment including the possibilities for economies of scale not previously attained near shore.

Development of exposed aquaculture sites around the globe has been further expedited by nations not having intricate coastlines that otherwise allows protected aquaculture development. Such countries include those in much of the Mediterranean, Ireland, Faeroe Islands, Japan, and Australia. Each of these countries is aware of their present, and/or future, dependence on foreign seafood supplies and potential for domestic seafood production through aquaculture. A desire to develop domestic aquaculture production in the open ocean has been the result. In many of these cases, developing exposed sites does not simply represent an evolution of near shore aquaculture operations and technology. To the contrary, many regions presently operating in exposed sites did so without first occupying protected coastal sites. Some individuals would consider the omission of protected sites a disadvantage. Others have grasped the opportunity for technological innovation that might otherwise have been constrained by technologies developed for near shore aquaculture.

Major research and development projects have been funded in several regions of the U.S. with funding allocated following the DOC Aquaculture Policy—including New Hampshire (Chambers et al. 2003), Puerto Rico (O'Hanlon et al. 2003), the Gulf of Mexico (focus of this book), and Hawaii (Ostrowski and Helsley 2003). Progress of these projects range, owing in large part to the very different environmental and oceanographic conditions experienced and degree of involvement from private investment driving the research agenda (i.e., Hawaii and Puerto Rico both presently have private investors, although commercial scale operations are relatively small; the Gulf of Mexico regional project has ceased to exist owing to fiscal constraints; and, New Hampshire remains in the middle of these two extreme situations).

Open ocean aquaculture operating in high energy exposed environments is expected to have numerous advantages over comparable operations in protected near shore sites. Direct comparison of near shore and offshore water bodies illustrate stark differences that will greatly benefit aquaculture operations and warrant costs associated with developing technologies for open ocean sites. Gowen and Edwards (1990) make comparisons related to biological and physical interactions in near shore and offshore environments. In broad terms, offshore water: 1) is in constant motion with presence of a residual flow regardless of tide or wind; 2) has decreased stratification owing to more frequent turbulent mixing and less likely to experience oxygen depletion at depth; 3) is less influenced by freshwater inflow, maintaining salinity regardless of season; 4) is less susceptible to summer heating and winter cooling that can be problematic in coastal waters; 5) has increased vertical mixing coupled with greater horizontal dispersion of farm wastes both resulting in decreased environmental loading; and, 6) has greater assimilative capacity of nutrients owing to increased water movement and decreased recycling compared to tidally driven near shore locations.

Anticipated broad advantages of open ocean aquaculture include increased production on a site area basis in better flushing water (Sveälv 1988), increased stocking density per cage volume with decreased stress (Gace 2003), decreased fish health issues in more suitable water conditions (e.g., Vågsholm and Djupvik 1998, 1999), minimal mortality also related to decreased fish stress, decreased environmental impacts with increased dilution of wastes over a larger spatial area (Gowen and Edwards 1990), increased economy of scale related to both larger site capacity and increased stocking density, and reduced user conflicts for necessary space (or volume) in vast expanses of ocean. Many of these advantages are as yet based upon expectation, but gradually becoming accepted with increasing scientific investigation and commercial experience in the open ocean environment.

As can be expected, new operating considerations exist for aquaculture establishments in the open ocean. Most importantly are: 1) increased logistic complexity resultant from operating in frequently hostile locations; 2) increased capital outlay to attain the desired economy of scale to meet the fiscal demands of operating further from a shore base; 3) more complex engineering considerations including enhanced mooring and cage designs to withstand the environmental loads; 4) increased dependency on technology for automation that may sometimes fail in the most foul weather; and, 5) the need to design entire farm operations from a holistic systems approach and not follow the traditional piecemeal strategy frequently adopted for near shore operations.

THE GULF OF MEXICO AND OFFSHORE AQUACULTURE

The Gulf of Mexico is the seventh largest marine area in the world and may be considered a very productive eutrophic sea; once described as the 'fertile fisheries crescent' (Gunter 1963). This productivity could potentially increase the assimilative capacity of the water, thereby reducing the environmental impacts associated with aquaculture effluents from offshore farms.

Selection of candidate aquaculture species is not trivial (Webber and Riordan 1976). Numerous species indigenous to the Gulf of Mexico have been identified as candidate species for aquaculture with excellent grow-out and market potential characteristics, including red drum (*Sciaenops ocellatus*), red snapper (*Lutjanus campechanus*), cobia (*Rachycentron canadum*), and greater amberjack (*Seriola dumerili*). Numerous criteria are used to select candidate species for aquaculture including the growth rate to a market size. A growth performance index (Φ'; Longhurst and Pauly 1987), using L_∞ and K values from wild stock literature for each of these species in the northern Gulf of Mexico, provide favorable growth attributes for economically feasible grow-out (Table 2). With the subtropical growing conditions, fingerlings for all of these species are anticipated to reach a consumer-driven market size within a 1–2 year grow-out cycle, increasing the economic feasibility of open ocean aquaculture ventures in the Gulf of Mexico.

Acquiring a site having water depth in excess of 25 m to avoid hurricane damage would be desirable and may require locating as far as 40 km from land. Further, some areas of the Gulf of Mexico are prone to experience seasonal hypoxia associated with runoff from the Mississippi River (Rabalais et al. 1994, 1996) and thermally stratified water during late summer that will not experience a turnover in the absence of tropical fronts. Although this hypoxic layer is generally restricted to the lower one-third of the water column, large cages or submerged operations may be impacted. An additional layer commonly experienced in Gulf of Mexico waters is the nepheloid layer developed from resuspension of fine sea-floor sediment generated from bottom turbulence (Shideler 1981). Little is known of this layer's impact on fish health or its seasonal extent in much of the Gulf of Mexico.

Complete hurricane avoidance is unlikely in the northern Gulf of Mexico. However, it may be possible to decrease hurricane impacts to aquaculture ventures by sinking cages to avoid such storms. With this strategy comes the risk of exposing the fish stock to sediment resuspension that may subsequently irritate the gills, create secondary bacterial infections, and result in mass mortality (Sherk et al. 1974; Brown 1993) and subsequent economic loss to the operation.

Finally, much of the Gulf of Mexico has long supported both commercial and recreational fishing. User conflicts must be carefully considered and dealt with to ensure success of a future open ocean aquaculture industry. All of these issues limit appropriate sites for open ocean aquaculture in the Gulf of Mexico to some degree.

There have been previous offshore aquaculture attempts in the Gulf of Mexico (reviewed in Kaiser 2003). However, although

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.

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]Φ' = log10K + 2log10L∞ (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 ($N = 340$).

proving invaluable from lessons learned, none of these have produced large quantities of fish for market or resulted in a commercial offshore aquaculture sector in the Gulf of Mexico.

THE GULF OF MEXICO OFFSHORE AQUACULTURE CONSORTIUM

In 1999, the Gulf of Mexico Offshore Aquaculture Consortium (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. By developing university/industry partnerships and seeking broad public/commercial input, the Consortium's goal was to develop socially and environmentally acceptable offshore aquaculture models that are appropriate to all stakeholders in the Gulf of Mexico region.

In most aquaculture development projects throughout the world, it has been fairly easy to accomplish the mere task of raising fish to a marketable size. However, in almost all cases, environmental and management decisions have been based upon primary scientific data collected from other regions of the world or models in an attempt to describe and predict impacts. The OAC intended to not only develop an economically feasible open ocean aquaculture sector, but also to defend the sustainability of the industry based on primary scientific data, collected throughout its development and subsequent commercialization, from the Gulf of Mexico. Primary data collection and industry development was planned using a proactive approach from the outset, learning from mistakes made by previous aquaculture development elsewhere, and in consultation with all Gulf of Mexico stakeholders, regardless of their perspective.

The OAC was officially created during its first workshop, hosted by the Texas Sea Grant College Program during February 2000. This workshop was designed to effectively bring together scientists, economists, engineers, legal experts, state and federal agency representatives, and industry leaders who had the interest and expertise to develop offshore aquaculture in the Gulf of Mexico. All aspects associated with the OAC research project and the protocols developed were discussed in an open forum. In addition, teams of participants were identified that possessed the capabilities to submit collaborative proposals for funding in subsequent years.

The ultimate goal of the workshop was to develop one or more groups of industry/academic/agency partnerships interested in developing demonstration projects in the Gulf of Mexico. In addition to forming partnerships, the meeting provided a forum for discussion of various engineering approaches to offshore aquaculture, site evaluation, species selection, social and economic implications, and related topics.

Following the success of the first OAC workshop, researchers chose a site having 26 m of water approximately 40 km off the coast of Mississippi in federal waters (Fig. 1; 29°58.649′N, 88°36.297′W). This distance separates OAC research from other U.S. open ocean aquaculture initiatives by extending aquaculture operations outside the sight of land to federal waters in the EEZ. The research operation was adjacent to a ChevronTexaco manned gas production platform, which minimized user conflicts with fishing and shipping activities while providing continuous surveillance of the cage to monitor for vandalism and storm damage.

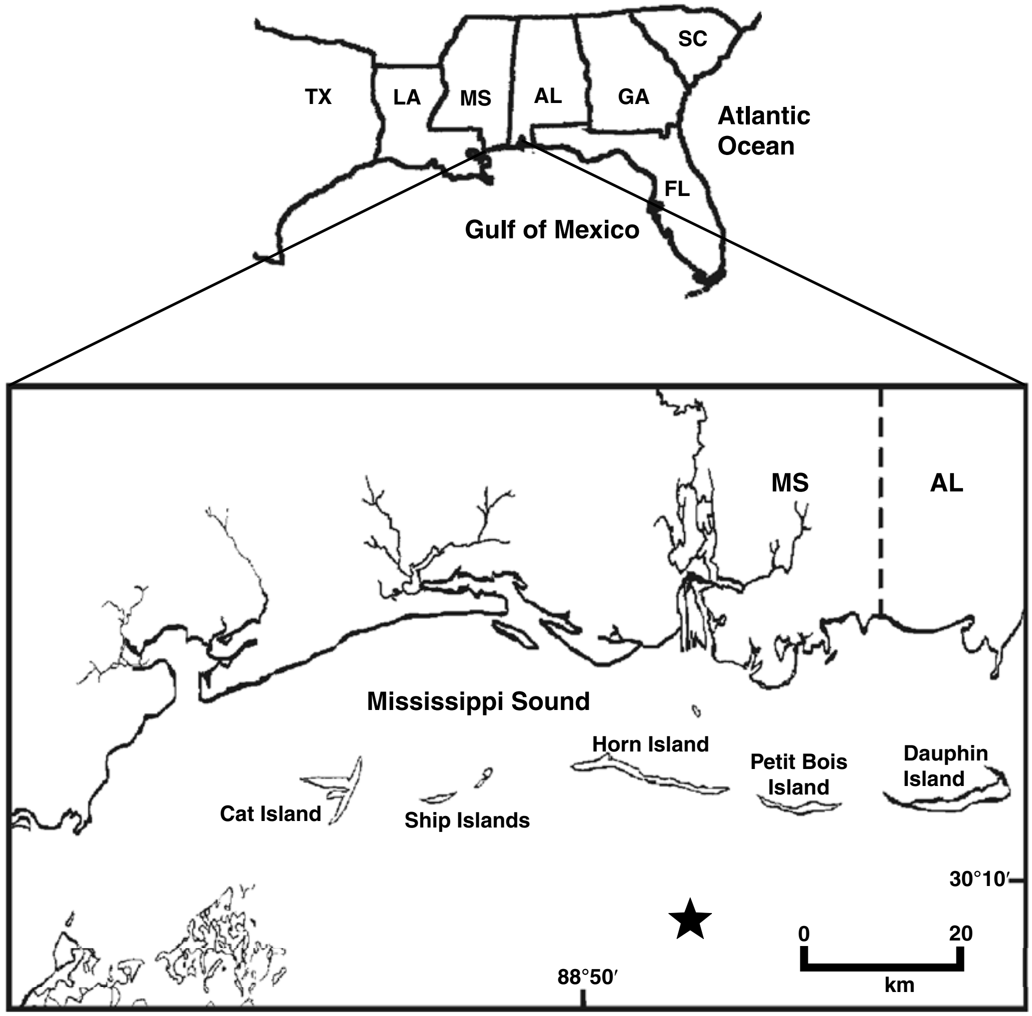
CONCLUSIONS

OAC research and development efforts were focused on legal/regulatory review, engineering and logistics mitigation, marketing, genetic forensic analysis, environmental impact monitoring and modeling, economic feasibility, disease assessment, and education/outreach. The remainder of this book consists of individual chapters that focus upon these broad research and development issues addressed by OAC researchers.

Following legal permitting review, the OAC acquired necessary permits to establish and operate an offshore aquaculture site in U.S. federal waters approximately 40 km off the Mississippi coast. The OAC offshore aquaculture cage was deployed without fish to observe the cage/mooring system and develop logistic mitigation procedures prior to transporting fingerlings to the site. An environmental impact model was developed to predict potential impacts from commercial-scale offshore aquaculture operations in the Gulf of Mexico. Economic modeling research was conducted for the Gulf of Mexico candidate species—red drum, red snapper and cobia—and anticipated grow-out costs and potential returns analyzed to determine commercial-scale economic feasibility.

Genetics researchers developed a genetic library (based on microsatellites and mitochondrial DNA) to identify aquaculture products from wild conspecifics. A Health Management Plan was considered for offshore aquaculture in the Gulf of Mexico based upon the regional oceanographic and biological characteristics and accepted cage culture health management practices adopted throughout the world. Finally, education/outreach was of utmost importance for proper

Fig. 1. OAC offshore aquaculture experimental site (★) 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 ChevronTexaco gas platform.



and effective OAC research dissemination. An aquarium exhibit was developed to help the general public visualize and understand commercial offshore aquaculture operations and outline specific research efforts of the OAC. Additionally, the OAC hosted a second two-day regional workshop to allow further discussion of research and development efforts in the Gulf of Mexico and resulted in a focused research and development strategy for offshore aquaculture based on consensus from the workshop attendees (Bridger 2002). Finally, the OAC maintained a web site to effectively disseminate research results and logistics procedures for a developing industry.

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