Research Summary on Potential Mariculture Species for the Gulf of Mexico

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Abstract

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

Introduction

Ocean fishing, the largest source of fish production, is producing about 90 million metric tons annually and can no longer sustain the over fishing and pollution pressures man has placed on it (Willinsky and Champ, 1993).
At the same time, the world’s demand for seafood is rapidly increasing and is expected to reach 110 to 120 million tons by the year 2010. In response to this demand aquaculture has developed into the fastest growing food production system in the world and is expected to produce 39 million tons by 2010 (FAO 1996). As the world’s second largest importing nation of fisheries products, the continued expansion of U.S. seafood production will diversify agriculture, reduce the nation’s balance of trade, relieve fishing pressures on native species, diversify the supply of products for seafood processing, provide fry and fingerlings for conservation projects, and provide high quality seafood grown under conditions that control the use of antibiotics, steroids and other additives used elsewhere.

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

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

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

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

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

Maturation/reproduction

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

Fish, like many other species, exhibit rhythmic physiological and behavioral patterns generally known as bio-rhythms. Fish reproduction (maturation, mating, and spawning) is often rhythmic and strongly correlated with
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the interrelated seasonal cycles of light, water temperature and food supply. This naturally leads to a period of the year that can be defined as the spawning season. The seasonal cycle can be either allowed to occur naturally in outdoor tanks and ponds or it may be induced artificially in the laboratory.

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

**Larval Rearing**

Current production technology for marine fish larvae requires the use of live feeds that can be expensive and unreliable. Consequently, a major focus of our research is to eliminate the live food requirement for marine fish larvae. Efficient use of artificial diets by marine fish larvae will have important implications for the economic viability of aquaculture. We have developed test tanks with a closed, recirculating design to evaluate nutrients and physical requirements of artificial diets (Holt, 1993). Previous to the development of this system, feeding artificial diets was difficult because of rapid
Fig. 1. Example of spawning data, averaged over 14-day intervals, from yellowtail snapper. Number of spawns represents the total number of spawn that were recorded over each interval.
deterioration of water quality. An added benefit gained by this closed culture system is the ability to rigorously control temperature and salinity. A feeding protocol was developed for red drum larvae based on combining a commercial microparticulate diet with live rotifers in the test tanks. In five feeding trials growth and survival were measured on larvae reared on a combination of live and artificial food for one to five days before being weaned to artificial diets. Results in each trial were compared to control larvae reared on the traditional diet of live rotifers and brine shrimp. The best results were feeding a combination of live and artificial food for five days and then completely discontinuing live prey. This meant that 8 day old larvae could be weaning, greatly reducing the need for live food. Survival and growth rates of larvae fed this combination were as good as larvae reared solely on live prey (Holt, 1993). Both groups metamorphosed to the juvenile stage at less than one month. Survival rates of the early weaned fish was a remarkable 60% from egg to juvenile.

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

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

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

Species of interest

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

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

The snapper family consists of approximately 100 species that are found throughout the world in tropical and subtropical areas. Because of their wide acceptance as an excellent food fish as well as declines in commercial fisheries, there is considerable interest in culturing various snapper species. In fact several species are commercially cultured in Asia. Although literature is scarce, information on spawning and raising several species of snapper
(e.g. *Lutjanus argentimaculatus*) is available. When considering species of this family one must recognize that in general the larvae are relatively small and hence difficult to raise. Although, considerable effort has been invested in the development of larval rearing techniques for snappers, success has been limited and techniques are considerably behind those developed for other marine species. Additionally in the wild, juveniles have relatively slow growth rates. Manooch (1987) has summarized the growth rates of a number of snapper species. Four species that are currently being evaluated for their culture potential in the US are the yellowtail (*Ocyurus chrysurus*), red (*Lutjanus campechanus*), grey (*Lutjanus griseus*) and mutton snapper (*Lutjanus analis*). Based on predictive growth equations these species will only reach 200-300 g in two years in the wild. Despite there slow growth in the wild, results under culture conditions indicate an improvement in growth rates. Utilizing semi-closed recirculating systems, we have raised yellow tail snapper to 489g in 767 day that is similar to the results obtained by Thouard et al (1990) using cage culture techniques in Tahiti. Similarly, wild juvenile grey snapper (approximately 3g initial weight) raised in our laboratory have reached 500g after two years of culture. Despite improvements in growth rates under culture conditions, a two to three year production period will be required to produce a 0.5 to 1 kg fish.

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

Another species of potential interest is the greater amberjack. Life history, abundance and ecological data for amberjack are restricted to relatively few publications concerning: anatomy of the digestive tract (Grau et al. 1992), descriptions of foods (Manooch and Haimoviczi 1983), evaluation of genetic variability as determined by mitochondrial DNA variation (Richardson and Gold 1993) and tagging studies (Mather 1962; Moe 1966). The development of larvae under culture conditions utilizing hormone induced spawning for this species have been described by Japanese scientists
(Tachihara et al. 1993), thus, confirming that larval and juvenile production is technically feasible. Unlike the snapper species, the growth rates are very impressive. Juveniles captured from the wild and raised at FAML have reached 2 kg in approximately one year. As with many of the marine fish this species has also been cultured (using wild seed stock) in cages with good success. Consequently, once maturation and larval rearing techniques are developed commercial culture for this species could develop relatively quickly.

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

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

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

Literature Cited


Holt, G.J. 1993. Feeding larval red drum on microparticulate diets in a closed


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

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Abstract

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

The Offshore Potential

The Oceanic Institute (OI) is located on the Island of Oahu in Hawaii and is part of a archipelago chain situated approximately 2500 miles from the western U.S. seaboard. The annual consumption of seafood in the state averages 49 lbs./person/year more than three times higher than the average 15 lbs./person/year consumption on the U.S. mainland. Many of the Islands' commercial fisheries have been greatly reduced leading to strict bag and size limits. As a result, the Pacific Marine Aquaculture Center (PMAC) was formed to combine marine finfish technologies and offshore containment systems and demonstrate the economic and environmental feasibility
of an offshore mariculture industry in Hawaii. The agencies involved include the University of Hawaii Sea Grant Program, the State of Hawaii’s Aquaculture Development Program, and the Oceanic Institute. Hawaii maintains stable water temperatures year round ranging from 24-27°C, the waters are oligotrophic and its infrastructure is in place. The state is strategically located between markets in Asia and the U.S. (Figure 1).

Hawaiian Fisheries Development

The Institute has been developing comprehensive technologies through the Hawaiian Fisheries Development Program (HFD) utilizing representative species from a variety of ecological niches. The HFD program is funded by the National Oceanic and Atmospheric Administration (NOAA) through the National Marine Fisheries Service (NMFS) for the commercial development of technology for stock enhancement and farm production purposes. The technology serves as a model for standardized, yet flexible protocols for the collection and quarantine of broodstock, maturation and spawning of broodstock, and intensive hatchery and grow out. Species that have been successfully cultured at the Institute include striped mullet (mugil cephalus—Eda et al., 1990: Liu and Kelly, 1994a), milkfish (Chanos chanos—Lee, 1986: Lee et al., 1986, Liu and Kelly, 1994b), mahimahi (Coryphaena
hippurus – Kim et al., 1993), pacific threadfin (polydactylus sexfilis – Ostrowski et al., 1996) and the bluefin trevally (Caranx melampygus).

Quarantine and Growout

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

Pit Tagging

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

Broodstock Management

Proper management is the key to strong healthy broodstock. Feeding a complete diet (2 percent total body weight of fish/day) consisting of fish, crustacean, cephalopod and vitamins will enhance the growth and development of the broodstock. Maintaining a clean tank with high water quality is essential. This can be accomplished by periodic cleaning with a brush of algae and scum and maintaining adequate water exchanges for the amount
of fish in the tank. Disease prevention through close observation and strict operating procedures (i.e. not handling broodstock with a net from quarantine), will decrease the risk of disease within a culture system. Knowing your fish through behavioral observations is very important. Problems can be diverted by carefully observing feed amounts and swimming patterns. Noticing these problems early on will reduce disease outbreaks and decrease the recovery time of the fish.

Maturation

Broodstock fish are scanned once a month and examined for growth and maturation. The fish are corralled with a PVC crowder and netted with a perforated, plastic net and placed into a 150 l bath of MS 222 (90 ppm). The fish are then scanned with the Power Tracker for identification, weighed, measured, and cannulated for gonadal development. Cannulation is facilitated with the use of a 26 cm long polyethylene tube. The inside diameter is 0.8 mm and the outside diameter is 1.52 mm. The cannula is placed into the urogenital pore at an 80° angle, between 1-2.5 cm deep (Figure 3). The other end of the cannula is gently sucked upon to extract eggs/semen from the fish. Semen extracted from a male it is placed onto a slide with a drop of seawater and examined under a microscope for motility. Eggs collected from a female are placed into a test tube with 5 percent formalin and later checked in the laboratory for development. The eggs are staged for devel-
Fig. 3. Cannulation of a greater amberjack (8 kg) with a polyethylene tube.

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

**Spawning**

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

Several ways that 01 induces maturation is through photo period and temperature manipulation and hormone implant/injection. Protocol regarding the use of chronic releasing cholesterol pellets has been established at the Institute. The chronic releasing cholesterol pellet is made in the laboratory (200 micrograms each) from combining LHRH-a, cholesterol and cocoa butter in a mortar and pestle. The mixture is pressed into a plastic grid,
dried in an incubator, and then a hammer and nail is used to punch the pellets out. The finished product can then be implanted into the fish through a 3 cm incision (made with a scapula) along the right dorsal musculature. The pellet is inserted with a special syringe approximately 2 cm deep. The cholesterol pellet will slowly release LHRH-a for approximately 5-6 months and promote maturation, increase egg production and extend the spawning season of the fish.

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

**Species Potential**

The characteristics of a good offshore species includes:

1. An established mass culture technique for consistent year round production of fry. In order for an offshore project to be economically feasible, cages must be stocked with thousands of fish for return on investment. It is essential that seed stock be produced or purchased in large amounts for year round stocking purposes.

2. Rapid growth rates (> 0.5 kg/year) and reliable feed conversions of 2:1 or less.

3. Adaptability to the rigorous offshore environment. A fish that can withstand currents greater than 2 knots and seas greater than 3 meters.

4. A species that is hardy, that can handle crowding, and is resistant to disease and parasites.

5. Marketability. A fish that is widely acceptable and can be sold for a profit.
**Bluefin Trevally Egg Production**

![Graph](Image)

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

**Blue Fin Trevally**

*Caranx melampygus* is in the family *Carangidae* (Figure 4). It is a strong swimming predator fish that frequents open ocean drop offs and reefs. They are especially prized by fisherman for their spectacular fighting ability (Hoover 1993) and have been caught at 10 kg from the wild. Developmental work through the HFD program indicates the trevally to exhibit excellent offshore qualities. The trevally can be readily collected, domesticated, and trained onto a commercial diet. They can be cultured to .5 kg in 11 months at densities of 20 kg/m³ on shore. Maturity of broodstock occurs between 1.5-2.0 kg. The broodstock can be spawned year round (naturally and/or induced) resulting in a constant production of eggs for a hatchery (Figure 5). Larvae culture has been successful on a research level but problems exist concerning first feed items on a commercial level. Currently, new feed studies are commencing at the institute to resolve these issues. New feed items such as copepods, trophaphores, and various larvae enrichments are being examined.

**Greater Amberjack**

Preliminary research at the Institute with the amberjack has been promising and indicates potential qualities for offshore culture. Captive juveniles collected from the wild (30mm) have taken to a dry feed within 36 hours and have grown to 2.8 kg in one year with a feed conversion of 1.2. This species can obtain weights of over 50 kg in the wild (Figure 6). The amberjack has been considered an excellent aquaculture candidate because of...
their rapid growth rates (Garcia et al. 1993; Greco et al. 1993; Porrello et al. 1993), their ability to adapt to confinements (Micale et al. 1993), high commercial value (Greco et al. 1993; Porrello et al. 1993), and tolerance to handling (Greco et al. 1993). *Seriola dumerili* are cultured intensively on land as well as in seacages in the Mediterranean (Greco et al. 1993; Garcia Gomez 1993; Grau et al. 1993), Japan (Masuma et al. 1990; Tachihara et al. 1993), and Hong Kong (Wong 1995).

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

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

**Conclusion**

This is an overview of the Oceanic Institute’s approach to broodstock husbandry, maturation and spawning for the hatchery development of marine fish species. The intent is to produce a protocol for the rapid develop-
Fig. 7. A current bottleneck of marine fish culture is commercially viable hatchery methods for seedstock.

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Summary Session

Abstract

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

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

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

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

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

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

Since the major theme of the conference centered on offshore platforms, the merits and problems with using platforms in the Gulf of Mexico and other U.S. waters for aquaculture were discussed. Our summary in laymen’s terms is: without a change in current laws, the real stumbling block to their use appears to be the U.S. Minerals Management Service
MMS) requirements on liability and bonding for accident and lease abandonment. MMS requires 100 percent assurance that each structure will be removed once its use is terminated. Even though an aquaculture venture group may obtain a bond to assume responsibility, MMS still looks to the original petroleum company/owner for final assurance. Therefore, the petroleum companies are hesitant to release the platforms to venture groups if they continue to be held responsible for the platform. MMS states that a Surety Bond, US Treasury or Zero Coupon Bond, will work. Apparently those bonds stage payments based upon production. Other ways that an oil company can release liability are to turn rigs over to the "Rigs to Reefs" program\(^1\) or to have a Federal agency take over the liability. A Department of Commerce (DOC) member said that he would check into the viability of the DOC assuming liability for one platform as a pilot for a multi-use effort (weather sensors, aquaculture, etc.).

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

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

\(^1\)The Rigs to Reef program exists in Texas and involves either dropping drilling platforms in place or moving them and dropping them into state water locations identified by the Texas Parks and Wildlife Department. The sunken platforms become fish attractions devices of interest to recreational fishermen [ed.]
Another speaker suggested that an entire offshore project would cost $US 7.5 million, with a startup cost of $US 2 million for the base, $1.1 million for the hatchery, and $2.5 million for the offshore operation. Such a venture was estimated to employ 20 to 25 people, and to have a US$1 million/year payroll and US$2.2 million/year operational costs. Two large boats would be required to meet the needs of such a project.

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

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

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

A well-known cage manufacturer reported on cage designs that have evolved for several applications, including a gravity cage system and a high current and exposed water environment cage system or Sea Station(tm) sea cage system. Commercial tests of the Sea Station(tm) sea cage system were
employed on three working farms: one farm growing summer flounder in Long Island Sound and two farms growing milkfish offshore in the Philippines. Apparently, the cages worked very well with production described in a single 3,000 cubic meter cage being at least 255 tons of milkfish per year. One innovative and progressive Filipino farmer has grown shrimp in a Sea Station™ with milkfish.

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

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

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

Larval production is where most bottlenecks occur, and biologists have
the most trouble with mass fingerling production. Maturation and spawning are the keys to developing new species, and they can be done with hormonal induction using pituitary extracts.

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

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

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