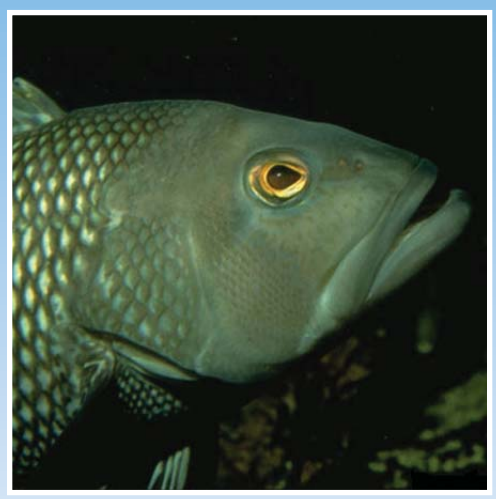
FLORIDA OCEANS & COASTAL RESOURCES COUNCIL



Current Status and Opportunities for Marine Stock Enhancement and Aquaculture in Florida

February 2007

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This report has been prepared to fulfill the requirements of Section 2 of Chapter 2005-161, laws of Florida. and a request from the Florida Ocean and Coastal Resources Council to **review the potential for inland, marine recirculating aquaculture technology in Florida and to recommend and implement a multi-institutional, collaborative pilot project for Florida marine stock enhancement and aquaculture initiatives.** While the Florida Fish and Wildlife Conservation Commission (FWC) is currently evaluating the efficacy of using stock enhancement as a management tool for helping replenish depleted fish stocks in the future, this work is underway with red drum and common snook, there is a clear and critical need to evaluate additional species that have the potential to be economically viable (cost effective) for future enhancement and for future farming activities in the State of Florida.

With **increasing seafood demand,** finite and declining wild fisheries, U.S. marine aquaculture production must greatly expand. A decade ago global fisheries reached maximum yield at 2.2 billion pounds. Earlier studies predict that aquaculture's contribution to seafood needs must rise from 30% to 50% in the next 25 years to meet the increasing seafood demand and ease harvest pressure on wild fish stocks.

The **expansion of Florida's aquaculture industry** is challenged by the high cost and limited availability of coastal land and water resources, environmental impact concerns, high production costs, and lack of sufficient quality fish seedstock. Expanding marine aquaculture will reduce the U.S. trade deficit, increase employment opportunities for inland rural sectors and displaced farmers, increase crop diversity, and enhance food biosecurity.

In the past ten years, there have been three **aquaculture industry workshops** in Florida addressing marine food fish opportunities. The first workshop, Marine Aquaculture Industry Development was held in 1998 at Harbor Branch Oceanographic Institution. Industry, government and research leaders evaluated and ranked 35 potential marine food fish species for culture based on production, marketing, and regulatory constraints. In 2003 and 2005, Harbor Branch and the USDA/ARS held the International Sustainable Marine Fish Culture Conference with the goal to bring together researchers, industry and stakeholders to identify and address constraints currently limiting marine fish production in Florida and the U.S. (www.sustainableaquaculture.org).

The pilot project will proceed in concert with the State of Florida's strategic plan to use aquaculture technology for marine stock enhancement and to investigate the biological and economical efficacy of potential species for stock enhancement and aquaculture. Year one (2007-2008) and year two (2008-2009) of the pilot project will focus on developing the inland, recirculating and aquaculture technology needed for stock enhancement research, and on establishing stock enhancement capabilities for new species in Florida.

Demonstrate economically feasible production and marketing of high-value marine fish species that can be farmed in land-based recirculating production systems in Florida

Culture of marine fish is an emerging sector of Florida's aquaculture industry. In 2006, marine fish culture activities in Florida were taking place at private non-profit and university research institutions, a government hatchery, and private commercial farms (Figure 1). Three research institutions have been investigating the potential for multiple high-value marine fish species for food production, stock enhancement (i.e., cobia, pompano, common snook, southern flounder, black sea bass, and mutton snapper), and for a variety of marine ornamentals for the aquarium trade. Commercial hatcheries have been producing and marketing juvenile marine fish (i.e., cobia, pompano) to farms located outside of the state (i.e., Puerto Rico, Bahamas) for growout in offshore cages. A recently established commercial farm has reported results of growout trials using pompano in ponds and tanks; however, farmed pompano are not yet available in Florida wholesale markets. At least two marine ornamental farms in Florida have been producing and selling a wide variety of fish species into U.S. and international markets.

Figure 1. Florida marine fish facilities (2006).

Experimental and pilot-scale production of **marine fish for stock enhancement** in Florida is underway. Husbandry techniques are being developed for common snook and experimental stock enhancement trials have been ongoing for approximately 10 years. Recent breakthroughs in captive maturation and spawning of snook may provide an opportunity to expand the stock enhancement research from experimental to pilot-scale level. Another experimental aquaculture and stock enhancement program was conducted by a team of Florida, Mississippi and Hawaii researchers using cultured red snapper that were stocked on offshore artificial reefs in southwestern Florida. This program was terminated in 2005 due to lack of funding. The State of Florida is conducting a large-scale prototype evaluation of red drum stock enhancement. Plans

are underway to develop a network of saltwater hatcheries to expand the aquaculture production for red drum to include multiple hatcheries on the west and east coasts of Florida.

Florida's marine aquaculture commercial and research facilities are producing fingerling and market-size fish in land-based tanks and ponds. Although there are currently only a small number of marine fish farms in Florida, there is interest in the private sector in diversifying land-based agriculture and aquaculture operations to include marine fish farming. In order to expand Florida's aquaculture industry, Harbor Branch Oceanographic Institution and Mote Marine Laboratory are developing techniques to expand the use of underutilized agricultural land through the culture of marine species that are adaptable to fresh water and low salinity environments.

Production of marine fish in submerged offshore cages has gained momentum in recent years in other parts of the world. Florida is not presently using this technology because of an intricate and complex permitting process. If offshore farms are established in Florida, they will continue to rely on land-based recirculating facilities for particular life stages (i.e., maturation, spawning, larval rearing, early nursery) of marine fishes. Thus, **inland recirculating systems will play an important role in the successful implementation of offshore aquaculture.**

Land-based marine farms are utilizing a range of culture system technologies from open (flow-through) tank and pond systems to recirculating tank systems to maintain the required water quality conditions to farm fish. The biological and water quality requirements may vary with different life stages (e.g., larval versus growout stage) of marine fish. The purpose of a marine recirculating system is to control the culture environment, conserve water resources, and provide optimal water quality. Filters are used to remove solid waste, carbon dioxide and organics; biofilters convert ammonia to nitrate; and denitrification and oxygen addition may be needed for intensive (high density) systems. Most existing marine fish farms and research laboratories in Florida that use recirculating technology are located near estuarine or marine coastal environments. These farms remove solids and exchange 10-30% of the system water each day through a series of outdoor water treatment ponds. At least one inland marine farm is trucking saltwater in and out of their facility to exchange and maintain appropriate water quality conditions for the cultured species. Although marine ornamental fish farms often recycle a larger portion of the culture system water using mechanical and biological filtration, these systems contain less biomass than food fish systems, which simplifies the necessary filtration equipment to maintain appropriate environmental quality. Mote Marine Laboratory's Aquaculture Research and Commercial Demonstration Park, which is located nearly 20 miles away from the coastal marine ecosystem, is in the process of developing the technology to recycle 100% of the water from their live food, marine fingerling and food fish culture systems.

A number of biotechnical issues need to be resolved with the expansion of commercial-scale, land-based recirculating marine fish farms. Reliable systems that allow farmers to maintain and monitor water chemistry parameters, strategies to conserve limited water resources, and economic feasibility will all factor into the success of Florida's marine aquaculture industry.

Finally, it is necessary to evaluate the market potential for candidate marine species targeted for food or ornamental outlets. A marketing-oriented approach suggests that candidate species only have commercial development potential if, in addition to biotechnical feasibility, there is a ready

market at prices that provide a reasonable profit. The first step in this approach is to identify marketing opportunities by estimating the total market demand, growth, and profit potential of a market.

Develop and demonstrate marine stock enhancement and stock restoration using recirculating marine aquaculture technology

The Economic Output of Florida's saltwater recreational fishing industry was $5.4 billion dollars in 2001 based on the latest data available, the greatest economic output from saltwater sportfishing in the world and three times greater than in any other state or territory in the U.S. The Florida Fish and Wildlife Conservation Commission (FWC) has made it a high priority to develop adequate measures to protect this resource. Much emphasis is now given by FWC to develop and implement effective and responsible stock enhancement technology to rapidly replenish depleted high-value sportfish and to boost productivity of those fisheries.

Saltwater fishery management in Florida is mandated to include user-supported hatchery-based stock enhancement. The FWC's Marine Stock Enhancement Program, led by Fish and Wildlife Research Institute (FWRI), is developing saltwater stock enhancement technology in partnership with Mote Marine Laboratory (MML) in order to develop a viable approach to restore U.S. fisheries. This public-private partnership has established a multidisciplinary approach to developing effective strategies for integrating stocking into traditional fishery management. FWC and MML have established that stocking red drum into Biscayne Bay and Tampa Bay can affect fishery landings near release sites, and that small-scale stocking of common snook can affect fishery landings in Sarasota Bay. FWC is planning a large-scale release of red drum in Tampa Bay, and MML continues to make progress toward developing effective strategies for stocking snook into Sarasota Bay and resolving impediments to large-scale production of snook in recirculating systems.

The focus of FWC's stocking program has shifted emphasis over the past decade from a program that had become by the mid-1990s largely driven by stakeholder demand for primarily "production-oriented stocking" (essentially, stock fish and hope that it works) to using best management practices to develop economical stock enhancement based on assessments of stocking effects on fishery yields for various stocking-strategy scenarios. This approach will provide economically successful and ecologically sound stocking technology for replenishing high-value fish stocks that fuel the multi-billion dollar fishing industry in Florida. **Stock enhancement can potentially provide rapid response disaster relief, increase fishing opportunities and maintain economic value, supplement weak year classes, and recover endangered and threatened species.**

Using the framework in FWC's Strategic Plan for Florida Stock Enhancement (see Appendix IIIa), red drum and snook were identified as the target species for developing stock enhancement technology in Florida. Included in the top 5 species for enhancement were spotted sea trout, flounder and pompano. **The FWC/MML team developed and implemented protocols to protect genetic diversity, health, and ecological attributes of target stocks.** These genetic and

health policies apply to the release of cultured fishes statewide and provide the foundation for legislative rule-making and activity permitting.

By incorporating adaptive pilot-release experiments, with state-of-the-art tagging technologies, the FWC/MML team made rapid progress in designing and improving stocking technology to enhance red drum and snook stocks in coastal bays and estuaries (see Appendix IIIa). With the clear and unambiguous results gained from these studies, Florida is now poised to lead the nation in demonstrating the value of stock enhancement in saltwater sportfish restoration.

Marine Species Candidates for Florida

Since the 1998 Marine Aquaculture Industry Development workshop evaluation of 35 candidate marine fish species, Florida's research and commercial community has focused their efforts on the development and evaluation of husbandry and system technologies for seven marine fish species or species groups. These species are targeted for food, stock enhancement and ornamental production and include: cobia, Florida pompano, black sea bass, southern flounder, mutton snapper, spotted sea trout, common snook, red drum, and marine ornamentals. The Florida Keys National Marine Sanctuary and Mote Marine Laboratory have recently partnered to examine the potential to culture hard corals for reef restoration and FWC is developing culture and restoration techniques for seagrasses and coastal plants. A brief review of the species characteristics, research and commercial status is presented below.

Cobia

Other Common Names: ling, lemonfish, bacalo
Scientific Name: *Rachycentron canadum*

Cobia is a highly sought after food fish found in tropical and subtropical waters around the world. This pelagic species is found in a variety of habitats and prefers water temperatures between 20 to 30°C. This exciting new aquaculture species can reach 6-7 kg in one year. There are numerous research programs underway in Gulf of Mexico and southeastern Atlantic U.S. investigating the technological feasibility of culturing this species for market. Until recently, the only commercial hatchery was located in the Florida Keys. The Keys hatchery is closing down operations and the only Florida hatchery producing cobia is the University of Miami Experimental Hatchery. A commercial growout farm for cobia is located in Puerto Rico where cobia are being grown out in offshore cages. Research trials are also underway in Florida in ponds and will be evaluated in recirculating systems in 2007 at Harbor Branch. Stock Enhancement research trials have been conducted in South Carolina.

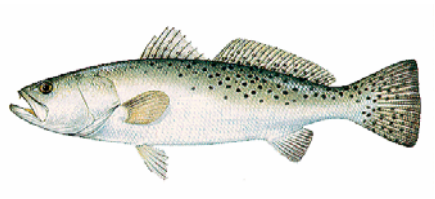
Florida Pompano

Other Common Names: pompano, common pompano, Atlantic pompano, sunfish
Scientific Name: *Trachinotus carolinus*

Florida pompano are one of the highest priced marine food fish in U.S. The species ranges from Massachusetts through Gulf of Mexico, in Central and South America to Brazil, and in the West Indies. Pompano are found in coastal waters (bays, estuaries, sandy beaches) where they form small to large schools along the beaches. Aquaculture efforts with Florida pompano were initiated in the late 1960s and were stopped in the early 1970s because of limitations in growth using commercially available diets. Research was initiated again in 2002 at Mote Marine Laboratory and in 2004 at Harbor Branch with USDA/ARS and two commercial farms began hatchery production in 2002/2003 at Mariculture Technologies, Inc. and Dyer Aqua. Maturation and spawning research trials have documented successful larval production using hormone and environmentally induced spawning techniques. Diet development for juveniles and for broodstock is underway. Commercial-scale larval, nursery and growout protocols for inland recirculating systems are being developed. Research trials to evaluate opportunities for inland, low-salinity aquaculture of Florida are underway. The market for Florida pompano looks very promising. There is a limited supply in the market and a high ex-vessel price, ranging from $7 to $13 per kg for whole fish.

Spotted Sea Trout

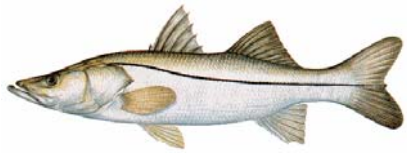
Other Common Names: spotted weakfish, speckled trout
Scientific Name: *Cynoscion nebulosus*



Spotted sea trout occur from Massachusetts to Mexico in estuaries, bays and lagoons and can be grown in fresh or salt water conditions. Aquaculture efforts have mainly focused on culture of juveniles for stock enhancement in Texas and South Carolina; experimental stock enhancement efforts have also been initiated in Mississippi. This popular sport fish may be a good candidate for farming. Spotted sea trout will spawn in captivity with environmental and hormonal manipulation. Cannibalism seems to be the main problem but can be minimized if the fish are weaned early, fed well, and graded.

Common Snook

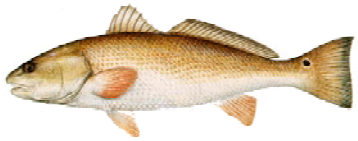
Other Common Names: robalo, thin snook
Scientific Name: *Centropomus undecimalis*



The geographic distribution of common snook includes Florida, South Texas, the eastern coasts of Mexico, Central and South America (to Brazil), and the Caribbean. Common snook are found in estuarine and near-shore environments and attain weights up to 27 kg and lengths of 1.3 m. This prized game fish is cultured experimentally in Florida at Mote Marine Laboratory as part of the stock enhancement research program with FWC. Approximately 1.8 million snook are caught by anglers annually in Florida. Food production of common snook in Florida is currently prohibited. Aquaculture research has been ongoing since the 1970s. Spawning efforts have focused over the past 10 years on field strip spawning, which can be successful. The inconsistent results from field spawning efforts led to a recent shift to captive maturation and spawning research. In 2006, Mote Marine Laboratory demonstrated that wild broodstock could be acclimated, matured and spawned in large tank systems.

RED DRUM

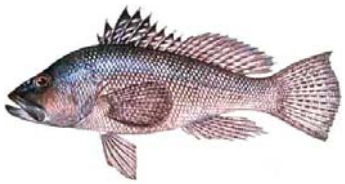
Other Common Names: redfish, channel bass, spottail bass
Scientific Name: *Sciaenops ocellatus*



Red drum is found in coastal environments from Maine to Mexico. Red drum are an extremely popular sport fish in Florida. Aquaculture production efforts have primarily focused on culture of juveniles for stock enhancement in Florida, Texas, and South Carolina. Captive red drum broodstock are conditioned to spawn at FWC's fish hatchery and grown to stocking size in ponds at Port Manatee. Over 4 million red drum have been released in the pilot-scale stock enhancement studies conducted by the FWC/MML team.

Black Sea Bass

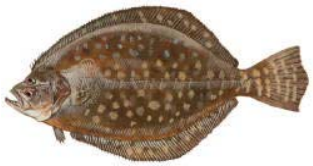
Other Common Names: sea bass, black fish, black bass, rockfish, talywag
Scientific Name: *Centropristis striata*



The geographic distribution for black sea bass range includes western Atlantic inshore areas from Maine to northeastern Florida and the eastern Gulf of Mexico. They inhabit reef and rubble areas offshore. Controlled spawning and rearing techniques of sea bass were established at the Florida Marine Research Laboratory in the early 1970's. Current aquaculture research programs are underway in North Carolina and Florida. Preliminary market analyses indicate there is potential for a cultured black sea bass industry, given the small current market, relatively high dockside prices, and excess demand for the species.

Southern Flounder

Other Common Names: flounder, mud flounder, doormat, halibut
Scientific Name: *Paralichthys lethostigma*



The geographic distribution for southern flounder includes the western Atlantic, from North Carolina to Texas. Southern flounder occur in brackish water bays and estuaries and occasionally in freshwater areas. Aquaculture research programs are underway in North Carolina, South Carolina and Florida. There is a lot of interest in this species because of the potential for fresh or low salinity culture. A recent market analysis was done for Southern Flounder by University of Florida, IFAS, in Ft. Pierce, Florida, as part of the Harbor Branch and USDA-ARS collaborative project. The conclusion of the study is that unless niche markets are targeted, the outlook for Southern Flounder aquaculture in the U.S. is not promising due to current low dock side prices, which equal farm gate prices, and the excess supply from fisheries and imports.

Mutton Snapper

Other Common Names: mutton fish, king snapper, virgin snapper, and snapper
Scientific Name: *Lutjanus analis*

The geographic distribution of mutton snapper includes the western Atlantic, from Massachusetts to southeastern Brazil, the Caribbean, and the Gulf of Mexico. They occur in inshore estuarine habitats (seagrass beds, mangroves) and occasionally in offshore reefs. Mutton snapper can reach 0.5-1.0 kg in 1 year. Aquaculture research and commercial efforts have been carried out in Florida (University of Miami, Harbor Branch, and Aquaculture Center of the Florida Keys) Puerto Rico and the Bahamas.

Marine Ornamental Fishes

Common Names: Clownfish, etc.

The roots of the U.S. marine ornamental tropical fish culture began in St. Petersburg, Florida, in the early 1970s with the culture of clownfish. In the 1980s and early 1990s, a few small companies began producing multiple ornamental fish species in the Bahamas, Florida, and California. In the late 1990s, Oceans, Reefs and Aquariums began operations in Ft. Pierce, Florida at Harbor Branch, and they have made great strides in advancing the propagation of clownfishes and other reef fishes, adding many new species to the list of commercially cultured marine ornamentals. A few other Florida companies (Florida Aquatics, Maritech) have begun producing and marketing marine ornamentals in the past few years. The primary constraint to expansion of ornamental species is the small eggs that hatch into planktonic larvae, which require a diet of small live zooplankton (i.e., rotifers, copepods).

Seagrasses, mangroves, and other coastal plants

Development of viable culture and micropropagation techniques for native coastal plants would greatly benefit coastal habitat conservation and restoration efforts in Florida. Coastal plant communities contribute countless benefits to Florida's economy and quality of life. From salt-marsh grasses and mangroves stabilizing shorelines to seagrasses providing shelter and feeding areas for a large number of important fish and shellfish. Nursery culture of some sand dune vegetation such as sea-oats is commonly done, although improvements need to be made in the techniques of dune restoration and plant culture. Tissue-culture approaches are being refined by commercial enterprises (e.g., Environmental Plant Resources, Inc. and the University of Florida). However, newer approaches for creating functional dunes need to be explored. Techniques for rearing plants typical of saltmarsh and mangrove communities have been employed for a number of years. Tissue-culture methods are being developed to provide predictable sources of material year round, but these need to consider the genetic nature of the organisms and the specialized applications for which they may be used. Research in this area is almost nonexistent. Methods for planting red mangroves in deeper water need to be developed in such a way that plants can flourish in the first years of planting. Year round access to planting materials using laboratory culture methods and selection for special uses could be addressed through aquaculture-oriented research. Scientists at FWC's Fish and Wildlife Research Institute have been involved in

expanding and improving on culture and planting techniques for plants typical of Florida's coastal communities. In particular, the focus in recent years has been on developing methods for culturing seagrasses via micropropagation, but because of the extreme difficulty inherent in this methodology, additional research is necessary to advance the techniques to economically viable uses. Rearing seagrasses in saltwater ponds is another feasible approach to providing enough material to support restoration of natural communities. Refining these approaches would contribute to methodologies for aquaculture of fisheries species using plants to buffer environmental fluctuations affecting fish-rearing protocols. Methods need to be explored to incorporate plants into the culture protocols for fish and shellfish. This would likely have long-term benefits for controlling infections.

Hard Corals

Culturing corals to restore coral reefs damaged by various direct human impacts, such as vessel groundings, represents a promising opportunity. Various state and federal statutes require the use of funds collected for damages to be used for restoration purposes. Coral aquaculture for use in replacing natural stocks of corals intentionally removed or damaged at construction sites is not a suitable application or goal for coral aquaculture. Instead coral aquaculture should target restoration of coral reefs that have been damaged by weather, global warming, or ship damage.

Numerous factors limit coral growth in the ocean, including erosion, predation, and chemical acids from certain animals that dissolve limestone coral. Culturing corals in a controlled environment can eliminate many of these factors and allow corals to grow up to three times their normal growth rate. Replanting damaged reefs with cultured coral fragments may greatly reduce the time required for successful reef restoration. Mote Marine Laboratory's Tropical Research Laboratory (MML-TRL) in Summerland Key partnered with the Florida Keys National Marine Sanctuary (FKNMS) to culture more than 20 species of hard corals beginning in 2003.
A consortium of coral research laboratories (University of Florida's Tropical Aquaculture Laboratory, Florida Aquarium, MML-TRL, MML, FKNMS) are working together to develop aquaculture and stock enhancement strategies for disturbed reef ecosystems in the Florida Keys. In addition are working to develop a Coral Health Certification program to assure only healthy corals are stocked. The aquaculture of stony corals has progressed considerably in the last decade. However, aquaculture of stony corals in closed systems is not the only option. Some in-situ aquaculture operations for stony corals have progressed in the Florida Keys and this option should be open for consideration.

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Appendix I
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Appendix II
HISTORICAL INFORMATION ON FOOD FISH CULTURE IN FLORIDA

Anthony (1908) stated that certain basic questions should be considered when contemplating rearing a particular fish species:

- Is the fish of sufficient commercial value to render its breeding profitable?
- Is its growth in captivity sufficiently rapid?
- Is the cost of raising it to commercial size disproportionate to its market cost?

Jones (1972) expanded these considerations by stating that breeding and rearing of young in captivity must be relatively easy. In past ventures, value was usually the primary motivation for attempting to breed and rear fish and invertebrates. During the 1960's to the mid 1970's no less than thirty private business, State and Federal agencies were involved in aquaculture of fish, shrimp and oysters in Florida alone.

In 1970 the Marine Research Laboratory of Florida Department of Natural Resources entered into a three-year, federally assisted mariculture program designed to develop methods of spawning and rearing commercially important fish species. Initial work was with Florida pompano, *Trachinotus carolinus,* because of its high commercial value. Later work included southern sea bass, *Centropristis melana*, because of its rapid adjustment to artificial culture conditions and ease of handling. The objectives of this research were to develop methods of controlled conditioning of fish for spawning throughout the year and to rear larvae to juveniles. Earliest known attempts to commercially rear Florida pompano from captured wild juveniles to market size adults in Florida was initiated in 1957 by Marvin Groves. Although his methods were crude and inconsistent, his results demonstrated it was possible to capture, transport, contain in earthen tidal ponds, feed variable diets and produce a market size fish in a reasonable time. Ideas on his tidal circulated ponds were later patented (Groves, 1970). Berry and Iverson (1966) and Fielding (1966) published early data from these trials and tribulations of Marvin Groves work. Based on the limited data Fields (1962) and Berry and Iverson (1966) listed recommendations and problems to be considered before pompano farming could be a secure, profitable business. Although optimistic they warned that considerable controlled experimentation was necessary. They further suggested consideration of various other fish that did not command a high market value, but did show excellent growth potential, ease of handling, and availability of published biological information.

Research on food fish culture, especially pompano, greatly accelerated in the late 1960's and early 1970's when governmental agencies (Florida Department of Natural Resources, St. Petersburg; Bureau of Commercial Fisheries Biological Laboratory, St. Petersburg Beach; Alabama Marine Resources Laboratory, Dauphin Island, Alabama), universities (Auburn University, Auburn, Alabama; University of Miami, Miami, Florida), and numerous private companies (Florida Mariculture Corporation, International Oceanographic Corporation, Inmont Corporation, Marine Protein Incorporated, Neptunian Mariculture Industries, Wometco Enterprises, Oceanography Mariculture Incorporated) invested substantial sums of money into

feasibility studies of pompano mariculture. Numerous popular articles claimed varied successes of private companies through the years (Palm Beach Times, April 8, 1970; Palm Beach Times, November 20, 1970; Palm Beach Daily News, April 5, 1972; Orlando Sentinel, April 9, 1972), but few fish were ever marketed.

The State of Florida basically forced all the entities to find methods to condition, spawn, and rear pompano within their facilities. During this era, thousands of small juvenile pompano and permit were captured with beach seines for stocking in the various aquaculture tanks. Pressure from the commercial and sports fisheries forced the State to issue limited permits for collecting these small fish. Each received a permit allowing them to collect diminishing numbers of juveniles over a three-year period. After this point, it was expected that each venture could provide or obtain their own cultured juveniles for stocking.

Unfortunately, valuable techniques developed by private companies remained closely guarded secrets and were never published. This slowed progress and caused governmental agencies and universities to duplicate their work to provide public information for future investments. Several public publications emerged during this period, which helped set the stage for current endeavors. Stevens and Fuller (1962) published some of the first attempts to induce spawning using hormones on striped bass. Smith (1973) and Swingle (1972) published early attempts to culture marine fish in cages. Tatum (1972) published comparative feed studies on pompano. Hoff (1970) published on the induced spawning of black sea bass and in 1972 Hoff et al. published techniques on controlled conditioning using temperature and light control and hormonal induced spawning of pompano.

After this explosive era of private and public research to develop food fish aquaculture businesses in Florida ceased, work continued primarily in public facilities, but was mainly directed towards producing marine fish for stock enhancement. In the mid 1970's, Martin Moe and Frank Hoff started two new yet different private ventures for rearing marine tropical fish in Florida. Aqualife Research utilized an open seawater system and Instant Ocean Hatcheries, which was located inland, utilized an artificial seawater system. These early ventures set the stage for the formation of a new surge of marine tropical fish farms established in the early 1990s. In addition, Instant Ocean Hatcheries clearly demonstrated that marine fish could be completely culture in closed artificial seawater systems. Results from Instant Ocean Hatcheries and other early ventures were published by Hoff (1996). In the mid 1980s and early1990s, private aquaculture investors again emerged to culture of stripped bass and redfish. Over the last 10-12 years, market value and dietary health concerns has initiated a resurgence of interest in captive cultivation of marine food fish. Again, pompano is included in the mix that consists of stripped bass, black sea bass, flounder, mangrove snapper, redfish and sturgeon.

Past pioneers ventured into unknown areas and biological problems never seen before. They were working with fish that no one else had ever spawned and reared. They had very little published work or personal contact to help formulate and guide them towards a timely successful venture. Often investors pushed to make quick money in a short period of time. Biologists strove to please their investors, but the problems were more then expected and only time could help solve the unknowns. Published technical information on spawning, rearing, handling, growth,

feeding and diseases of commercially valuable fish species is critical for future ventures to succeed.

Unlike the early pioneer work, considerable biological and engineering expertise now exists that is helping reduce problems and the time needed to solve them.

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Appendix III
BACKGROUND ON MARINE STOCK ENHANCEMENT IN FLORIDA

Current status of red drum stock enhancement technology:

Although Texas has the largest red drum production hatcheries in the U.S., Florida and South Carolina are farther along than any other state in developing and testing economically effective red drum stocking technology – the principal difference being that both FL and SC have developed and implemented technologies for optimizing economic effectiveness of its stocking strategies (e.g., Willis et al., 1995). For example, to determine stocking protocols for large-scale stock enhancement initiatives, the FWC/MML program routinely examines fish size-at-release, release habitat, release season, release magnitude and multiple other critical factors that can now be designed to maximize stocking contributions to fishery landings, while minimizing costs – including caging fish initially at their release sites to acclimate them to their new surroundings and reduce stress caused by harvest, transport and release.

Some of this new technology was used in Biscayne Bay beginning in the latter part of the 1990s to rejuvenate FWRI's red drum stocking program there. Using fundamental aspects of the "responsible approach" concept (Blankenship and Leber, 1995) to optimize release strategies, the FWC/MML team determined that releasing only large red drum juveniles, and only in certain key habitats, were critical factors in developing a red drum sport fishery in the Bay, thus saving millions of dollars by revising the previous strategy of stocking mostly very small juveniles throughout Biscayne Bay, which was totally ineffective.

In an ongoing stocking effort involving pilot releases of cultured red drum reared at FWC's fish hatchery at Port Manatee, empirical culture-tag-release-recapture experiments have been used by the FWC/MML team to explore the effectiveness of different release strategies in Tampa Bay. Pilot-scale release-recapture experiments have now been underway with red drum in Tampa Bay for 6 years. This research has involved replicate stratified releases of about 4 million red drum juveniles.

Fishery independent stratified-random sampling has been used to identify initial hatchery contributions to annual recruitment and to explore the effects of various stocking variables (e.g., size-at-release, release location, release season) on recapture rates of hatchery fish after they had grown to sizes landed in the fishery. Fishery-dependent monitoring has provided quantitative data from contact interviews with fishers, stratified by gear, location, and time of day, to characterize the red drum sport fishery and to evaluate hatchery contributions to the fishery. The local fishing community has also participated in data recovery through a fin-clip return program. All fin clips, whether procured from anglers or fishery-dependent / fishery-independent sources, are analyzed using microsatellite (DNA-based genetic fingerprinting) tools to identify recaptured members of particular hatchery release groups and to estimate the contribution of hatchery-fish to the catch-and-release red drum sport fishery.

To date, over 20,000 red drum caught in Tampa Bay have been examined; using tissue samples obtained from fishery-independent and fishery-dependent sampling and from the fin clip angler-return program. Of these, approximately 3,000 specimens have been genetically identified as stocked hatchery fish. Genetic-fingerprint data from these specimens revealed that a relative large proportion of the recovered hatchery fish were some of the smallest fish released into Tampa Bay, a good sign for the future evaluation of economic effectiveness of red drum stock enhancement in that Bay system.

Even while post-release monitoring continues, experimental findings are being coupled with associated data on production costs to determine the culture and release strategies for red drum that are the most cost-effective and likely to achieve fishery management objectives. The potential to have a significant impact on fishery catch rates in Tampa Bay will subsequently be tested via large-scale stocking trials, employing the optimal release strategies developed to date in the Tampa Bay study. Results of this comprehensive R & D process in multiple locations are thus being used to evaluate the efficacy of stocking as a fishery management tool and to model the economic impact of stocking on the sport fishing industry in Florida. Clearly, incorporating the principals embodied in Florida's strategic plan for stock enhancement has enabled the state to better understand how to manage marine stock enhancement effectively.

Current status of snook stock enhancement technology:

Snook stock enhancement technology development by the FWC/MML team has been steadily advancing in Florida since 1993. Initial studies, dating back to 1984 at FWRI and the early 1970s at the Florida Game and Freshwater Fish Commission, concentrated almost exclusively on developing the aquaculture technology needed to produce snook juveniles and stocking larvae and postlarval snook in inland ponds. In 1997, a series of pilot release-recapture experiments with hatchery-reared snook marked with benign tags were initiated by MML/FWC in Sarasota Bay, Florida, to begin to develop and evaluate snook stock enhancement (Brennan and Leber, 2001). From mid 1997 through mid-2005, approximately 50,000 4 to 9-inch long juvenile snook were tagged and released within the estuarine habitats of Sarasota Bay (Brennan et al., 2005). Hatchery snook represented 6-12% of sampled catches of juvenile snook in their nursery habitats 4 to 6 months after each release (Brennan and Leber, 2002). By 2000, three years after the pilot experiments began, 3.7% of the adult snook sampled (age-3 and age-4) were hatchery snook and five were captured within spawning aggregations (Brennan and Leber, 2001). Approximately 0.5 to 3% of adult snook caught during annual sampling events since 2000 were hatchery-tagged fish (Leber, 2006).

In addition to examining the effectiveness of release strategies, the pilot experiments included a three-year study of interactions of hatchery and wild snook. Those experiments examined snook density effects on abundance of both hatchery and wild snook in juvenile nursery habitats (Leber and Brennan, 2003). This work revealed that many age-1 snook habitats are underutilized by snook (recruitment limited), and also found major differences in the productive capacity among the nursery habitats chosen for these studies. Some juvenile nurseries showed the capacity to support snook densities up to 10 times what similar, but more developed (housing, dredging), nursery habitats could support (Brennan and Leber, in review). In the latter case, when snook were stocked into a "poor quality" nursery habitat, a portion of the hatchery snook appeared to

be displaced by wild snook, whereas abundance of wild snook appeared to be unaffected by the stocking of hatchery snook.

These pilot-release studies also revealed that post-release survival of snook stocked into their juvenile habitats could be doubled (effectively cutting hatchery cost-per-recruit in half) by simply acclimating snook in cages installed in tidal creeks (the release sites) for three days prior to release (Brennan et al., 2006). To make snook stock enhancement a cost-effective fishery management tool, several aquaculture bottlenecks remain to be solved to reduce the costs of mass production of snook in hatcheries.

Much progress has been made in advancing the effectiveness of pilot-scale red drum and snook stocking, with measurable, albeit small, contributions to fisheries in Biscayne Bay, Tampa Bay and Sarasota Bay. However, the economic effectiveness of using stocking to help manage saltwater fish abundance in Florida has not yet been evaluated, as the technology for stocking both species is still under development. Economical snook stocking technology is dependent upon more progress in reducing the costs of snook aquaculture production. Aquaculture technology for red drum was developed over two decades ago, but until recently the effectiveness of red drum stocking strategies was unknown. The FWC/MML team has now nearly completed optimizing the economic efficiency of stocking strategies for Tampa Bay.

The results of the pilot scale stocking experiments with red drum and snook are so encouraging that they warrant greater attention now on expanding FWC's saltwater fish production capacity, using recirculating seawater systems where feasible. The encouraging results also warrant developing more cost-effective aquaculture technology for snook. Expanded production facilities will provide the capability to produce enough red drum juveniles for large-scale releases that are needed to significantly impact fishery landings and to conduct an economic analysis.

Strategic Plan for Stock Enhancement in Florida:

On January 24, 2001, at a FWC Commission meeting in Miami, the Research Administrator for Stock Enhancement at FWC's Fish and Wildlife Research Institute (FWRI) presented FWC's stock enhancement plan to FWC Commissioners. This strategic plan, entitled "Florida Stock Enhancement: Long Range Plan for Success" (see Appendix III-A) was developed by FWC with the aid of the Director of the Center for Fisheries Enhancement at MML, who co-authored the highly cited "Responsible Approach to Marine Stock Enhancement" (Blankenship and Leber, 1995). This concept has become a world standard best-management-practice (BMP) template for developing saltwater stock enhancement programs.

The goal of Florida's strategic plan for stock enhancement is to develop a clearly effective technology that can amplify the results of current fishery management plans, when applicable. State-of-the-art stocking programs in North America, Europe and Asia are closely following Florida's implementation of this plan. Several states in the U.S. are already following Florida's example, and are developing their stocking programs around the framework of Florida's strategic plan – for example, the new marine stock enhancement programs in Georgia, and Mississippi, and enhancement projects in Hawaii, Maryland, New Hampshire, North Carolina, South

Carolina, Virginia and Washington. The *Responsible Approach to Marine Stock Enhancement* is discussed in more detail in the *Key Issues* section below.

FWC staff recommended in 2001 that the FWC Commissioners integrate stock enhancement into fisheries management decisions, and promulgate rules governing stocking of marine life. Such rules would guide enhancement efforts according to the "Responsible Approach" concept with due attention to economic accountability of stocking results and ample protection of wild stocks from disease and adverse genetic or ecological effects. This is consistent with hatchery-reform processes now being used in salmon restoration, and recommended by the American Fisheries Society as well as the United Nations Food and Agriculture Organization (FAO). The Florida FWC Stock Enhancement Program is positioned to become a world model for sportfish restoration.

FWC's Saltwater Stock Enhancement Program is also guided in part by an advisory board composed of stakeholders, the "Florida Marine Stock Enhancement Advisory Board (MSEAB)", which meets semi-annually with program biologists and FWC administrators to discuss program achievements and future plans. This advisory board is comprised of representatives from the recreational fishing industry, conservation groups, business sector, anglers, fishing guides, NGO's, fishery scientists, and FWC commissioners. FWC staff and science advisors provide updates to the MSEAB and seek consensus on adaptive-management recommendations, which can change the direction of the program to achieve program goals.

Florida's saltwater stock enhancement program is user-supported, with costs paid for by state and federal fishing-license fees. Moreover, FWC is developing satellite, intensive recirculating fish hatchery and nursery facilities at remote locations to help expand fish production for stocking and to develop stocking technologies for additional species. This work is conducted under the recently funded Florida Saltwater Hatchery Network, an FWC partnership with stakeholders from the private-non-profit sector (e.g. MML and Harbor Branch Oceanographic Institution, HBOI, with plans to expand this partnership in the future to include universities and other stakeholder groups).

MML has recently constructed the largest intensive recirculating fish-hatchery complex in the U.S. This state-of-the-art facility was designed through MML partnerships with aquaculture engineers who are International leaders in the field of recirculating hatchery technology. One of FWC's strategies is to build off of this new technology towards eventual complete reliance on recirculating systems for its saltwater stock enhancement program. FWC's freshwater stock enhancement hatchery at Richloam has already adopted recirculating systems. And, FWC is in the design phase of incorporating recirculating seawater systems into new hatchery facilities.

Hatcheries based on recirculating water-treatment systems can be built farther from the coast, where land costs in Florida are much more economical. Furthermore, saltwater recirculating systems can eliminate the need to discharge effluent, converting all waste products generated from production of fish in hatcheries to carbon dioxide and solids that can be used to fertilize conservation nurseries (to grow salt-marsh plants, mangrove and seagrass seedlings to help re-vegetate disturbed estuarine habitats).

Increased awareness of the value of marine fisheries, particularly sportfishing in Florida, and the importance of maintaining biodiversity at all levels, has led to codes of conduct for responsible fishing (FAO, 1995), and responsible stocking practices (Blankenship and Leber, 1995). Stock enhancement in Florida is planned and guided according to these principles, which were recently highlighted by noted International authorities in this field who included a chapter in their "Advances in Marine Biology" book Series (Bell et al., 2005) on progress towards a "responsible approach" to stocking. The chapter explains: *"Blankenship and Leber (1995) have set out clear principles for restocking and stock enhancement programmes to help ensure that releases of cultured juveniles conform with the codes and guidelines developed by FAO. In this section, we compare progress against the 10 components elucidated by Blankenship and Leber (1995) that are now widely accepted to represent a responsible approach for releasing cultured juveniles to replenish or enhance marine fisheries."*

The "Responsible Approach" concept guides the development of stocking practices to ensure both conservation of wild stocks as well as effective and economically sustainable results from stocking. The concept embraces 10 key issues that should be incorporated into all stocking programs:

1. *Prioritize and Select Target Species for Enhancement* – using formal decision-making tools;
2. *Develop A Management Plan* – that identifies the context into which enhancement fits into the total strategy for managing wild stocks;
3. *Define Quantitative Measures of Success* – with explicit indicators of whether objectives of the stocking program are met;
4. *Use Genetic Resource Management* – to protect wild stocks from reductions in genetic fitness, by preventing loss of rare alleles (gene forms) or changes in gene frequency, by preventing translocation of exogenous genes (from other stocks), and by preventing hatchery releases of inbred offspring;
5. *Use Disease and Health Management* – to maintain healthy wild stocks;
6. *Consider Ecological, Biological, and Life-History Patterns When Forming Stocking Objectives and Tactics* – focusing on those patterns that can contribute to the success or failure of stocking;
7. *Identify Released Hatchery Fish and Assess Stocking Effects* – to quantify successes and failures of the stocking program;
8. *Use an Empirical Process to Define Optimal Release Strategies* – to maximize the economic efficiency and ecological sustainability of the stocking program;
9. *Identify Economic and Policy Objectives* – needed to capitalize the value of the stocking program to society;
10. *Use Adaptive Management* – to adjust stocking strategies and tactics as needed based on the program's results.

Incorporation of these 10 key issues has become a world standard best-management-practice (BMP) template for developing stock enhancement programs. Results from the FWC/MML collaborative stock enhancement projects with snook in Sarasota Bay and red drum in Tampa Bay showcase the effectiveness gained from incorporating these 10 issues. Details about these projects are described in the *Synopsis of Current Activities* section, above.

Future Directions and Opportunities

- Greater reliance on recirculating seawater systems.
- Development of Conservation Hatchery technology that can be used to help recover endangered species and coral reefs**.**
- Improvements to economic effectiveness of enhancement programs
  Greater involvement of stakeholders in funding enhancement in Florida.

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Appendix IIIA - Strategic Plan
October 12, 2000 Draft

Florida Stock Enhancement: Long Range Plan for Success

Florida Fish and Wildlife Conservation Commission
In Partnership with
Mote Marine Laboratory

Florida Marine Stock Enhancement Mission Statement

The mission of FWC's marine stock enhancement program is to provide a clear capability to rapidly replenish, help maintain, and supplement sustainable, high-value, coastal recreational fisheries using responsible, effective, economically viable, and adaptable hatchery-release technology linked integrally to sound fishery management.

Many fish species produce millions of eggs from a single mating, but because natural mortality in the early life-history stages is very high, few offspring survive to juvenile stages in natural ecosystems. Hatcheries can improve the survival of eggs to juvenile stages by spawning and rearing fish in protected, predator-free ponds to a size where natural mortality is much lower. The technology to spawn and rear fish in captivity has existed in the U.S.A. for more than 100 years, but saltwater fish such as red drum, snook and spotted sea trout only recently have been raised on a scale large enough to support stock enhancement.

Many of Florida's economically important marine species have declined in abundance due to over-fishing, estuarine nursery habitat loss and acute environmental perturbations such as chemical spills or periodic cold kills. Hatchery production is frequently suggested as one remedy for declines related to early-juvenile-habitat loss and acute perturbations. The release of hatchery-reared fish may be particularly effective in restoring a population in areas where the abundance of naturally occurring fish has declined to a level at which natural recovery is unlikely in a reasonable amount of time. Hatchery releases may also increase fishing opportunities by providing a source of juveniles to supplement weak year classes and to stock inland ponds in urban areas suffering from coastal-habitat degradation.

Objectives

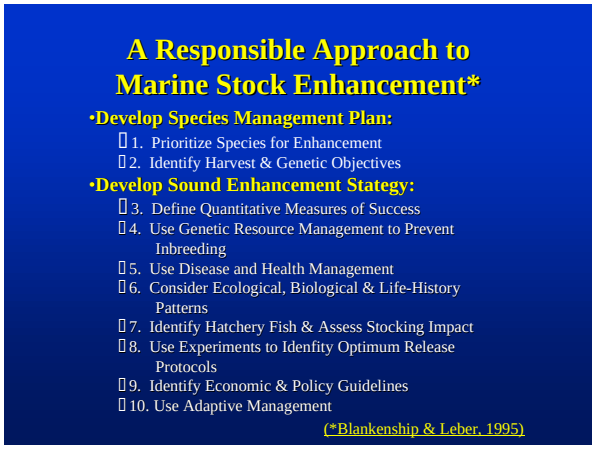
- **To provide a rapid-response diaster relief for replenishing depleted stocks**
- **To increase fishing opportunites, quality of fishing & urban fishing possibilities**
- **To supplemnet weak year classes of selected high-value coastal fishes and invertebrates**
- **To maintain economic value of high-value coastal fisheries**

Red drum (*Sciaenops ocellatus*), common snook (*Centropomus undecimalis*), and spotted sea trout (*Cynoscion nebulosus*) have been identified as high priority fishes for stock enhancement research in Florida. During Fall 1999, the Fish and Wildlife Conservation Commission Institute (FMRI), Commission's (FWC) Florida Marine Research (MML), began a in partnership with Mote Marine Laboratory Tampa Bay. large-scale stock enhancement project in of choice for this Redfish (red drum was identified as the species Florida. The goal investigation of stock enhancement potential in recreational catch of 'Project Tampa Bay' is to increase the determine the rates of redfish in the bay and to experimentally

best sizes, timing, release magnitude and locations for stocking in order to meet that goal in the most cost-effective manner. Approximately 1.7 million red drum (1.5 - 8 inches in length) will be stocked in 2000. A program of angler outreach will be developed to keep anglers informed and seek their assistance and support for the Tampa Bay redfish-stocking project.

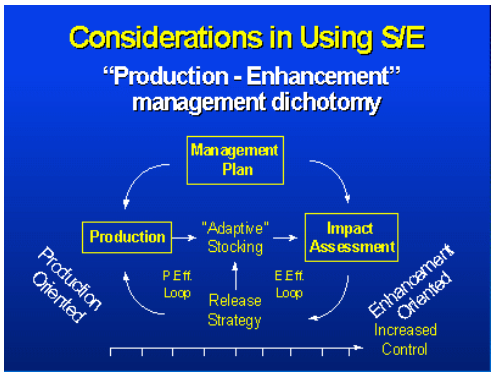
- **Enhancement Strategy**

Although many gains have been made in rearing marine and estuarine fishes, the effectiveness of using hatcheries as a tool for managing coastal fisheries has yet to be fully understood. As marine stock enhancement is developed and evaluated in Florida, implementation will be guided by clear goals and measures of success (stocking effectiveness, economic viability, conservation) and the other principles embraced in a "Responsible Approach" concept that is gaining support world wide. Attention to critical uncertainties about how to ensure that stocking is effective is the key to success. Successful case studies in stock enhancement that are emerging around the world can attribute their effectiveness to a basic premise: "To manage stocking for success, a process is needed to steadily incorporate and adapt stocking tactics to new information about hatchery-release effect on the fishery and on the ecosystem -- a process that also provides information about the effects of the ecosystem on the released fish."



- **Adaptive Management: the Key to Success**

The success of the hatchery as a fishery management tool hinges on the ability to couple a responsible mass-production and stocking capability with an effective assessment activity. Coupling production with release-impact assessment provides a mechanism for resolving critical uncertainties about stocking effects and effectiveness. With each stocking, key questions about stocking effects are asked within a modest research framework using tagged hatchery fish. Such "adaptive stocking" provides the information needed for adaptive fisheries management (Hilborn & Walters, 1992), a process for making rapid gains in fisheries management capability. The more "enhancement oriented" the overall approach is, the greater the effect of hatchery production on the fishery targeted for enhancement. The process increases control over the success of stocking. Without it, there is no way to gauge stocking effects and, more important, no way to refine stocking strategies to maximize effectiveness of this fishery management tool.



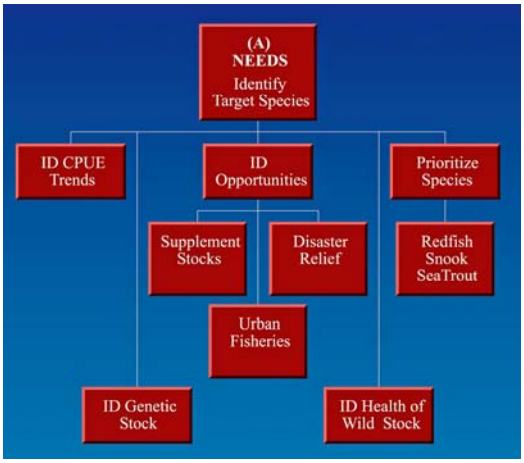
• **Florida's Long-Range Strategic Plan**

A long-range plan for marine stock enhancement in Florida has been under development since 1998. The long-range plan places considerable emphasis and accountability on the effectiveness of stocking in achieving fishery-management goals and objectives. There are seven basic components in the long-range strategy for developing an effective marine stock enhancement tool for fisheries management in Florida (a) identifying target species in need of enhancement; (b) expanding hatchery production capability; (c) pilot releases to document the potential contribution that stocking may provide to fisheries management in Florida; (d) a stocking plan that shows how stock enhancement is integrated into fisheries management objectives; (e) full-scale stocking to enhance appropriate stocks; (f) evaluation of stocking effects to document the effectiveness of enhancement; and (g) integrating an adaptive-management process into the stocking plan.

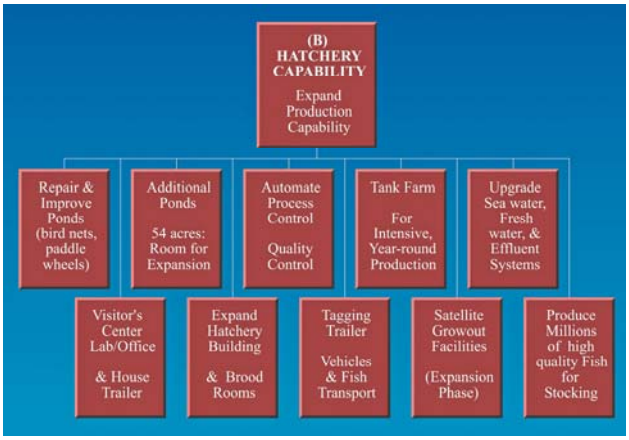
The seven components above include within them all of the issues involved in implementing a "responsible approach" to stock enhancement. This plan includes the flexibility needed to respond to new information about critical uncertainties, as advances are made in this emerging new field of fisheries management.

• **Component (A): Needs**

The "Needs" Component of the strategic plan involves examining catch trends to identify depleted or declining stocks and establish fishery management objectives; identifying opportunities for enhancement; prioritizing species for stock enhancement research; and understanding genetic stock structure and health of the wild stocks targeted for enhancement. For Tampa Bay, much of the "Needs" component has already been conducted. CPUE trends are available for the past several years for several sport fishes, including redfish. Redfish has been identified as the highest priority fish for stock enhancement research, followed by common snook and spotted sea trout. Research to determine genetic stocks in Florida has been completed for all three species. The physiological health of wild stocks has been examined in some detail, particularly for snook, but more work is needed in this area for redfish and sea trout.



• **(B) Hatchery Capability**



Component B involves increasing hatchery production capability and capacity in Florida to provide the scale of releases needed to have a significant impact (millions of fish per year). To expand production capability, repairs and improvements are needed to existing hatchery facilities at the FWC Stock Enhancement Research Facility (SERF) at Port Manatee including ponds (e.g. bird nets, power lines to all ponds, paddle wheels, new liners). New tanks are needed in the existing greenhouse, as well as upgrades to seawater, freshwater, and effluent systems. Addition of automated process control will increase fish production and quality control. To expand production capacity, additional facilities and equipment are needed, including additional ponds on the 54 acre Port Manatee site, a new tank farm for intensive, year-round production, expansion to the hatchery building and brood rooms, a tagging trailer, vehicles and fish transport tanks, additional lab and office space, a visitor's center to keep the public informed, a house or trailer on site to provide 24-hour rapid access for the hatchery manager or an overnight caretaker, and during the expected expansion phase, satellite growout facilities are needed in other locations in Florida targeted for stocking. In the second phase of expansion, satellite growout facilities at key sites will be upgraded to full-scale hatcheries.

• **(C) Pilot Releases**

To develop a stocking program that can achieve its potential, test releases are being conducted prior to expanding stock enhancement statewide. The test releases are focused entirely in Tampa Bay to document what the potential effect of stocking can be in an ecosystem: that (a) clearly supports a variety of sport fishes, (b) has a comprehensive historical data base for the species targeted for enhancement research, and (c) is in close proximity to the SERF redfish hatchery and FMRI.

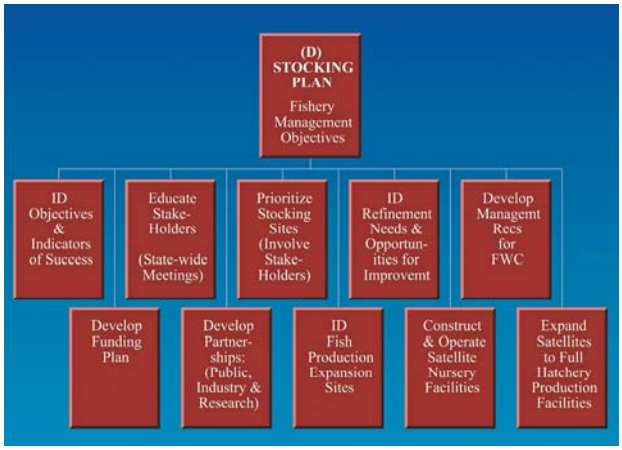
The test releases will be conducted in two phases: the first is a preliminary phase needed to resolve critical uncertainties about stocking tactics, such as optimal size-at-release (size-at-release that provides the maximum yield/cost ratio; i.e. maximum yield in the fishery per rearing cost at the hatchery), optimal stocking sites and microhabitats, optimal timing of releases, and optimal stocking densities. The second phase of pilot releases ("Test Release") is designed to determine if productive capacity of the ecosystem is available to sustain additional fish, and to demonstrate the fishery

management potential that can be achieved when the optimal release strategies (identified via the initial pilot releases) are used to supplement wild stocks with hatchery-released juveniles. In both phases, the results of the pilot releases will be carefully assessed through rigorous field sampling to recover marked hatchery fish, and identify release contribution to wild stocks, CPUE of hatchery and wild fish, and compare the relative effectiveness of the various release variables (size-at-release, release site, release season, etc.).

Two models will be developed, a socio-economic and a stocking model, to examine cost-benefit relationships and provide predictions of stocking effectiveness in Tampa Bay and other target sites in Florida. Based on the results of the "Test Release" in Tampa Bay, the models will be used to assess stock enhancement potential. Assuming a positive outlook, a plan for state-wide use of stock enhancement as a fisheries management tool will then be developed and submitted to the FWC.

- **(D) Stocking Plan**

Given that significant fishery-management potential is realized from the pilot releases in Tampa Bay, a risk-averse stock enhancement plan will be developed. As part of the plan, stocking objectives and opportunities and indicators of success will be linked with fishery management objectives, and fishery-management recommendations will be developed for FWC consideration.



Expansion of marine stock enhancement beyond Tampa Bay will involve state-wide meetings to educate stakeholders, prioritizing stocking sites, identifying refinement needs and opportunities for improvement to production and stocking tactics, developing a funding plan, developing key partnerships with public, industry, and research organizations, identifying fish-production expansion sites, constructing and operating satellite nursery facilities at the expansion sites, and finally expanding some of the satellite nurseries to full hatcheries.

- **(E) Full-Scale Stocking**

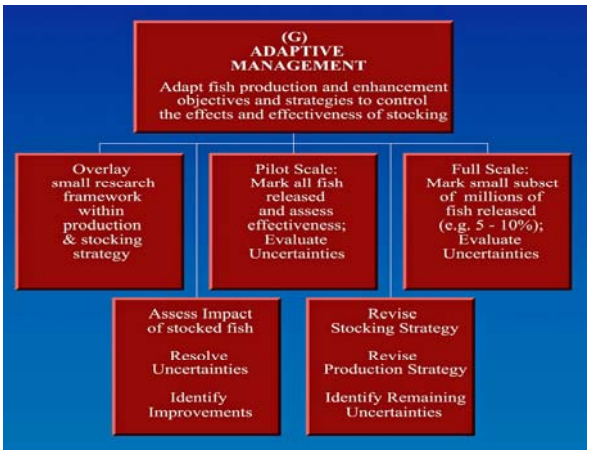
With an approved stocking plan in place, full-scale stocking would begin at the high-priority sites identified in the plan. Fry or fingerlings will be mass produced according to protocols established as a result of pilot release experiments conducted as the first phase of implementing enhancement at new sites. High health and appropriate genetic background will be managed accordingly during the fish

production cycle. A portion of all fish released will be marked to allow remaining critical uncertainties to be addressed with each release. This will enable adaptive stocking, which is key to continued refinement of enhancement strategies. Selected locations will be stocked according to protocols developed to manage stock enhancement responsibly.

- **(F) Stocking Effect**

Stocking effects and effectiveness will be documented by an assessment team that will sample the fisheries targeted by enhancement efforts. Cost-effectiveness will be evaluated as in terms related to the enhancement impact on the fishery and wild stock. Remaining critical uncertainties will be identified and research needs specified. Results of each release will be analyzed to provide feedback for adaptive management.

- **(G) Adaptive Management**



Adaptive management is essentially the framing and testing of hypotheses related to critical uncertainties that impede fishery management. Attempts to understand and resolve critical uncertainties can be ad-hoc, trial and error studies (passive adaptive management) or carefully designed, controlled experiments superimposed over a subset of the stock being managed (active adaptive management) (Hilborn and Walters, 1992).

Fish production and enhancement objectives and strategies can be adapted to provide incremental improvements in controlling the effects and effectiveness of stock enhancement. By overlaying a small research framework within the stock enhancement team and marking released fish, key questions about how to control enhancement effectiveness can be posed with each release and improvements identified, based on the results. Such ongoing research can be used to revise stocking and production strategy, recycling the process until all critical uncertainties are resolved.

- **Timeline**

The timeline for the pilot releases (component C) to evaluate stock-enhancement potential is 3 to 5 years. The first phase of pilot releases will be completed, and the “Test Release” started, in 2003. The stocking plan is already under development and will be

presented to FWC for consideration in 2004. With adequate funding, expansion of redfish releases to include other areas in Florida could begin in 2005.

• **Acknowledgements:**

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Appendix IV

AQUACULTURED MARINE ORNAMENTALS: LAND-BASED FARMING OF CORALS AND LIVE ROCK

Improvements in technology over the past several years have led to relatively inexpensive and easy to maintain home aquariums. These technological improvements have driven growth in the demand for marine ornamentals. The global trade value of marine ornamentals is estimated at US $44 million (Wood 2001). Approximately 98% of the animals in the trade are wild collected animals (Moe 2001). Only a very small portion of this demand is being met by farm raised fish and invertebrates. Wild collected marine animals originate from the coral reef systems of developing Indo-Pacific countries. This industry has important economic and social impacts on the rural coastal communities of these small island countries. The pressures placed on tropical reef ecosystems around the world by pollution, storm damage, global warming and over fishing have increased greatly. As the availability of wild stocks decline, cultured marine ornamentals will become a major factor in the market.

It is a very time consuming and costly endeavor to make the transition from wild collection to aquaculture. It has been a continuing struggle for the commercial sector to over come the financial and the technical issues involved with culturing marine organisms. Very little is known about the reproductive behaviors or first larval foods for marine fish and invertebrates. Research funding for commercial operations is almost non existent making future growth into culturing new marine species difficult.

In order to determine the necessity for culturing specific marine species, there is a real need for accurate trade statistics in the marine ornamentals industry. The reliability of the current trade and scientific data is not adequate enough to base a coral reef management, conservation or aquaculture program on. While more research is desperately needed, recent efforts have been instituted by several organizations to improve the volume and accuracy of data on the state of the world's coral reefs resources. The United Nations Environmental Program, the Marine Aquarium Council, and the World Conversation Monitoring Centre have developed a Global Marine Aquarium Data Base (Lem 2001; Green 2001).

The long term goal must clearly be the utilization of sustainable collection, culture and handling practices throughout the marine ornamentals industry (Smith 2001). Resource management programs should be developed to help collectors learn how to best manage their fisheries, both foreign and domestic. Education and training into viable alternatives to wild collection should be provided. The industry as a whole needs to endorse sustainable collection practices and promote aquaculture species by expanding marketing efforts for both sources. There are many advantages to cultured products that include size standardization, consistent supply sources, and the increased survival rate of animals which have already adapted to the aquarium environment. Increased consumer acceptance is key to reducing pressures on wild stocks and coral reef conservation efforts.

The vast majority of corals in the marine ornamentals trade come from developing countries whose people depend on the reef ecosystems for their livelihoods. They rely on the ocean to provide food and income to their families. Because of the high trade value of many species, they are being collected by destructive fishing practices and at unsustainable rates. In 1973 the Convention on International Trade in Endangered Species (CITES) was created so the trade in wild animals and plants does not threaten their existence. CITES contains three appendixes. Appendix I lists species threatened by extinction. Appendix II lists species that may become threatened with extinction unless trade is regulated. Appendix III lists species that are protected because a CITES country has requested assistance in controlling trade in that species. Stony corals and live rock are listed as Appendix II species. Although soft corals are not listed on any CITES Appendix, the live rock base they are attached to is an Appendix II species, therefore as long as they are attached to a base, soft corals must follow CITES Appendix II regulations.

Live rock has been described as "a living marine organism or an assemblage thereof attached to a hard substrate" (Gulf of Mexico Fishy Management Council 1994). In 1997 a United States federal ban on the collection of wild harvested live rock was enacted. Commercially aquaculture live rock was offered as an alternative to wild collection. Several companies subsequently attempted the off shore culture of live rock. According to the rules of live rock aquaculture, a site must be in an area where there is no hard bottom, no natural reef, no sea grass present and shallow enough to support the growth of organisms. Only 50 sites in the Gulf of Mexico and the Atlantic Ocean meet such criteria (FDACS 2002). Site selection and environmental factors have made the aquaculture of live rock a difficult process. The past storm and hurricane seasons, and red tides in the Gulf of Mexico, have seen the demise of the majority of open ocean live rock aquaculturists.

Many government agencies are involved with regulating the marine aquaculture industry. County, state and federal agencies all have license and management requirements that commercial aquaculture companies must comply with. The agencies work to address many issues surrounding the industry which include "Best Management Practices", non-indigenous species issues, invasive species issues, water management, and chemical usage. The goal is to promote responsible aquaculture practices for the marine ornamentals industry.

The decision making process for a marine aquaculture production facility is quite extensive. Great consideration must be given to species selection, site selection, production management and marketing.

Species selection is the first critical decision to be made. Extensive research and market analyses must be conducted to determine production feasibility. The issue of brood stock procurement is also an important consideration. Quarantine procedures must be carefully planed before designing a production facility.

When considering site selection the first decision is in system design. What type of system is necessary to support the production of the selected species? Will the system be a flow thru or a recirculating system? What will the estimated water usage be and how will the production facility handle storage and discharge issues? Environmental and regulatory issues are a deciding factor on a site location.

Once the site has been selected production management decisions must be made. This is not a simple process. There are many areas that must be researched including available labor force, economic factors, is this a seasonal industry, what are the expenses both fixed and variable, health and disease control and environmental factors.

When the production management decisions have been made, marketing is the next step. Questions that must be answered concerning; market demand, market level, pricing, product diversity, shipping, cultured vs. wild caught animals, and customer service policies.

It is a difficult road to travel when venturing into the field of cultured marine ornamentals. In order to secure the future of the industry, both foreign and domestic government agencies must enact programs that will protect the coral reef systems throughout the world. Research, development and resource management programs should involve a cooperative effort between government, academia, and private companies. If the three sectors can find an avenue to share research and information the long term goal of the utilization of sustainable collection, culture and handling practices throughout the marine ornamentals industry can be met.

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Gulf of Mexico Fishy Management Council 1994. Amendment 2 July. Tampa, Florida.

Lem, Audun 2001. International trade in ornamental fish. In Marine Ornamentals 2001, Program and Abstracts, University of Florida Sea Grant College Program, p.26.

Moe, Martin A. 2001, Marine Ornamentals: The industry and the hobby. In Proceedings of Marine Ornamentals ’99, University of Hawaii Sea Grant College Program, pp. 53-63

Smith, Walt 2001. Responsibilities for collection and opportunities in aquaculture for developing countries through the marine aquarium trade. In Marine Ornamentals 2001, Program and Abstracts, University of Florida Sea Grant College Program, pp.167-168

Wood, Elizabeth 2001. Global advances in conservation and management of marine ornamental resources. Aquarium Sciences and Conservation 3(1-3):65-77

Appendix V
MARINE AQUACULTURE RESEARCH, DEVELOPMENT AND EDUCATION PROGRAMS

Private and Non Profit Research Institutions:

Harbor Branch Oceanographic Institution (HBOI) is working to (1) develop economically feasible and environmentally sustainable methods to farm aquatic organisms, (2) establish techniques to raise saltwater food fish in low salinity environments in collaboration with USDA-Agricultural Research Service, (3) develop culture methods to grow tropical marine species for stock enhancement and for food, (4) produce seaweeds for commercial purposes, (5) improve growth and survival of cultured clams and other new bivalve species, (6) commercially grow marine ornamentals for the aquarium markets, (7) develop energy efficient and cost effective water reuse systems for growing a variety of species, (8) provide diagnostics and health assessments for fish, crustaceans and mollusks, (9) teach students through aquaculture training and education programs to support industry expansion in Florida and the Caribbean and offer Associate and Certificate degrees in Aquaculture in collaboration with Indian River Community College and (10) expand collaborations with academic, government, private sector, and research institutions to design and implement culture technologies for marine animals and plants.

Marine species addressed: Black Seabass, Clams & other Bivalve Species, Cobia, Florida Pompano, Marine Ornamentals, Queen Conch, Spiny Lobster, Seaweeds

Contact Information

Center for Coastal Research, Aquaculture
Harbor Branch Oceanographic Institution Inc.
5600 US 1 North, Fort Pierce, Florida 34946
Contact: Megan Davis
(772) 465-2400 ext. 298, mdavis@hboi.edu
Website: www.hboi.edu/aqua

Mote Marine Laboratory (MML) - is working to (1) design and test economically feasible technologies that allow marine aquaculture to move inland, (2) develop culture techniques for high-value marine and freshwater fishes and invertebrates for food production and/or stock enhancement, (3) demonstrate the commercial viability of sturgeon aquaculture in Florida, (4) develop a nucleus breeding center for native bait shrimp, (5) demonstrate the commercial viability of bait shrimp aquaculture in the U.S., (6) evaluate opportunities to integrate marine and freshwater aquaculture, together with agriculture, (7) develop and implement marine stock-enhancement technology and assessment, and (8) educate the local community and aquaculture industry through outreach and education programs.

Marine species addressed: Snook, pompano, sturgeon, marine shrimp, bait shrimp, conch, corals, and associated live food organisms (i.e., rotifers, copepods, and brine shrimp)

Contact Information

Mote Marine Laboratory/Mote Aquaculture Park,
12300 Fruitville Road, Sarasota, FL 34240
Contact: Kevan Main (Aquaculture, Sarasota)
(941) 388-3373, kmain@mote.org
Contact: Ken Leber (Marine Stock Enhancement)

(941) 388-1748, kleber@mote.org
Contact: David Vaughan (Summerland Key)
305-745-2729, dvaughan@mote.org
Website: www.mote.org/aquaculture

The Living Seas Animal Care Program – is working to develop culture techniques for marine ornamental species and to manage health issues in captive marine fishes and invertebrates.
Contact Information
Jane Davis
Aquarium Curator, The Living Seas
Walt Disney World Co.
P.O. Box 1000, Lake Buena Vista, FL 32830
(407) 560-7534, Jane.Davis@disney.com

***The Florida Aquarium* –** is working to develop culture methods for Florida Keys corals and marine ornamental species and to manage health issues in captive marine fishes and invertebrates.
Contact Information
Ilze Berzins, Vice President of Biological Operations
The Florida Aquarium
701 Channelside Drive, Tampa, FL 33602
(813)367-4010, IBerzins@flaquarium.org
http://www.flaquarium.org/

Universities:

***University of Miami/RSMAS (UM)* –** is working to (1) develop offshore aquaculture production techniques for high-value marine fishes and (2) develop technology to close the life cycle and produce high value marine fishes.
Marine species addressed: Cobia, Yellowtail Snapper, and Mutton Snapper
Contact Information
Dr. Daniel Benetti
RSMAS/MAF, University of Miami
4600 Rickenbacker Causeway, Miami, FL 33149
(305) 421-4889, dbenetti@rsmas.miami.edu

University of Florida (UF) – is working to (1) conduct health management research and to assist the marine aquaculture industry with diagnostic health services, (2) develop marine ornamental and shellfish culture technologies, and (3) to provide extension and outreach services to Florida's aquaculture industry.
Contact Information - University of Florida
Gainesville Contacts: Frank Chapman, Shirley Baker, Denise Petty, Ruth Francis-Floyd
Department of Fisheries and Aquatic Sciences
7922 NW 71st Street, Gainesville, FL 32653
(352)392-9617, fchapman@ufl.edu, smbaker@ifas.ufl.edu
Fort Pierce Contact: Courtney Ohs
Indian River Research and Education Center
2199 South Rock Road, Fort Pierce FL 34945-3138
772-468-3922, cohs@ufl.edu

Cedar Key Contact: Leslie Sturmer
c/o FWC Marine Lab
PO Box 89, Cedar Key, FL 32625
(352) 543-5057, LNST@ifas.ufl.edu
Ruskin Contacts: Carlos Martinez, Craig Watson, Roy Yanong
Tropical Aquaculture Laboratory
1408 24th Street S.E., Ruskin, FL 33570
(813)671-5230, caw@ifas.ufl.edu, cvmartinez@ifas.ufl.edu

Florida Sea Grant (FSG) is working to develop better culture techniques for clams. This work includes not only production methods, but the development and teaching of the business and financial aspects of operating a clam business. An additional priority is the development of culture techniques for marine ornamental species. Producing cobia in hatcheries and follow-up offshore growout has been accomplished through funding from a national Sea Grant aquaculture initiative. Finally, general aquaculture education is provided to citizens and youth on a statewide basis.

Contact Information
Jim Cato
Florida Sea Grant
P.O. Box 110800
University of Florida
Gainesville, Florida 32611
352.392.5879
www.flseagrant.org <http://www.flseagrant.org/>

Florida State University (FSU) – is working to develop the technology to produce live food organisms for marine species at FSU and FSU Marine Laboratory. Current focus is directed toward identifying and developing culture technology for copepod species as a food source for larval marine fishes. Educational programs are focused at the graduate degree level (M.S., Ph.D.).

Marine species addressed: copepods

Contact Information
Nancy H. Marcus, Dean, Graduate Studies
Florida State University
408 Westcott Bldg.
Tallahassee, FL 32306-1410
(850) 644-3500
nmarcus@mailer.fsu.edu

Florida Institute of Technology (FIT) – is working to develop aquaculture technology for marine ornamental species; student internships (FIT is the only university in Florida that offers a B.S. in Aquaculture).

Marine species addressed: seahorse, larvae of several fish species, shrimp, & other crustaceans

Contact Information
Dr. Junda Lin

Florida Institute of Technology
150 West University Boulevard, Melbourne, FL 32901-6975
(321) 674-7587, jlin@fit.edu

Florida International University – is working to develop maturation and spawning techniques for marine and freshwater fishes and to provide student internships.

Contact Information
Dr. Christopher Brown, Professor of Biology
Florida International University
3000 NE 151st Street, North Miami Beach, FL 33181
(305) 919-4793, brownch@fiu.edu

Hillsborough Community College – offers 1-year certificate & 2-year degrees in Aquaculture.

Contact Information
Craig Casper, Aquaculture Program
Hillsborough Community College: Brandon Campus
10414 E. Columbus Dr. Tampa, FL 33619-7850
813-253-7881, ckasper@hccfl.edu

Government/State Research Initiatives:

Florida Fish and Wildlife Conservation Commission (FWC) – is working on the development of stock enhancement protocols and on the aquaculture technology for species that have stock enhancement potential. Areas of emphasis include: breeding, genetics, stock-enhancement technology, assessment, and education and outreach. Current aquaculture and stock enhancement efforts are focused on red drum in Tampa Bay.

Contact Information
Dr. Chris Young
Florida Fish & Wildlife, Stock Enhancement Research Facility
14495 Harlee Road, Port Manatee, Florida 34221
(941) 723-4505 Ext. 203, Chris.Young@MyFWC.com

Florida Department of Agriculture and Consumer Services Division of Aquaculture - is responsible for six marine-related programs: annual aquaculture certificate of registration for all commercial aquaculturists; compliance inspections to ensure implementation of Best Management Practices to achieve the state's environmental conservation and preservation goals; leasing of sovereignty submerged, coastal lands for bivalve mollusc cultivation; oyster resource development; bivalve mollusc processing plant certification; bivalve mollusc harvesting area management; and technical support.

Contact Information
R. Sherman Wilhelm, Director
Division of Aquaculture
Florida Department of Agriculture and Consumer Services
1203 Governor's Square Blvd, Fifth Floor Tallahassee, Florida 32301
850-488-4033
wilhels@doacs.state.fl.us

Florida Department of Agriculture and Consumer Services, Division of Marketing and Development, Bureau of Seafood and Aquaculture Marketing - provides information to the Florida seafood and aquaculture industry to help buy, sell and market Florida seafood and aquaculture products. The bureau produces educational materials for consumers; promotional materials, supplier directories, and training for retailers, foodservice, wholesalers, processors, fishermen and aquaculturists; public relations to the media on behalf of the seafood, aquaculture and marine life industries.

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