THE TEXAS AQUACULTURE INDUSTRY – 2012
Continued Part 2 (269 pages)
Compiled By
Granvil D. Treece*

Eels

Eels have been grown in Texas at several locations, but none were sustainable. Southern Star Shrimp Farm in Arroyo City grew eels one year in the 1990s. The species cultured was Anguilla rostrata (the only species presently allowed to be cultured in Texas). Texas Parks and Wildlife accused Southern Star of culturing *Anguilla anguilla,* but the genetic analysis was confirmed to be

A. rostrata. The problem Southern Star had was that later it was confirmed to have a parasite not thought to be found in North America. However, TPWD obtained some samples (small eels or elvers as they are called) from the East coast of the USA, either South Carolina or North Carolina, and TPWD found the elvers to have that same parasite. The main problems with culturing eels are predatory birds and the eel feed. It is hard to train the wild eel to eat prepared feed economically. There was also another farm in Brookshire, Texas (Long Shan) that was owned and operated by an Asian family. They grew turtles, carp, and eels in several ponds. The species cultured was *A. japonicus,* (an exotic from Japan). They had a special mixer to make the paste diet for the eels, and the eels were prepared in a number of ways for the market, including smoked and vaccum packed in plastic and frozen. It takes a special knowledge to be able to process the animals after harvest. Usually a nail in the head and a very sharp knife is used to separate the meat from the bones. There are now eel fillet machines available in the seafood processing industry that replaces the dangerous labor-intensive method of processing. The farm in Brookshire was eventually closed by TPWD for growing exotic “snake heads” without proper permits.

Anguilla rostrata (the only species allowed to be cultured in Texas)

Turtles

Common carp

Algae to Biofuels

Satellite photo of Aroyo Aqua Farms (formerly Southern Star Shrimp Farm) in Arroyo City, Texas. Leased by PetroSun on April 1, 2008 for the production of marine algae to be converted to biofuels. Web link: http://www.growfish.com.au/content.asp?contentid=11136.

This was taughted as the nation's first commercial-scale, open-pond algae farm to produce oil as a biodiesel feedstock and was supposed to begin operating near South Padre Island, Texas, on April 1, 2008. However, this lease never occurred.

LeCrone, representing PetroSun said tests conducted at the PetroSun Biofuels pilot algae farm in Opelika, Ala., showed oil production between 5,000 and 8,000 gallons per acre per year. He said challenges with extracting the algae from the water and the oil from the algae were overcome at the pilot facility. "All of the technology was developed at Opelika over the last year," he said. "We have a process that is totally different than what anyone else has been doing. We can't divulge what that process is, but we don't have a problem with any of those things." After extraction, the residual algae biomass can be made into ethanol or other products. Also promoting the process, LeCrone stated, "the oil is extracted on-site using a proprietary process, ishipped to company-owned or joint-venture biodiesel production facilities. "We can ship by land, sea or rail, so this site is pretty nice that way," he said. PetroSun proposed to conduct jet fuel and bioplastics research and development projects supported by the supply of oil from the operation. An aerial view of the algae farm can be found at **http://tinyurl.com/2clmzc.**

However, again, this lease did not happen in Texas and the project went nowhere.

Companies doing R&D Aquaculture in Texas in 2009 - 2011

American Fish Farms Inc. (AFF) was a new research and development company for Texas located in Rio Hondo/Arroyo City. It's purpose was sustainable aquaculture.

AFF was exploring principals of natural pond ecosystems to understand how these systems could best be applied in commercial operations. As the U.S. faces rising fuel, feed and labor costs and unsustainably harvested wild fisheries, the need for economical and environmentally sustainable farming practices is growing. Concerns about disease control and the spread of exotic species leads to a desire for new methods of water reconditioning and fish management. Using natural pond flora and fauna, AFF was investigating interspecies relationships with multiple trophic levels to investigate some of these challenges. The company operated about a year and closed down the Arroyo City operation. Dr. David Stephens was in charge of the operation at Arroyo City.

For more information about the company contact: Carey Jones Livefuels Inc. American Fish Farms Inc. Gower Design Group LLC 302 Garfield St Chelsea, MI 48118 p) 734.433.0150 fax) 407.902.0150 .

American Fish Farms, Inc

Another group doing R&D in Texas in 2011 is Global Blue Technologies in Port Isabel. Global Blue is building a one acre lined pond with greenhouse cover to raise shrimp. Their spokesperson said there is nothing secretive or new about the process they plan to use. It will use a modified floc system with some solids removal.

Offshore Marine Aquaculture in the US : Multiple Administrative and Environmental Issues Need to Be Addressed in Establishing a U.S. Regulatory Framework. This summary is from the US Govt. Accountability Office. GAO-08-594 May 9, 2008 Highlights Page (PDF) Full Report (PDF, 53 pages)

U. S. aquaculture--the raising of fish and shellfish in captivity--has generally been confined to nearshore coastal waters or in other water bodies, such as ponds, that fall under state regulation. Recently, there has been an increased interest in expanding aquaculture to offshore waters, which would involve raising fish and shellfish in the open ocean, and consequently bringing these types of operations under federal regulation. While the offshore expansion has the potential to increase U.S. aquaculture production, no comprehensive legislative or regulatory framework to manage such an expansion exists. Instead, multiple federal agencies have authority to regulate different aspects of offshore aquaculture under a variety of existing laws that were not designed for this purpose. In this context, GAO was asked to identify key issues that should be addressed in the development of an effective regulatory framework for U.S. offshore aquaculture. In conducting its assessment, GAO administered a questionnaire to a wide variety of key aquaculture stakeholders; analyzed laws, regulations, and key studies; and visited states that regulate nearshore aquaculture industries. Although GAO is not making any recommendations, this review emphasizes the need to carefully consider a wide array of key issues as a regulatory framework for offshore aquaculture is developed. Agencies that provided official comments generally agreed with the report.

In developing a regulatory framework for offshore aquaculture, it is important to consider a wide array of issues, which can be grouped into four main areas. (1) Program administration: Addressing the administration of an offshore program at the federal level is an important aspect of a regulatory framework. Stakeholders that GAO contacted and key studies that GAO reviewed identified specific roles and responsibilities for federal agencies, states, and regional fishery management councils. Most stakeholders and the studies agreed that the National Oceanic and Atmospheric Administration (NOAA) should be the lead federal agency and emphasized that coordination with other federal agencies will also be important. In addition, stakeholders and some of the studies recommended that the states play an important role in the development and implementation of an offshore aquaculture program. (2) Permitting and site selection: It will also be important to establish a regulatory process that clearly identifies where aquaculture facilities can be located and for how long. For example, many stakeholders stated that offshore facilities will need the legal right, through a permit or lease, to occupy an area of the ocean. However, stakeholders varied on the specific terms of the permits or leases, including their duration. Some stakeholders said that longer permits could make it easier for investors to recoup their investments, while others said that shorter ones could facilitate closer scrutiny of environmental impacts. This variability is also reflected in the approaches taken by states that regulate aquaculture in their waters.

One state issues 20-year leases while another issues shorter leases. Stakeholders supported various approaches for siting offshore facilities, such as case-by-case site evaluations and pre-permitting some locations. (3) Environmental management: A process to assess and mitigate the environmental impacts of offshore operations is another important aspect of a regulatory framework. For example, many stakeholders told GAO of the value of reviewing the potential cumulative environmental impacts of offshore operations over a broad ocean area before any facilities are sited. About half of them said that a facility-by-facility environmental review should also be required. Two states currently require facility-level reviews for operations in state waters. In addition, stakeholders, key studies, and state regulators generally supported an adaptive monitoring approach to ensure flexibility in monitoring changing environmental conditions. Other important areas to address include policies to mitigate the potential impacts of escaped fish and to remediate environmental damage. (4) Research: Finally, a regulatory framework needs to include a federal research component to help fill current gaps in knowledge about offshore aquaculture. For example, stakeholders supported federally funded research on developing (1) alternative fish feeds, (2) best management practices to minimize environmental impacts, (3) data on how escaped aquaculture fish might impact wild fisheries, and (4) strategies to breed and raise fish while effectively managing disease. A few researchers said that the current process of funding research for aquaculture is not adequate because the research grants are funded over periods that are too short to accommodate certain types of research, such as hatchery research and offshore demonstration projects.

Subject Covered in the Report to Congress

Aquaculture Environmental law
Environmental monitoring
Environmental policies
Environmental protection
Federal regulations
Federal/state relations
Fishery legislation
Fishes Fishing industry
Leases Marine policies
Marine resources
Marine resources conservation
Marine resources development
Oceanographic research
Program evaluation
Program management
Proposed legislation
Regulatory agencies
Research grants
Shellfish Strategic planning
Sustainable fisheries
Water pollution control

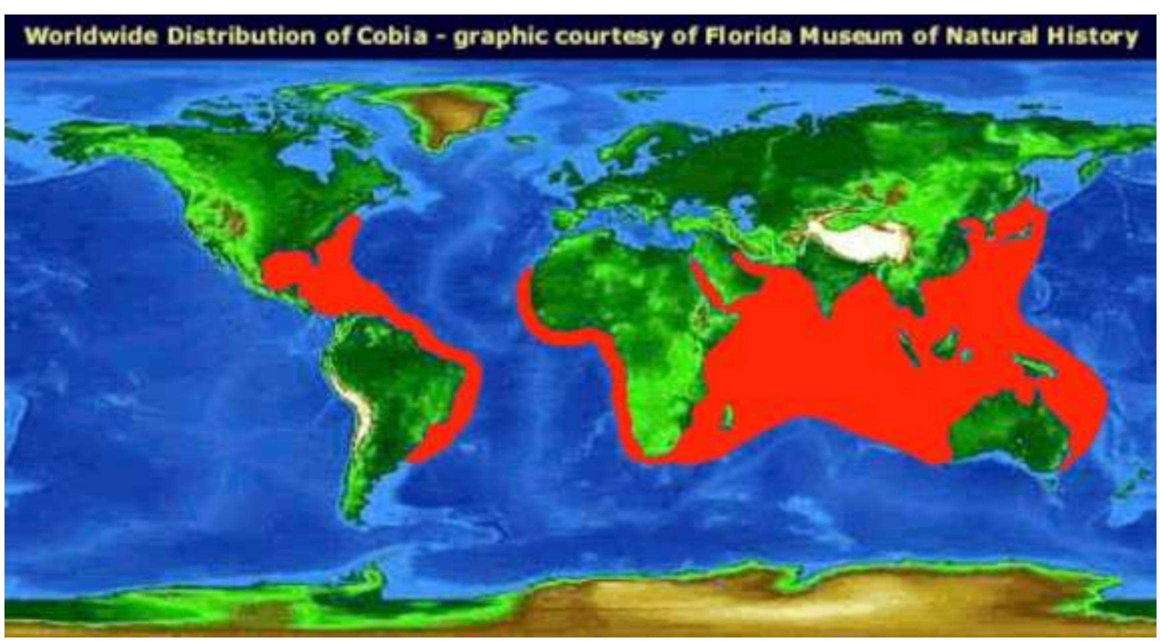
Native species in Texas with offshore aquaculture potential:

Cobia (ling, lemon fish). Family Rachycentridae, *Rachycentron canadum*

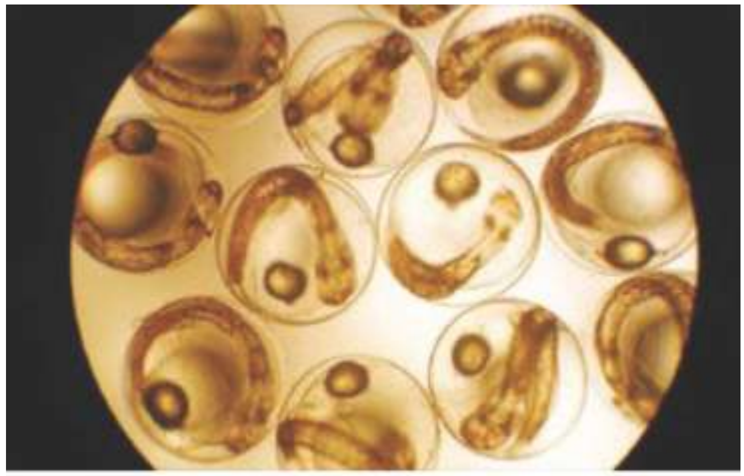
Cobia adults.

Cobia (*Rachycentron canadum*), also known as Ling and Lemonfish, is a widely distributed migratory species of significant commercial and recreational fishery value. There are no large commercial fisheries supplying Cobia to the seafood market.

The life cycle of the Ling has been closed by a number of researchers, including Texas researchers, meaning that controlled spawning has been accomplished. Cobia's larval rearing techniques are perfected, and this fish grows rapidly and has a very high market appeal around the Gulf of Mexico because of the good flesh quality and taste. This species offers great potential for future culture offshore. Taiwan and now the Philippines are producing large quantities of this species and may soon be very competitive as imports to the US.



Cobia eggs



Cobia Yolk Sacs – post hatch

Very young Cobia

Close up, Cobia fingerling

Cobia fingerlings

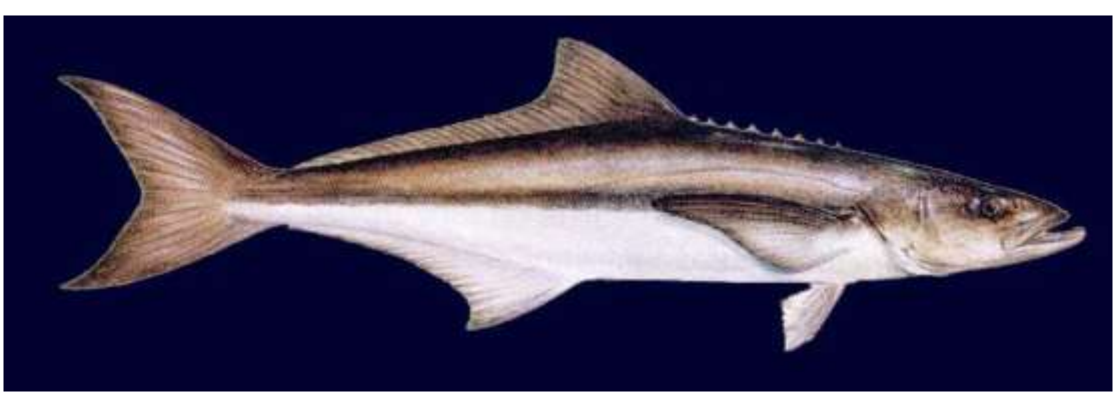
Family Rachycentridae

Commercial landings of Cobia in the Gulf and Atlantic region from 1991 to 1996 totaled 1,046 metric tons (1151 tons) with an average ex-vessel value of $ 3.54 (NMFS 1998). Commercial-scale culture of Cobia has never been attempted in the United States; however, operations in Korea and South Carolina have successfully produced fingerlings. Cobia can be sold to the Japanese market or the US market with ease.

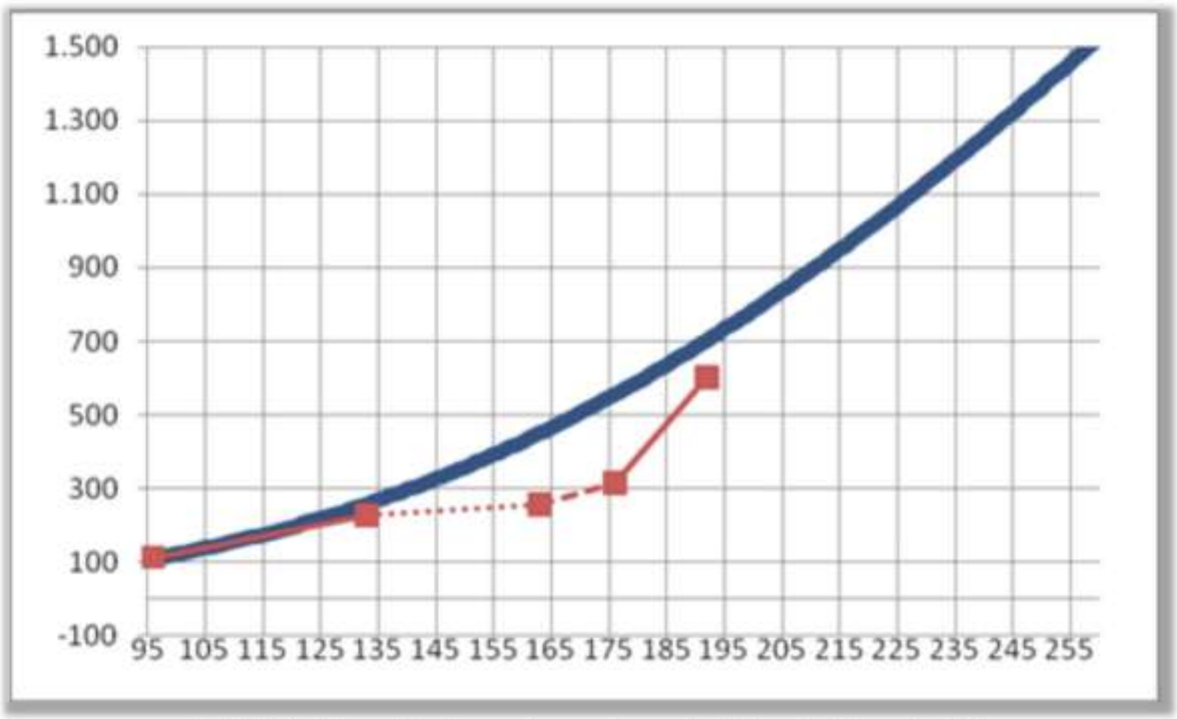
Some preliminary studies on growth rates and spawning suggest that Cobia has excellent potential for mariculture (Hasler and Rainville 1975, Calor et al 1994). Given their salinity and temperature requirements Cobia appear to be best suited to coastal cage culture. Cobia grow rapidly according to Dr. Joan Holt of the University of Texas Marine Research Center in Port Aransas, Texas.

She stated that ¼-pound Cobia fingerlings were grown to 21 to 22 pounds in just 18 months and can reach a maximum size of around 132 pounds. Because of their rapid growth rates, excellent palatability and prolific spawning capacity, they offer excellent potential for commercial culture. These characteristics of Cobia have been recognized in Taiwan as well, where they are under development as a mariculture species (Liao et al 1995). Currently, the Gulf Coast market price is $4.00 per pound, whole and round. Some studies on growth rates and spawning have shown that Cobia can be domesticated and is an excellent species for mariculture. Given their salinity and temperature requirements Cobia appear to be best suited to coastal cage culture, but recent studies by Holt and Kaiser indicate that they can adapt to lower salinities. Cobia grow rapidly. At the UTMSI laboratory in Texas, 1⁄4-pound Cobia fingerlings were grown to 21 to 22 pounds in just 18 months and can reach a maximum size of around 132 pounds. Because of their rapid growth rates, excellent palatability and prolific spawning capacity, they offer excellent potential for commercial culture. These characteristics of Cobia have been recognized in Taiwan and the Philippines as well, where they are under development as a mariculture species. Harlingen Shrimp Farms, Ltd. has grown Cobia from eggs and reared them in tanks and ponds in 2005. Pond culture of Cobia offers the industry potential for diversification if the problem of cold winters can be overcome. Young cobia die when the water temperature reaches the 12 degree C range. Cobia lack an air bladder to keep them afloat, which is common to most other fish.

Cobia Juveniles



Cobia Adult



One commercial trial with cobia has shown juvenile fish starting at 100 grams, stocked in cages offshore, will grow to between 600 to 700 grams (6 or 7 times larger) in only 190 days.

Red Drum (Redfish)

Family Sciaenidae, DRUMS, *Sciaenops ocellatus*

Redfish or red drum, were overfished and its stocks depleted in the Gulf of Mexico. Some overfishing occurred partly because of Chef Paul Prudhomme, the well-known New Orleans chef, who created his recipe for "blackened redfish" in 1980. The national Cajun food craze that he started is still popular today. As a result of increased demand for this species, federal waters were quickly depleted by overfishing and were closed by emergency federal regulations in July 1986. Texas Parks and Wildlife stock redfish fingerlings into Texas bays, and the redfish for recreational fishing has made a big recovery.

As demands on natural fisheries increased and supplies of wild fish decreased, interest in Red Drum culture increased and it was soon recognized as a viable candidate for mariculture. Several red fish farms were established in Texas in the late 1980s and early 1990s. A new 200-acre farm was built on the coast in 2004.

Redfish is an estuarine-dependent species, which spawns near tidal passes and inlets along the Gulf Coast in the Fall (September through November). Adults and juveniles tolerate a wide range of water temperature and salinity making them especially well suited to culture in cages and ponds. Redfish are long-lived and grow reasonably fast as juveniles, thus making it possible to produce a market-size fish in about one year, with proper culling of fast growers. Current (2008) farm-gate price for redfish whole and round is $2.40 per pound.

Greater Amberjack

Family Carangidae, JACKS and POMPANOS.

Amberjack (*Seriola dumerili*).

Also called Yellowtail, the Amberjack can be found throughout the Gulf of Mexico as well as in oceans around the world. In the Gulf of Mexico Amberjack are found around reef areas and oil platforms. The Greater Amberjack is the most abundant species caught and is readily accepted as table fare throughout the world. This is a fast-growing fish and grows to four to five feet in length and weighs up to 140 pounds. The Lesser Amberjack (*Seriola fasciata*) is a much smaller fish that reaches only 18 inches in length. The federal government has now limited Amberjack to a 1000-pound daily vessel limit. The general public view in Florida is that the Greater Amberjack is depleted. NMFS believes the Amberjack is overfished in the Gulf of Mexico.

Red Porgy

Pagrus pagrus.

The Red Porgy, also known as the Sea Bream is a valuable fish worldwide and easily grown in cage culture. The fish has been popular with sports fishermen and it is on the list of regulated species because of declining population (NMFS 2000). Japan was conducting culture research with this species as long as 70 years ago. Greece has been extremely successful raising these fish in sea-farm enterprises. Recent production was reported to be more than 220,000 pounds and future production is expected to rise significantly. Established markets exist in Europe and the Far East. This fish species is indigenous to areas of the Gulf of Mexico and the Mediterranean.



Flounder

Flounder populations in Texas are on the decline according to researchers. This would be a very good candidate fish species for commercial aquaculture. It has a very strong market appeal in Texas.

Dolphin Fish

Coryphaena hippuras.

Dolphin Fish (Mahi mahi or dorado) is a highly prized food fish from offshore marine waters. It has been cultured for many years using aquaculture techniques. It is very colorful until it is removed from the water, then it rapidly loses its color.

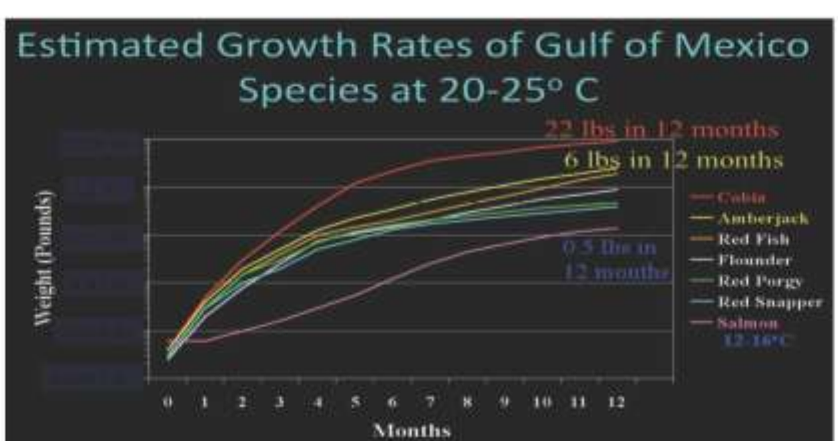
The Red Snapper is a species with future potential for offshore aquaculture. Red snapper already has a strong market in Texas and is harvested from the wild.

Red Snapper

Red Snapper, Family Lutjanidae

Speckled Trout

The speckled trout also has aquaculture potential. TPWD has a hatchery development program for this species, and is considering implementing a stock enhancement program for this species.



Oil Platforms in the Gulf of Mexico as possible mariculture platforms:

The conclusions reached at the 3rd International Open Ocean Aquaculture Conference in Corpus Christi in 1998 indicated that oil and gas platforms had too much ‘baggage’ and liability associated with them to work for mariculture. Experts from around the world suggested that the industry use existing cage and net technology in use off Ireland and other areas of the world. A platform, for example, can cost in excess of $50,000 a year just to maintain (corrosion prevention, navigational light maintenance, etc.). However, a number of groups have utilized platforms off the Texas coast in the past for offshore aquaculture platforms (both for R&D and for commercial culture of red drum). The Occidential Petroleum R&D pilot off Port Aransas found that red drum production costs on their platform were far in excess of the current market price for the fish. The pilot commercial project on a Shell-Offshore platform operated a few years and closed when the oil company needed the platform once again for oil and gas. There are still several groups very interested in starting mariculture ventures using offshore platforms. The Gulf Marine Institute of Technology (GMIT) tried to get permits to conduct mariculture on a platform in Federal waters off Galveston. When unsuccessful, they moved to a platform in state waters, 10 miles off Port O’Conner, Texas, but after permitting attempts were made from 1998 to 2008, the group gave up. GMIT President, John Ericsson stated on May 11, 2009, “the last appeal by the GLO and the AG’s Office of Texas to the Texas Supreme Court overruled the district court rule that gave GMIT a lease. **Our site lease is dead by the ruling and we have delayed further efforts with the GLO to obtain a new state lease because of unreasonable demands by the GLO to reinstate our platform removal bond for $2.6 million without knowing if we would get a new lease.”**

GMIT platform 10 miles off Port O’Connor, Texas (above and below)

Salmon net pens off Killary, Ireland.

Tuna Cages off the coast of Mexico

This cage can be raised and lowered.

A similar submersible cage (SeaStation 3000 – Ocean Spar) is another cage being used to grow Moi off Hawaii. Red snapper is being raised in similar cages off South Eleuthera, Bahamas and Cobia off Culebra Island, Puerto Rico.

An Ocean Spar cage was also tested in Gulf of Mexico off MS/Alabama with Cobia.

Spar cage off Hawaii with Pacific threadfin or Moi (Cates submersible cage)

Spar cage off Alabama coast.

Sea Station 3000 – Ocean Spar, Culebra Island, Puerto Rico.

Young cobia

Snapperfarm, Inc. cobia in cage off Puerto Rico

Results of Snapperfarm cage trials with cobia in Puerto Rico (from Dan Benetti):

12 months (1 year) from eggs: Total Feed: 31,435.12 kg Total Morts: 342 Harvested: 114 Estimated Remaining in cage: 2,500 Average weight: 6.03 kg (SD=2.4; CV=39%) or 13.3 lb [1.7-9.1 kg] FCR = 1.95 Survival > 90%

18 months (1.5 yr) from eggs: Total Feed: 52,255.20 kg Total Morts: 663 Harvested: 2,175 Estimated remaining: 100's Average weight: 7.75 kg (17.06 lb) [5-16kg] FCR = 2.29 Survival = 75% Total biomass harvested: 15 Ton (< 33,000 lb) Total number of fish: 3,200

Cobia (photo from Dan Benetti)

Boxed cobia (photo from Dan Benetti)

Boxed cobia (photo from Dan Benetti)

COBIA
Order: Perciformes
Family: Rachycentridae
Genus: *Rachycentron*
Species: *canadum*

Taxonomy

The cobia was originally described as *Gasterosteus canadus* by Linnaeus in 1766. It was later changed to *Rachycentron candum* (Linnaeus, 1766). Synonyms for the cobia include *Apolectus niger* Bloch 1793, *Scomber niger* Bloch 1793, *Naucrates niger* Bloch 1793, *Elacate nigra* Bloch 1793, *Centronotus gardenii* Lacepede 1801, *Centronotus spinosus* Mitchill 1815, *Rachycentron typus* Kaup 1826, *Elacate motta* Cuvier and Valenciennes 1829, *Elacate atlantica* Cuvier and Valenciennes 1832, *Elacate bivittata* Cuvier and Valenciennes 1832, *Elacate malabarica* Cuvier and Valenciennes 1832, *Elacate pondiceriana* Cuvier and Valenciennes 1832, *Meloderma nigerrima* Swainson 1839, *Naucrates niger* Swainson 1839, *Elacate falcipinnis* Gosse 1851, *Thynnus canadensis* Gronow 1854, *Elacate nigra* Gunther 1860, *Rachycentron canadus* Jordan and Evermann 1896, and *Rachycentron pondicerrianum* Jordan 1905.

Common Names

English language common names are cobia, black kingfish, black salmon, cabio, crabeater, cubby yew, kingfish, lemonfish, ling, prodigal son, runner, sergeant fish, and sergeantfish. Other names include aruan tasek (Malay), bacalao (Spanish), bacalhau (Portuguese), balisukan (Bikol), bonita (Susu), bonito (Spanish), cobie (Spanish), cuddul-verari (Sinhalese), dalag-dagat (Tagalog), foguesteiro-galego (Portuguese), gabus laut (Malay), gile (Tagalog), goada (Arabic), itang (Bikol), jaman (Malay), kadal-viral (Tamil), kobia (Afrikaans), kume (Visayan), kumi nu'aakhr (Arabic), langlanga (Maranao), mafou (French), mondoh (Javanese), mudhila (Sinhalese), ndjika (Portuguese), offiziersfisch (German), okakala (Finnish), pandauan (Bikol), pandawan (Cebuano), peixesargento (Portuguese), peje palo (Spanish), pejepalo (Spanish), rachica (Polish), sakalan itang (Bikol), seekel (Arabic), segel (Arabic), seheeha (Arabic), sikel (Arabic), sikin (Arabic), sungoro (Swahili), sugi (Japanese), takho (Somali), and tayad (Visayan).

Geographical Distribution

The cobia is distributed worldwide in tropical, subtropical and warm-temperate waters. In the western Atlantic Ocean this pelagic fish occurs from Nova Scotia (Canada), south to Argentina, including the Caribbean Sea. It is abundant in warm waters off the coast of the US from the Chesapeake Bay south and throughout the Gulf of Mexico. During autumn and winter months, cobia migrate south and offshore to warmer waters. Cobia prefer water temperatures between 68°-86°F. Seeking shelter in harbors and around wrecks and reefs, the cobia is often found off south Florida and the Florida Keys. In early spring, migration occurs northward along the Atlantic coast. In the eastern Atlantic Ocean, cobia range from Morocco to South Africa and in the Indo-West Pacific from East Africa and Japan toAustralia. Cobia do not occur in the eastern Pacific Ocean.

Habitat

As a pelagic fish, cobia are found over the continental shelf as well as around offshore reefs. It prefers to reside near any structure that interrupts the open water such as pilings, buoys, platforms, anchored boats, and flotsam. The cobia is also found inshore inhabiting bays, inlets, and mangroves. Remoras are often seen swimming with cobia.

Biology

· *Distinctive Features*

The body is elongate and torpedo-shaped with a long, depressed head. The eyes are small and the snout is broad. The lower jaw projects past the upper jaw. The skin looks smooth with very small embedded scales. Easily distinguished by the first dorsal fin which is composed of 7-9 short, strong isolated spines, not connected by a membrane. Second dorsal fin is long with the anterior portion elevated. The caudal fin is round to truncated in young fishes, and lunate in adults with the upper lobe extending past the lower. The origin of the anal fin is beneath the second dorsal apex and the pectoral fin is pointed. Cobia lack an air bladder.

Cobia Courtesy
NOAA

Young cobia. Courtesy NOAA

· *Coloration*

The body is dark brown to silver, paler on the sides and grayish white to silvery below, with two narrow dark bands extending from the snout to base of caudal fin. These dark bands are bordered above and below by paler bands. Young cobia have pronounced dark lateral bands, which tend to become obscured in the adult fish. Most fins are deep brown, with gray markings on the anal and pelvic fins.

·*Dentition*

Cobia have bands of villiform teeth on jaws, and on roof of mouth and tongue.

Cobia courtesy Virginia Institute of Marine Science

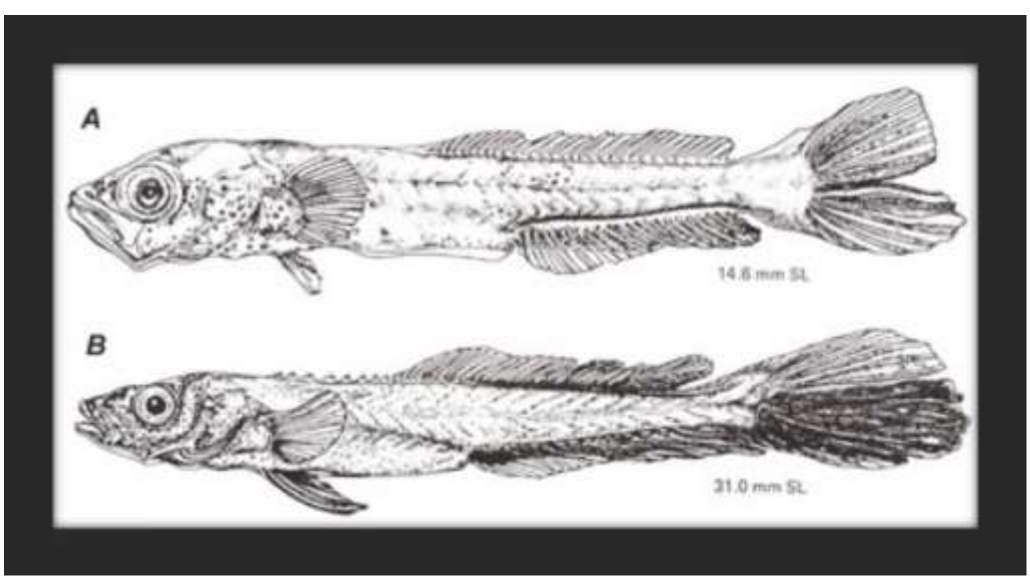
·Size, Age, and Growth

Weighing up to a record 135 pounds (61 kg), cobia are more common at weights of up to 50 pounds (23 kg). They reach lengths of 20-47 inches (50-120 cm), with a maximum of 79 inches (200 cm). Cobia grow quickly and have a moderately long life span. Maximum ages observed for cobia in the Gulf of Mexico were 9 and 11 years for males and females respectively while off the North Carolina coast maximum ages were 14 and 13 years. Females reach sexual maturity at 3 years of age and males at 2 years in the Chesapeake Bay region. Cobia in other parts of the world may mature earlier.

· Food Habits

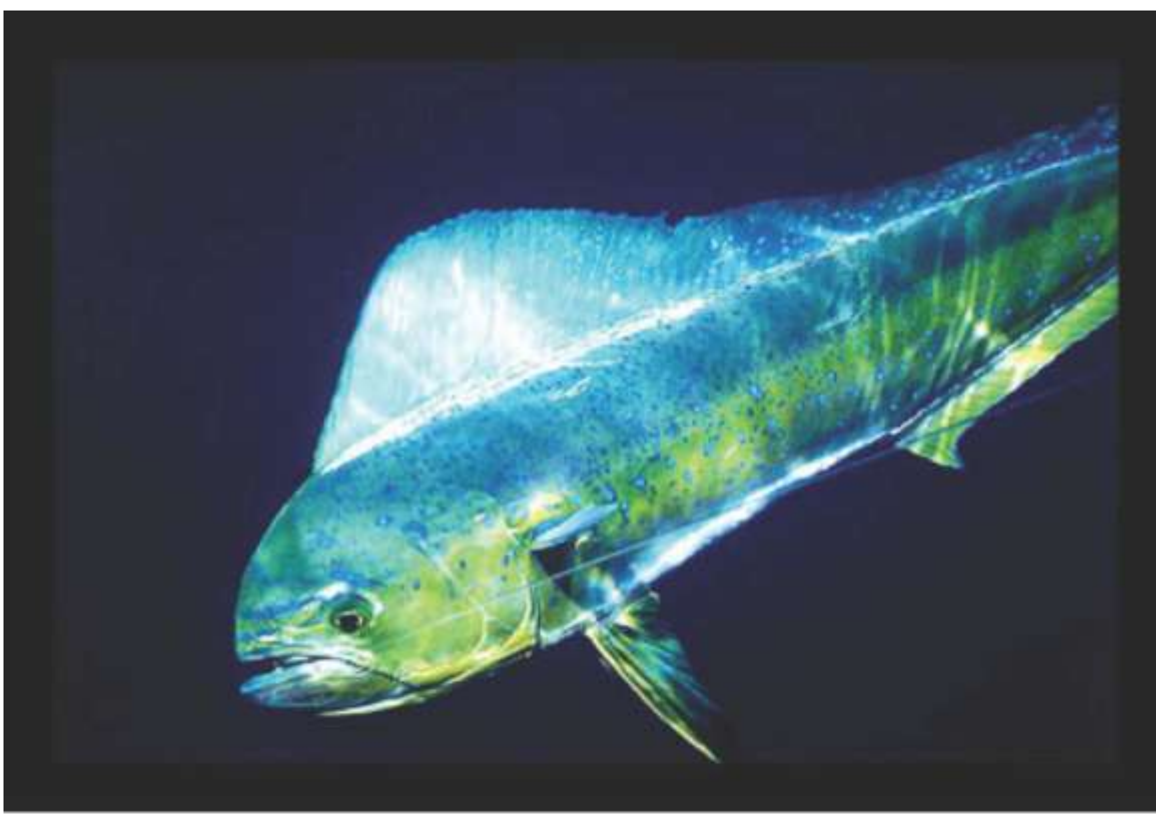
As voracious eaters, cobia often engulf their prey whole. They are carnivores, feeding on crustaceans, cephalopods, and small fishes such as mullet, eels, jacks, snappers, pinfish, croakers, grunts, and herring. A favorite food is crabs, hence the common name of "crabeater". Cobia often cruise in packs of 3-100 fish, hunting for food during migrations in shallow water along the shoreline. They are also known to feed in a manner similar to remoras. Cobia will follow rays, turtles, and sharks, sneaking in to scavenge whatever is left behind. Little is known about the feeding habits of larvae and juvenile cobia.

A. Late larva cobia, B. juvenile cobia courtesy
NOAA Technical Report NMFS 82



· *Reproduction*

Cobia form large aggregations, spawning during daylight hours between June and August in the Atlantic Ocean near the Chesapeake Bay, off North Carolina in May and June, and in the Gulf of Mexico during April through September. Spawning frequency is once every 9-12 days, spawning 15-20 times during the season. During spawning, cobia undergo changes in body coloration from brown to a light horizontal-striped pattern, releasing eggs and sperm into offshore open water. Cobia have also been observed to spawn in estuaries and shallow bays with the young heading offshore soon after hatching. Cobia eggs are spherical, averaging 1.24mm in diameter. Larvae are released approximately 24-36 hours after fertilization. These larvae are 2.5 mm long and lack pigmentation. Five days after hatching, the mouth and eyes develop, allowing for active feeding. A pale yellow streak is visible, extending the length of the body. By day 30, the juvenile takes on the appearance of the adult cobia with two color bands running from the head to the posterior end of the juvenile.



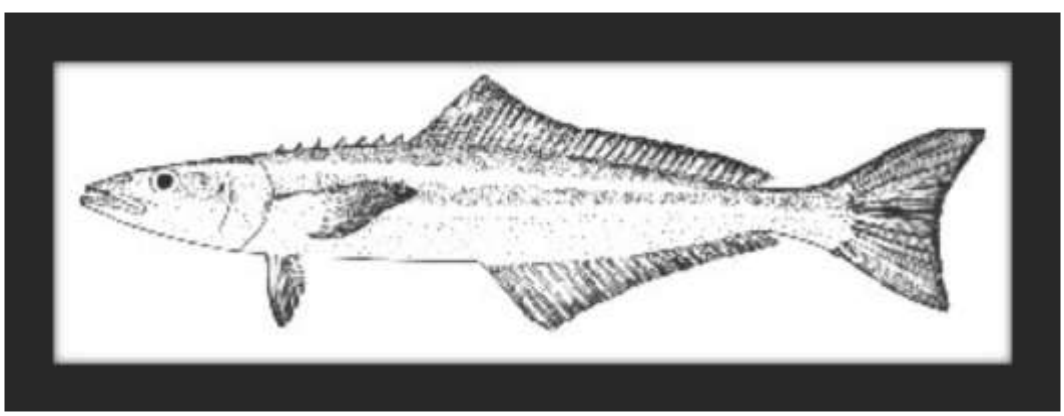
Dolphin - predator of small cobia (photo by Don DeMaria)

Predators
Not much is known regarding the predators of cobia, however they are presumably eaten by larger pelagic fishes. **Dolphinfish** (*Coryphaena hippurus*) have been reported to feed on small cobia.

· *Parasites*
The majority of parasites are host-specific, suggesting this fish is not closely related to any other fishes. Parasites include a variety of trematodes, cestodes, nematodes, acanthocephalans, and copepods as well as barnacles. Thirty individuals of a single trematode species, *Stephanostomum pseudoditrematis*, were found in the intestine of a single cobia taken from the Indian Ocean. Infestations of the nematode *Iheringascaris inquies* are quite common in the stomachs of cobia.

Importance to Humans

Cobia is considered an excellent game fish and are highly prized by recreational fishers. It is a powerful fish and exciting to catch on hook and line. In the US, cobia are caught commercially in pound nets, gill nets, and seines. They are also taken incidentally by shrimp trawlers and longliners in the Gulf of Mexico. Cobia are usually caught in small quantities due to their solitary existence. It is a good food fish for human consumption and is typically marketed fresh, frozen, or smoked.



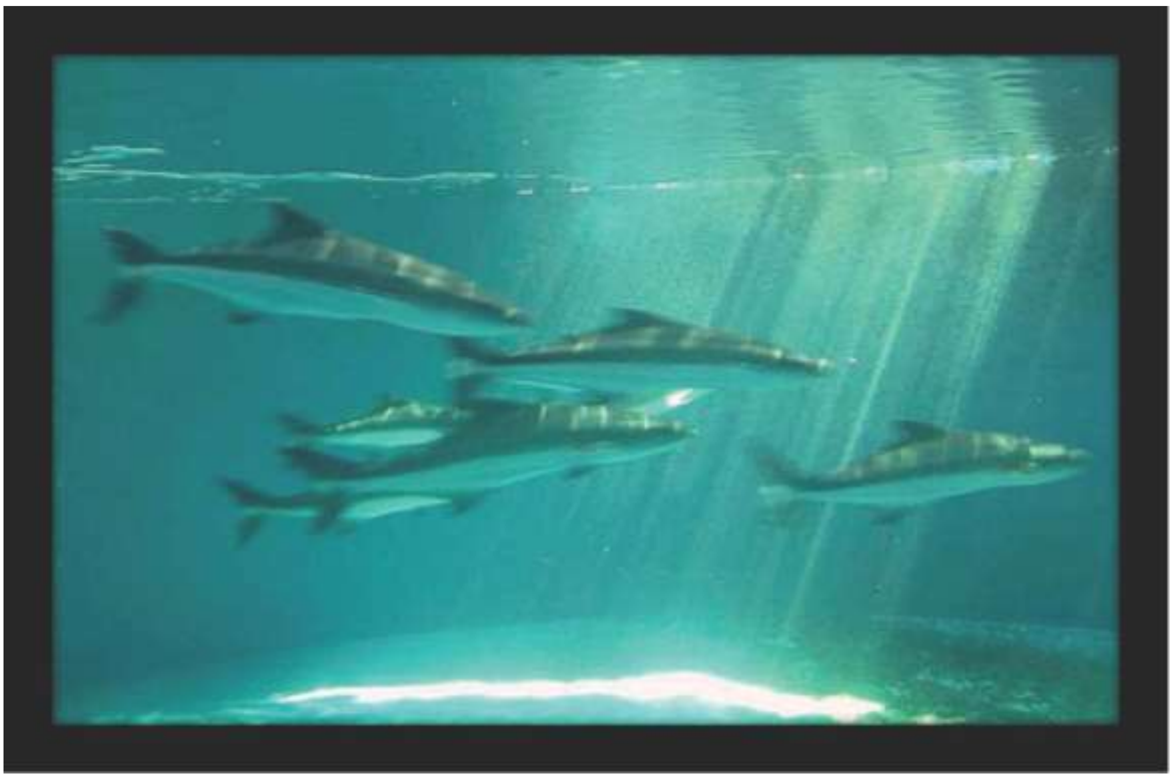
Profile of a cobia, notice the sharp dorsal spines

Danger to Humans

There are 7-9 dorsal spines, each depressible into a groove, that are very sharp and stout. Care must be taken when handling these strong fish to avoid injury.

Conservation

The cobia is not listed as endangered or vulnerable with the World Conservation Union (IUCN). The IUCN is a global union of states, governmental agencies, and non-governmental organizations in a partnership that assesses the conservation status of species.



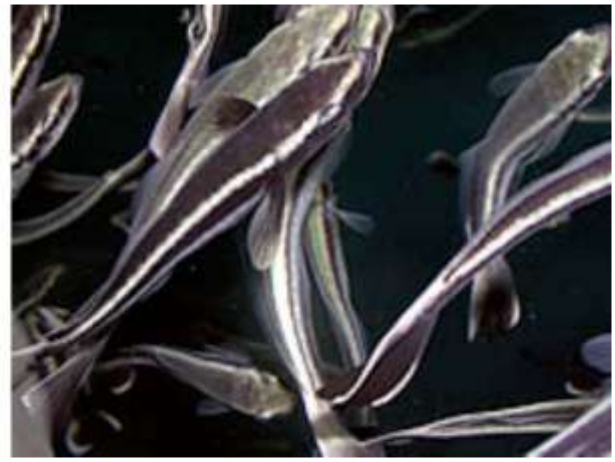
Cobia in captivity as part of a research project. Courtesy NOAA

Prepared by:
Cathleen Bester

Cobia are also being raised off Ecuador. Web link: www.oceanfarmsa.com.


COBIA

Belize Cobia



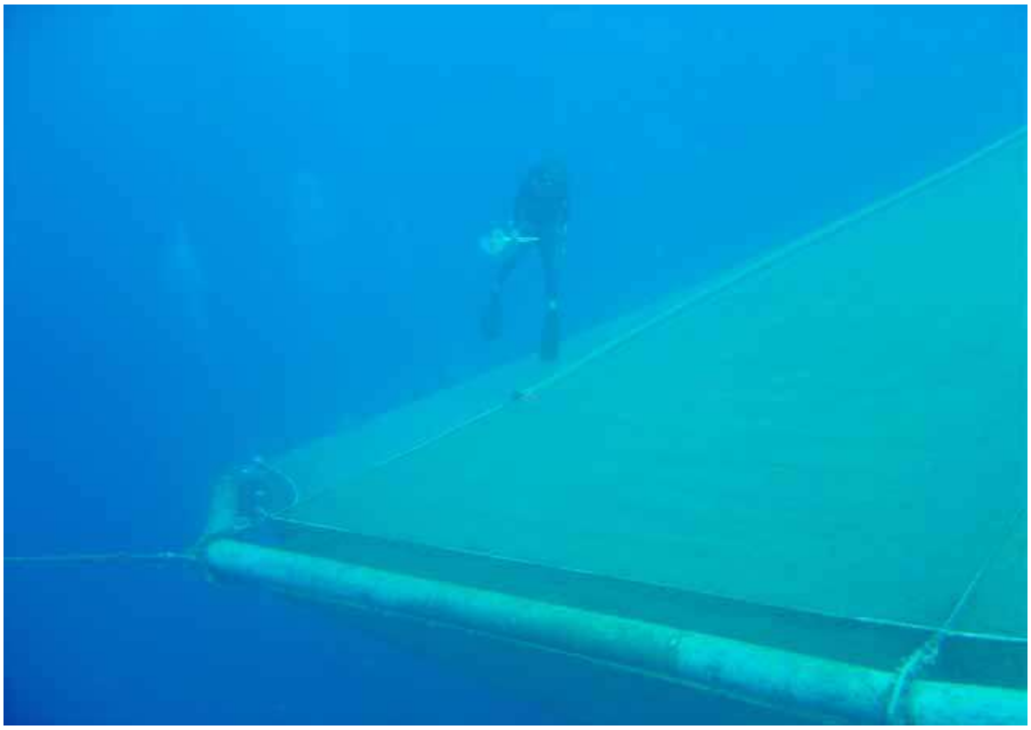







Hot, smoked Cobia from Belize

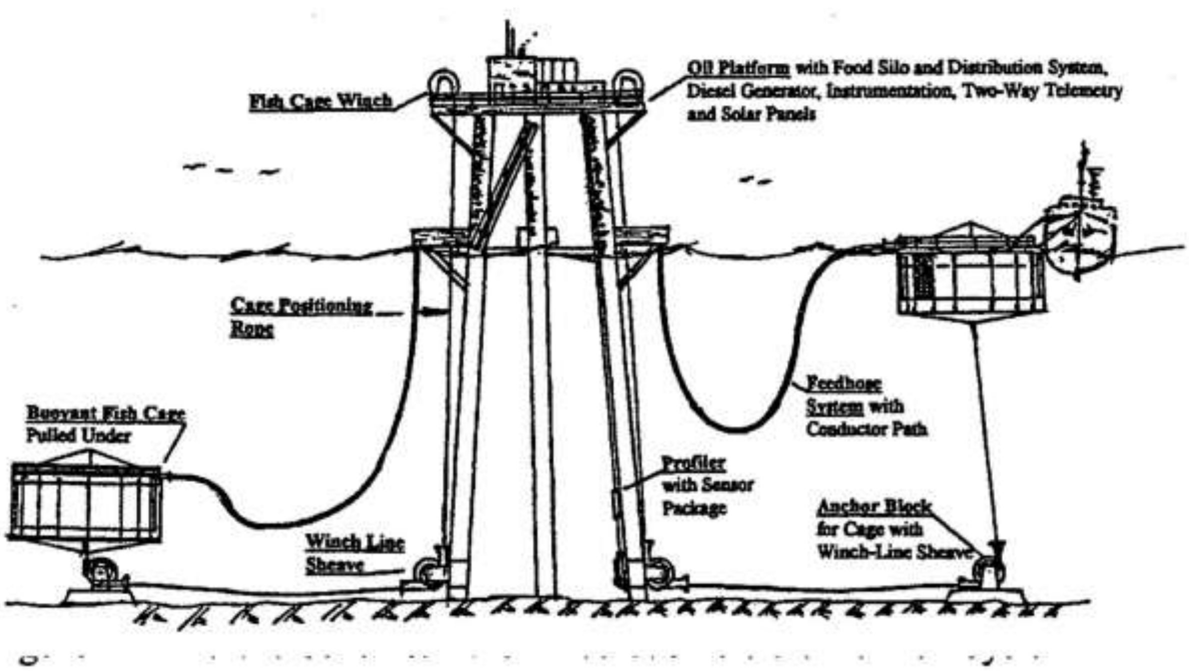
Pan seared Cobia from Marine Farms Belize web site:
http://www.marinefarmsbelize.com/



AquaSense, LLC's Sea Station 3000 – Ocean Spar, off South Eleuthera, Bahamas (photo from Dan Benetti)

Mediterranean Model - $1 billion annual gross income, largest producers of marine fry in the world, vertically integrated production of seed, cage farm production, processing and distribution. (Photo from Phillip Lee).

Mediterranean Fish Hatchery (Photo from Phillip Lee)



Oil platform with food silo and distribution system, diesel generator, instrumentation, two-way telemetry and solar panels. Source: Offshore Mariculture in the Gulf of Mexico: Feasibility Report Louisiana Sea Grant College.

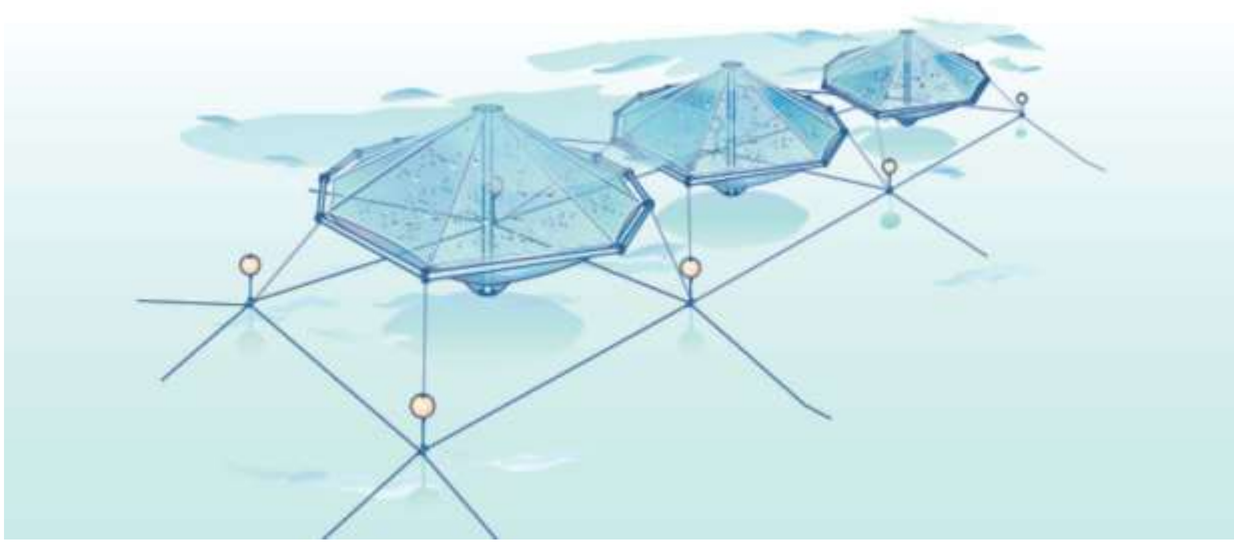
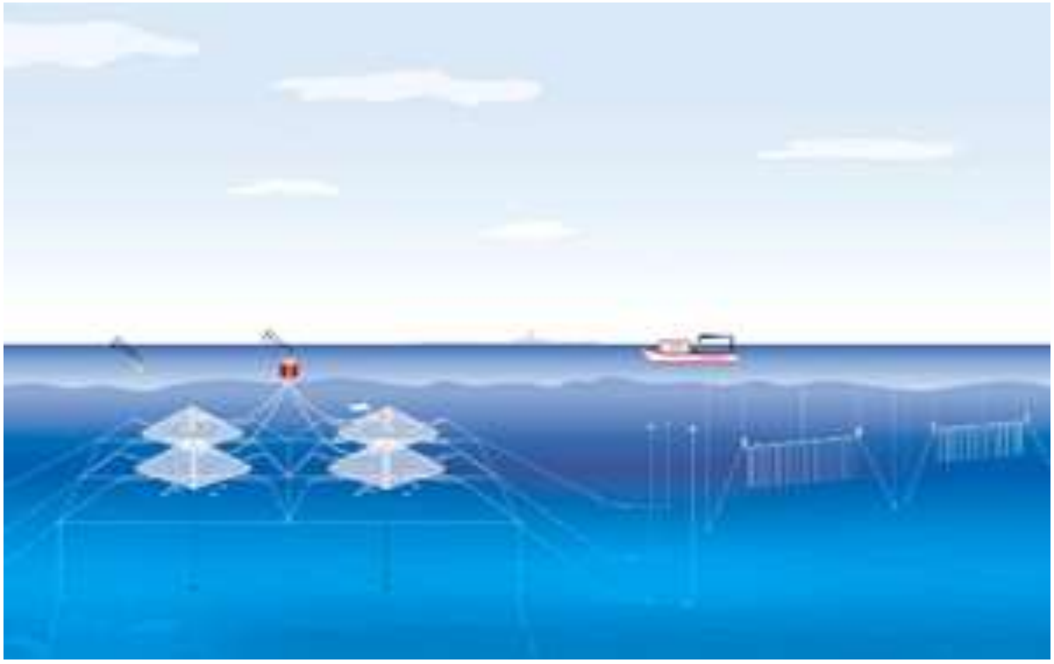


Illustration of Open Ocean Sea Station by Ocean Spar, www.oceanspar.com



Schematic of a net pet operation from Univ. of New Hampshire OOA project.

NOAA – NMFS Statistics No. 2003 states the total fish and shellfish production for the Gulf of Mexico was 194 million pounds, excluding Menhaden and shrimp. According to Joe Hendrix (appointed by Governor Rick Perry to represent Texas on the Gulf of Mexico Fisheries Management Council, and President of SeaFish Mariculture in Houston, Texas) 457 cages (32 meter diameter) carrying 20 kg/cubic meter could produce as much as the entire annual commercial finfish catch of the Gulf, requiring a sea bottom area of only 800 hectares or about 2,000 acres. Of course you would not want to concentrate the cages in one area, but spread them out over the Gulf. This method offers much potential for future aquaculture expansion.

The potential for offshore aquaculture in the Gulf of Mexico offers the US a way to help offset part of its huge seafood trade deficit, and produce some of its own fish. HOWEVER, there are still some very large obstacles to overcome.

The federal and state regulatory agencies have rules and regulations concerning aquaculture that keep this industry from expanding offshore. For example, EPA states that the State of Texas (TCEQ) can not issue NPDES permits out further than 6 miles offshore, even though the state claims the boundary goes out to 10.3 miles offshore. Therefore, two duplicate permits are required (TPDES from the state and NPDES permit from EPA) if the mariculture operation falls within the area from 6 miles offshore to the state boundary line, 9 nautical miles or 10.3 miles offshore. From 10.3 miles out in the EEZ to 200 miles in US waters, there is only one discharge permit required (the NPDES from EPA). This could easily be changed if government regulatory agencies wanted to simplify the process.

Details of a Specific Example of an Offshore Project in Texas

BioMarine Technologies, Inc. Farming the Sea

BioMarine Technologies, Inc.
P.O. Box 776, Gulf Breeze, Fl 32562
Phone: (850) 932-9038 Fax: (850) 932-0422
Email: j.ericsson@biomarineinfo.com Website: www.biomarineinfo.com

To give a specific example of an offshore aquaculture project in Texas, the Gulf Marine Institute of Technology (GMIT) will be used. GMIT is a 501(c)(3) nonprofit research institute that acquired an oil production platform off the Texas coast from Sea Gull Marine and surface rights from Tenneco. GMIT acquired a 115 ft powered barge with 7.5-ton crane and service vessel- 27 ft Silverton water taxi. The permitted site consists of 500 acres, a main platform with 2 decks, each 40 m X 24 m, and the main deck is 25 meters above water. Water depth on the platform legs is 24 meters. They have two 250 kW diesel generators on the platform, sleeping quarters for 18, a galley and office. There are 3 satellite platforms with 2 decks on each platform measuring 14 m X 18 m.

The first attempt by GMIT in Texas was made on a different platform in federal waters 12 miles off Galveston. The problem in federal waters was that the U.S. Department of Interior, Minerals Management Service (MMS), with offices in New Orleans, La., would not release the original owner of an oil platform from the liability in Texas. The Outer Continental Shelf Lands Act established jurisdiction over submerged lands on the outer continental shelf and the Minerals Management Service has authority over lease sites on the shelf. Consult the MMS if the project will be near or attached to an oil or gas platform or if ownership will be transferred. A permit for platform removal approval or transfer of ownership may be necessary. If the mariculture company proposing to do a project (real life example, Gulf Marine Institute of Technology -GMIT, Gulf Breeze, Fla.) failed, for example, MMS would still require the original owner (real life example, Mitchell Energies Platform, 12 miles off Galveston, Texas in federal waters) to pay for dismantling the rig. Even though GMIT offered to obtain an irrevocable bond to insure the platform's removal, MMS still would not release Mitchell; therefore the transfer failed. In April 2009, The MMS published final regulations to establish a program to grant leases, easements, and rights-of way for renewable energy project activities on the Outer Continental Shelf (OCS), as well as certain previously unauthorized activities that involve the alternate use of existing facilities located on the OCS; and to establish the methods for sharing revenues generated by this program with nearby coastal States. These regulations will also ensure the orderly, safe, and environmentally responsible development of renewable energy sources on the OCS. The MMS prepared a Final Environmental Assessment (EA) analyzing this rule. The EA incorporates by reference the *Programmatic Environmental Impact Statement for Alternative Energy Development and Production and Alternate Use of Facilities on the Outer Continental Shelf, Final Environmental Impact Statement, October 2007.* The EA was prepared to assess any impacts of this rule. The Final EA is available on the MMS Web site at:

http://www.mms.gov/offshore/AlternativeEnergy/RegulatoryInformation.htm

GMIT then moved into state waters, almost 10 miles off Port O'Connor, Texas and acquired a platform from Sea Gull Marine. GMIT was given approximately $1.8 million to take responsibility of the platform. GMIT obtained a $2.6 million irrevocable bond to insure the platform's removal for $139,000; upgraded two donated boats to service the platform; and spent considerable money on attorneys' fees and court fees.

When permitting failed in Texas waters, GMIT sued the Texas General Land Office (GLO) and the Texas State Attorney General's Office handled the case for the State of Texas. GMIT won the court case in Matagorda County, but the state appealed.

GMIT won in the appeal case in district court in Corpus Christi, but the state appealed again and the case went before the State Supreme Court. GMIT won that settlement, which caused the Matagorda District Court to rule in favor of GMIT on Aug. 4, 2005. GMIT had to sell its barge to pay some of the bills and won a suit for damages and fees against the state of Texas. The Court awarded GMIT over $270,000, but did not receive it and sued again in 2006.

During the state permitting effort GMIT obtained the following permits:

- Texas General Land Office (GLO), Surface Lease from Tenneco #860161 (9/98).
- US Corp of Engineers permit #11830 (9) issued 6/99.
- Approval received from Texas Coastal Coordination Council (Dewhurst-Calnan, 4/99).
- TNRCC (Now TCEQ) Discharge permit #04095 (10/2000).
- Texas Dept. of Agriculture, aquaculture permit #293420 (11/2000).

GMIT obtained a $2.6 million irrevocable bond for GLO on Block 526-L, Matagorda County, off Port O'Connor.

As relates to the GLO lease issue, the Thirteenth District Court of Texas, Corpus Christi ruled on July 12, 2001 in GMIT's favor concluding the following: "because of the actions of Mauro and Dewhurst during and after the execution of the assignment (surface lease from Tenneco to GMIT), the forfeiture provision was waived and the State is stopped from terminating the assignment/lease by virtue of the two wells having been plugged and abandoned." The court ruling went on to say, "Dewhurst erroneously believes that the Assignment is not a contract and that his negotiations with GMIT were to form an entirely new contract. The Assignment is the contract which GMIT and Mauro agreed to amend to make it more compatible with the proposed mariculture operations, but they just did not memorialize the amendment before Mauro left office." Finally, the court ruled, "As a consequence, now Dewhurst cannot insist on the forfeiture provision and GMIT is entitled to a declaratory judgment: (1) declaring that the forfeiture provision in the lease cannot be enforced by Dewhurst or the State for the reasons above set forth, and (2) declaring that a reasonable construction of the lease term is that it did not end at the time the two wells were plugged and abandoned by agreement but shall continue for 50 years beginning on August 27, 1986, or until GMIT ceases its mariculture operations thereon." This is strong and conclusive language that the GLO surface lease for the platform is valid to GMIT for mariculture purposes for another 31 years. The only thing left on this issue was to finalize the legal paperwork with the State. The lease issue appeared to be over, however, the State appealed again and the Supreme Court ruled in favor of GMIT. GMIT won the appeal to the Supreme Court that recently resulted in the Matagorda court judge granting GMIT clear title to the platforms and balance of the 50-year land lease now converted for mariculture purposes.

According to GMIT, new ACOE, EPA and TCEQ permits were issued for a new 5-year period at the platform site in 2005. GMIT built a prototype marine nursery system in Gulf Breeze, Florida and operated the system with cobia and tilapia before hurricane Ivan. Since the destruction of their greenhouse facility, they have disassembled the nursery and they are hoping to move it onto the main platform when new funding is obtained. In 2007, a $1 million grant was awarded GMIT (personal communication with Dr. Phillip Lee, Galveston), and they will be setting up hatchery operations at Moody Gardens, Galveston.

According to John Ericsson, Managing Director, Gulf Marine Institute of Technology, “The GMIT office was hit directly by 2 hurricanes—Ivan and Dennis, and GMIT was told that the platforms off Texas belonged to the state of Texas, that the EPA did not have jurisdiction over the platform site by the TCEQ—while the EPA still says the TCEQ has no authority over the site. The ACOE originally said we could not get a Section 10 permit. We have won all these important battles for the development of offshore mariculture permitting with and without platforms in Texas and Alabama. We have 5 Bridgestone sea cage systems, one AKVA automatic feeding system for 20 sea cages, a marine nursery system ready for deployment and the ambition to make this industry called "mariculture" a success despite spending over $5.0 million dollars and 16 years fussing with the state and federal bureaucracy run by people who know little about this offshore business.” It has also been determined that GMIT will be required to obtain both discharge permits (NPDES discharge permit from EPA and TPDES discharge permit from TCEQ).

On May 22, 2008 John Ericsson stated that “BioMarine submitted an Environmental Assessment for northern Gulf region sea farming to NMFS in 2007 and again recently. This work should be considered as a partially complete EIS for federal purposes. Dr. Ed Cake did the composition with cooperation and information from NMFS in St. Petersburg, Fla. In addition, we have already established the EPA guidelines for environmental monitoring of sea cage operations at two locations in the Gulf with cooperation with the Atlanta and Dallas division of the EPA. Dr. Phillip Lee and I addressed the TPWD Commissioners today and received a 100% vote of approval of all modifications to the Texas Offshore Aquaculture Regulations, which we requested. Mike Ray did a fantastic leadership job within TPWD!. We also met with the GLO staff on a new 30 year lease which is progressing much better with the help of Governor Perry's staff and Senator Hegar pushing in the background.”

In 2008, GMIT remained in litigation to determine whether or not their lease for offshore aquaculture was valid. The most recent decision in the case states that GMIT’s aquaculture lease terminated by its own terms on July 9, 1999 (*Patterson*

v. Gulf Marine Institute of Technology, Tex.App-Corpus Christi, 2008. Not reported in S.W.3d.). GMIT President, John Ericsson stated on May 11, 2009, “the last appeal to the Texas Supreme Court overruled the district court. Our site lease is dead by the ruling and we have delayed further efforts with the GLO to obtain a new state lease because of unreasonable demands by the GLO to reinstate our platform removal bond for $2.6 million without knowing if we would get a new lease."

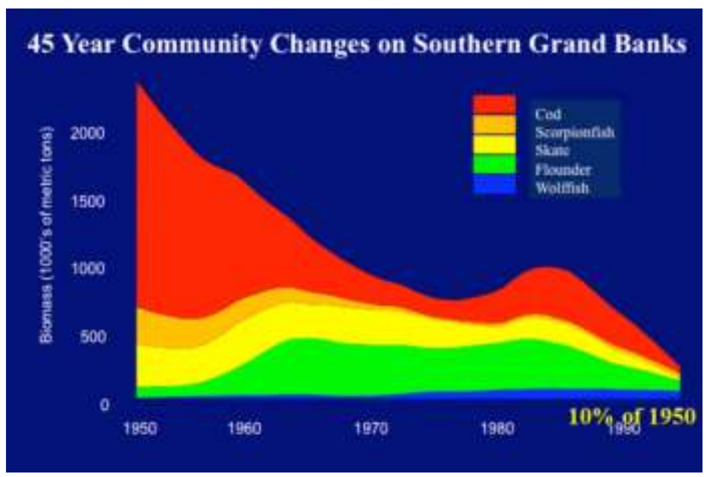
Other entities are discouraged when they see the permitting problems that GMIT has incurred offshore in both federal and state waters. This illustrates why there are still large obstacles to overcome before offshore aquaculture can grow in Texas.

Previously proposed hatchery on lower deck of GMIT platform off Texas

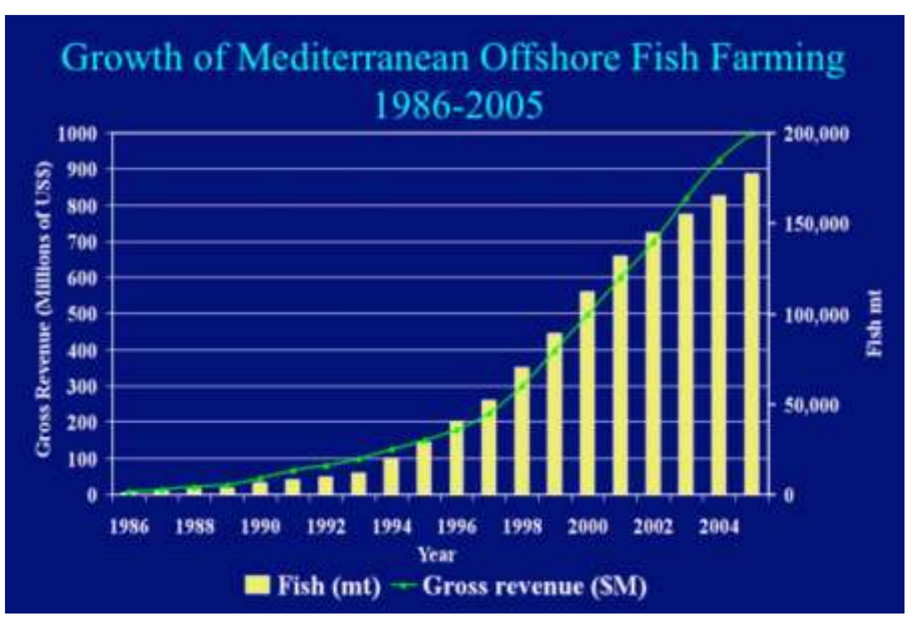
Today's regulation requires record-keeping in conjunction with implementation of a feed management system.

The USEPA is requiring flow-through, recirculating and net pen CAAP facilities subject to today's (2008) regulation to keep records on feed amounts and estimates of the numbers and weight of aquatic animals in order to calculate representative feed conversion ratios. The feed amounts should be measured at a frequency that enables the facility to estimate daily feed rates. The number and weight of animals contained in the rearing unit may be recorded less frequently as appropriate. Flow-through and recirculating facilities subject to today's requirements must record the dates and brief descriptions of rearing unit cleaning, inspections, maintenance and repair. Net pen facilities must keep the same types of feeding records as described above and record the dates and brief descriptions of net changes, inspections, maintenance and repairs to the net pens.

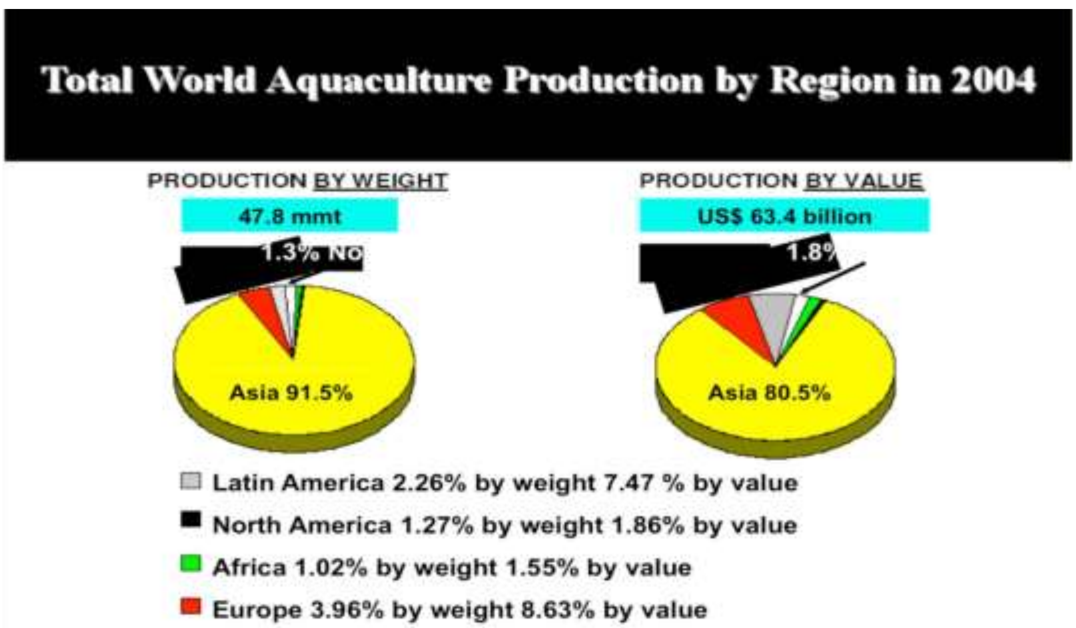
The offshore aquaculture bill of 2005 stalled in the US Congress and was still in a stalemate condition in 2008; however, at their meeting in Houston on June 5, 2008 the Gulf of Mexico Fisheries Management Council made the last series of modifications to the Offshore Aquaculture Amendment without significant objection and elevated the process from a Generic Amendment for all Fishery Management Plans to a full stand alone Fishery Management Plan. The Fisheries Management Plan will allow NOAA Fisheries SE Regional Administrator to permit aquaculture operations for any species of fish in the Gulf. Dr. Roy Crabtree, Director of the Southeast Regional Office of NMFS, stated at the meeting that the Environmental Impact Study will be completed and posted for a 60 day comment period. The latest version of the Public Hearing Draft of the Offshore Aquaculture Amendment can be downloaded from the Gulf of Mexico Fisheries Management Council's web site at http://www.gulfcouncil.org/.

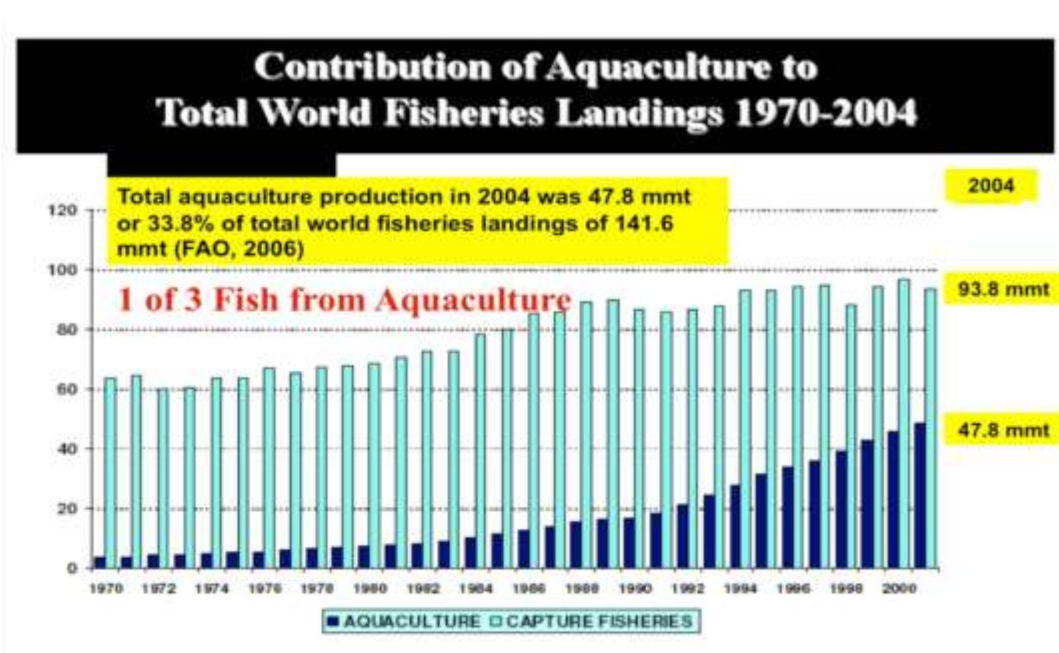


Various fisheries catches on Southern Grand Banks (USA) from 1950 to 1990 shows a dramatic decline (see above graph).

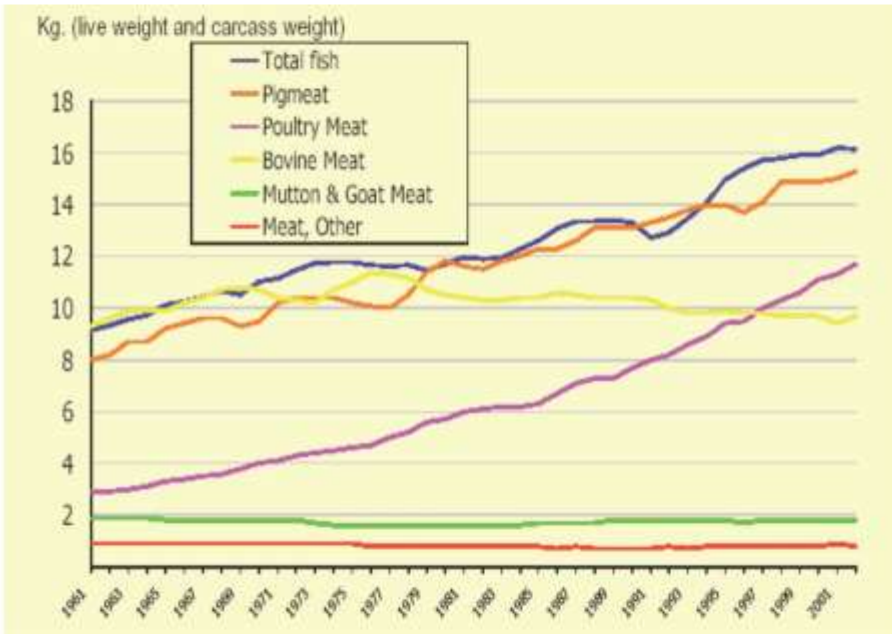


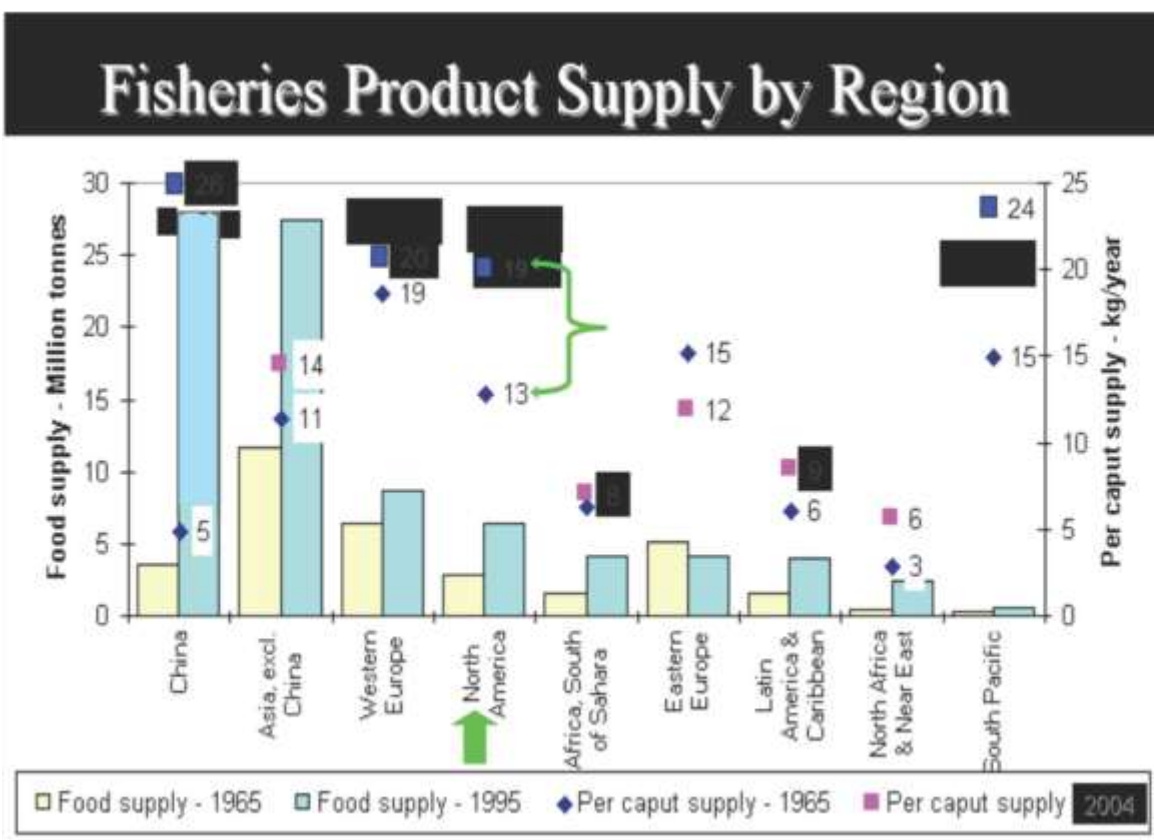
Texas has an opportunity to assist the US in trying to meet its growing seafood demand. Just look at some of the world aquaculture statistics and projections. Since the 1980s, aquaculture has steadily increased its contribution to world fisheries production and maintained its position as one of the fastest-growing food production activities in the world (World Aquaculture, New, Michael B., “Aquaculture and the Fisheries - balancing the scales.” The aquaculture industry could supply up to 35 MMT of fish food products by the year 2010 (World Aquaculture, New, Michael B., “Aquaculture and the Fisheries balancing the scales.”

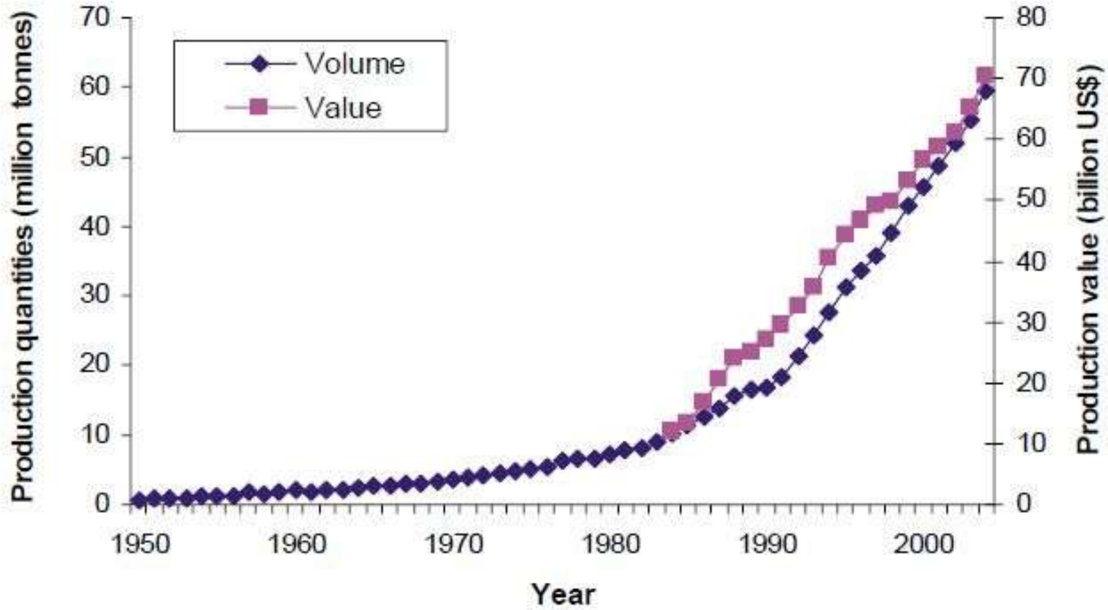




World Consumption of meat protein

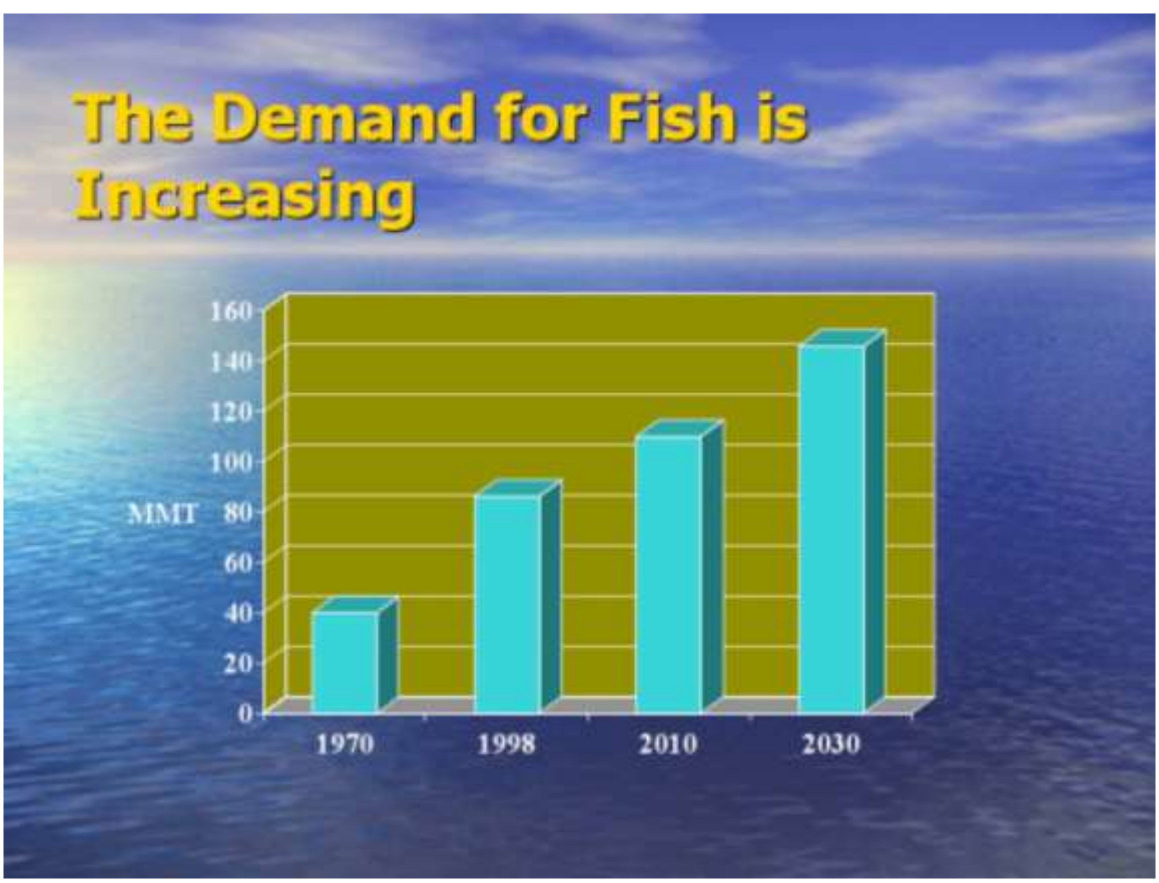




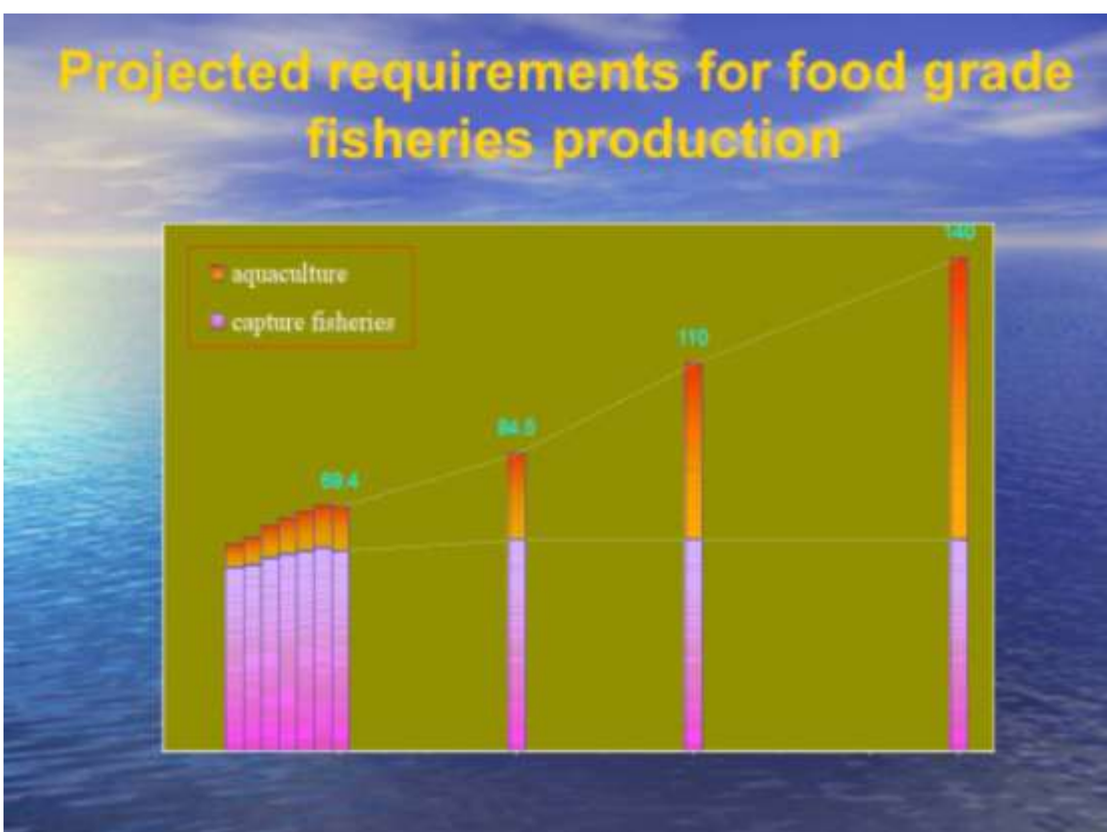


Growth of World Aquaculture (From Dr. Michael Masser, 2008) Demand

for Fish is Increasing (From Dr. Michael Masser, 2008)



Increase in demand for fish is due to human population growth (From Dr. Michael Masser, 2008). Project requirements (From Dr. Michael Masser, 2008)



Yellowtail larvae (above left)

Fresh Moi from Hawaii

Dr. Charles "Chuck" Helsley with moi raised in open ocean cage. Group sorting moi from OOA cage (Ocean Spar).

Konacampachi (raised by Kona Blue, Hawaii)

Sushi from Konakampachi (raised by Kona Blue, Hawaii)

Cod slide at Univ. of N.H. offshore pilot

Photos from Univ. of New Hampshire OOA project

Blue mussel lines from Univ. of N. H. OOA pilot

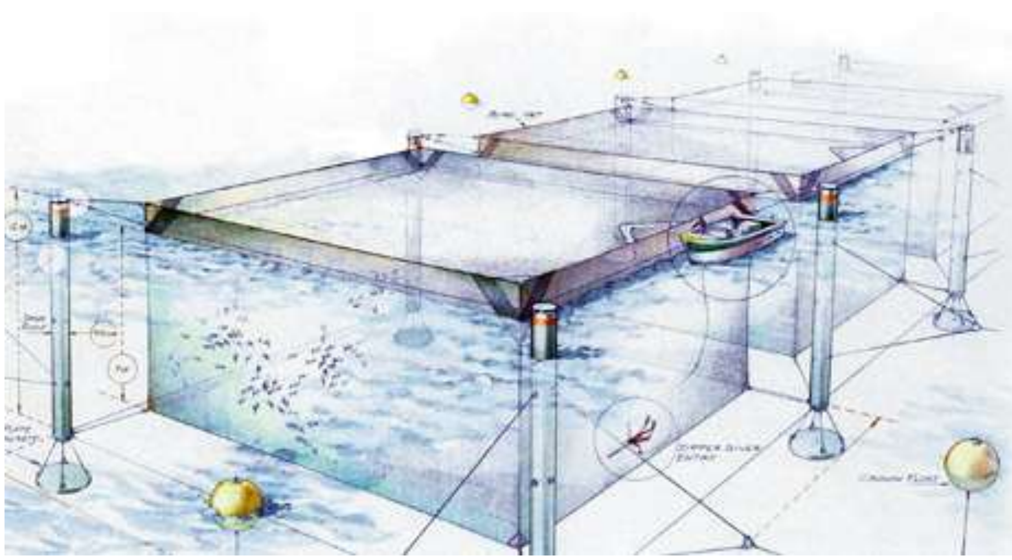
Other potential offshore species for culture

Mutton snapper

Greater Amberjack adult (above) and tuna (below)

Physical problems expected with cages in waters of Gulf of Mexico – Biofauling, as seen on this Sea Station cage and cage cleaner (http://www.oceanspar.com/index.htm.)

Ocean Spar cage, 18 miles of Texas coast.



Early rendering of AquaSpar fish pens (http://www.oceanspar.com/index.htm.)

Assembled SeaStation ready to deploy near Faro, Portugal (http://www.oceanspar.com/index.htm.)

Sea Station under tow for deployment (http://www.oceanspar.com/index.htm.)

Surfaced SeaStations (off Hawaii above). Kona Blue has 6 cages in place now. (http://www.oceanspar.com/index.htm.)

Submerged SeaStation near Kona, Hawaii
(http://www.oceanspar.com/index.htm.)

Submerged SeaStation near Kona, Hawaii
(http://www.oceanspar.com/index.htm.)

SeaStation near Culera, Puerto Rico
(http://www.oceanspar.com/index.htm.)

SeaStation bottom cone (http://www.oceanspar.com/index.htm.)

AquaSpar fish pen in New Brunswick, Canada (http://www.oceanspar.com/index.htm.)

AquaSpar fish pens in the Columbia river, USA (http://www.oceanspar.com/index.htm.)

In May 2008 The US Gov. Accountability Office published a report entitled "Offshore Marine. Multiple Administraative and Environmental Issues Need to Be Addressed in establishing a US Regulatory Framework". "Concluding remarks in that report were, "An effective federal regulatory framework for U.S. offshore aquaculture will be critical to facilitating the development of an economically sustainable industry, while at the same time protecting the health of marine ecosystems. As the Congress considers providing a cohesive legislative framework for regulating an offshore aquaculture industry, we believe it will need to consider a number of important issues. A key first step in developing a U.S. regulatory framework could be designating a lead federal agency that has the appropriate expertise and can effectively collaborate and coordinate with other federal agencies. In addition, setting up clear legislative and regulatory guidance on where offshore aquaculture facilities can be located and how they can be operated could help ensure that these facilities have the least amount of impact on the ocean environment. Moreover, a regulatory framework could also include a process for reviewing the potential environmental impacts of proposed offshore aquaculture facilities, monitoring the environmental impacts of these facilities once they are operational, and quickly identifying and mitigating environmental problems when they occur. Inclusion of an adaptive management approach by which the monitoring process can be modified over time could be useful not only to ensure that the most effective approaches are being used to protect the environment but also to help reduce costs to the industry. In addition, a transparent regulatory process that gives states and the public opportunities to comment on specific offshore aquaculture projects could help allay some of the concerns about the potential environmental impacts of offshore aquaculture. Finally, because the offshore aquaculture industry is in its infancy much remains unknown, and many technical challenges remain, such as the best species to raise offshore and the most effective offshore aquaculture practices. In this context, there may be a role for the federal government in funding the research needed to help answer these questions and facilitate the development of an ecologically-sound offshore aquaculture industry."

US Government regulatory movement for open ocean aquaculture has been slow and the offshore aquaculture bill in congress stalled and is not expected to pass with the present congress. In the mean time, new growth in this area of aquaculture will continue to go to other countries that are more receptive to offshore aquaculture.

NOTE****See Appendices A, B, and C at the end of this report for more background information on offshore aquaculture.

Appendix A. A literature review and information on the effects of offshore aquaculture.

Appendix B. TPWD offshore aquaculture rules and regulations for Texas (2008).

Appendix C. Gulf of Mexico Fisheries Management Council maps on areas in the Gulf of Mexico as defined as suitable for offshore aquaculture and areas in the Gulf of Mexico defined as not suitable for offshore aquaculture, and status of the offshore aquaculture fisheries management plan to be given to NOAA and Dept. of Commerce to implement.

Offshore Aquaculture Equipment for Sale in 2010

Atlantic Marine Aquaculture Center

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University of New Hampshire

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Aquaculture Research

The aquaculture industry in Texas is supported by a strong research programs, both Federal and State, with state-of-the-art facilities. The U.S.D.A.'s

U.S. Marine Shrimp Farming Program supported the shrimp farmers' efforts and responded to their research needs. For example if the industry needed assistance with problem solving, the USMSFP (web site: http://www.usmsfp.org/) emphasized that particular area in the next year's research. In the past, the program generally used industry's input to identify bottle necks and research needs and adjusted rapidly to those needs. It was an effective program in domesticating *Litopenaeus vannamei* and helping control diseases, but unfortunately the US Congress terminated the funded of the USDA program in 2011.

The U.S. Marine Shrimp Farming Program (USMFP) Past History of the Program, since the program was terminated in 2011

In its role as coordinator of the USMFP, the Oceanic Institute (OI) in Hawaii patterned its research and development of shrimp farming on modern food production industries (dairy, poultry, swine and salmon) that were wholly dependent on high-health and genetically improved seed stocks, sophisticated disease prevention and treatment programs, a high degree of environmental control and advanced culture systems. This program, which is credited with more than doubling farmed shrimp production in the United States since 1991, engaged leading U.S. scientists and research institutions in results-oriented projects dedicated to industry development. OI provided technologies, products, and consulting services that were essential for successful shrimp farming.

Part of the USMSFP funding came to Texas AgriLife Research (Formerly Texas Agricultural Experiment Station) in Texas. The AgriLife Research Laboratory in Port Aransas has in the past worked mainly on shrimp nutrition research and more recently has been working with sea urchins under different grant. The lab is also working on a patented raceway system for shrimp with funding from TAMU and a private company.

Texas A&M University System, Texas AgriLife Research, Shrimp Mariculture Research Laboratory. 1300 Port Street, Port Aransas, Texas. 77373. Dr. Addison Lawrence. Tel. (361)749-4625. Emphasis marine shrimp and urchin nutrition and more recently shrimp raceway technologies. Email: smpall@yahoo.com.

AgriLIFE RESEARCH
Texas A&M System

Facility description:

Over 900 tanks with 13 recirculating systems capable of conducting experiments for temperatures ranging from 15^{o}C to 35^{o}C and salinities from 0.1 ppt to 50 ppt and do salinity temperature interactions. Experiments are being conducted on marine shrimp and sea urchins. There are over 800 indoor experimental tanks and over 100 outdoor experimental tanks ranging in size from 0.1 m2 to 10.1 m2 bottom area.

Brood shrimp mating

TAMU Mariculture Lab (now known as Texas AgriLife Research Station, Port Aransas, Texas)

Outdoor tanks

Shrimp / Sea urchin nutrition lab

The Consortium for Biomedical, Environmental, and Economic Optimization of Coastal Resources (CBEEOCR)

Mission and Goals

The mission of the **CBEEOCR** is to provide the scientific basis for developing new technologies using coastal resources currently available in the U.S. The specific goals include:

- Enhance development of new biomedical tools that can be used to assess many pharmacological and toxicological effects on animal development, including models for human development. These tools, derived from marine resources, can be used instead of many traditional mammalian models, whose use is under increased scrutiny.
- Provide high-throughput biological sentinels for the evaluation of environmental contaminants and other biological hazards or threats, both real and unrealized. These models will evaluate sub-lethal effects on animal growth as well as long-term effects on their future offspring.
- Develop rapidly coastal industries related to on-shore culture of high-value seafood with high export potential.
- Transfer technologies and societal benefits to educational venues including primary and secondary schools, colleges and universities, and public science centers.

Contacts

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UAB
205/934-2045

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Co-Director
Texas A&M
361-749-4625

The first coastal organism selected to address these goals is the sea urchin. The sea urchin is an ideal organism for understanding how genes and proteins regulate growth and development with potentially profound implications for understanding human biology. In addition,

U.S. sea urchin fisheries have decreased by 70% (U.S. previously led the world in exports), but can be revitalized by newly-enhanced culture technologies.

Benefits

- Expansion of low cost, alternative models and assessment tools will greatly **reduce federal research expenditures** in many areas of public health.
- Technological development of these coastal resources, including land-based culture will greatly **reduce environmental impact** on already sensitive marine environments.
- Resource development and retraining of recently displaced fishing communities will **provide new economic stimulus** in many coastal regions.
- Implementation of culture technologies will develop the basis for **stock enhancement** and **management of coastal fisheries**.

Corpus Christi ship channel

Ship channel at Port Aransas Brown pelican

TAMU/Texas AgriLife Research, Bait Shrimp and Zero Water Exchange R&D Program, Flour Bluff. Also do algae-to-biofuels research. Facility Director: Dr. Tzachi Samocha. Josh Wilkenfeld assisting.

Algae-to-biofuels raceways.

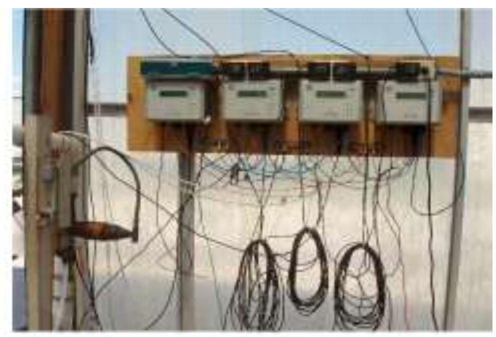
Bait shrimp ponds at TAR, Flour Bluff.

A zero water exchange, bait shrimp research station is operated by AgriLife Research in Flour Bluff, Texas. Both of the AgriLife labs (in Port Aransas and Flour Bluff) do a lot to assist the shrimp aquaculture industry in the state.

Shrimp greenhouse raceways at AgriLife Research, Flour Bluff.

Zero water exchange and feeding trials at AgriLife Research.


Greenhouse/raceway under construction at AgriLife Research in Flour Bluff (left). Raceway in operation on right.

Aerial of ponds at Flour Bluff built a number of years ago, but has changed since.


Bait shrimp

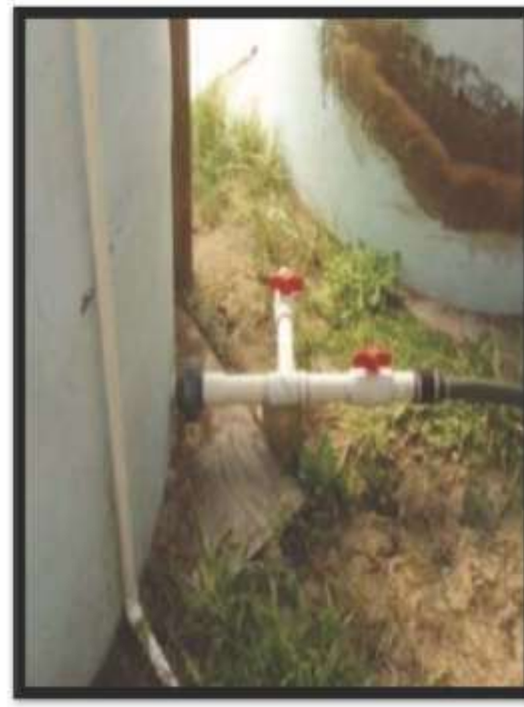
Texas Bait Shrimp Market Study

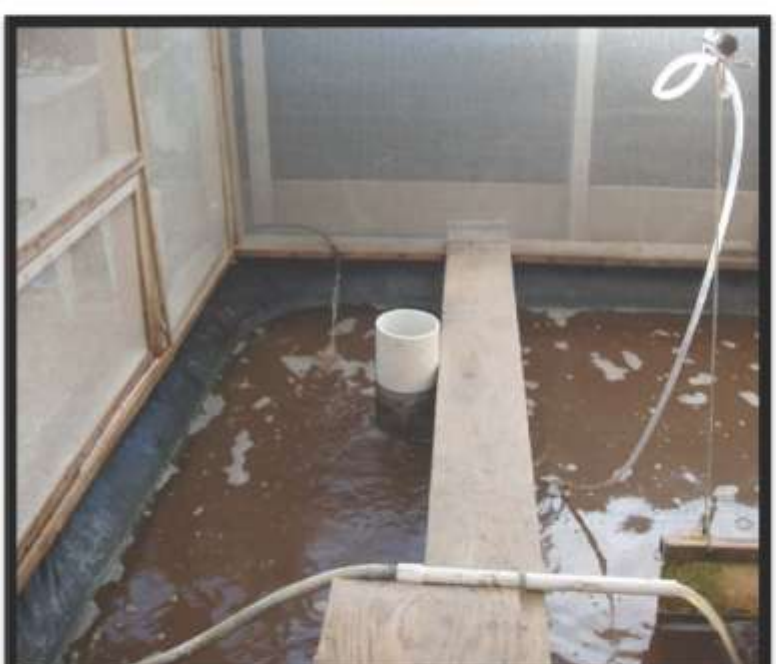
A Texas retail live bait shrimp market study was undertaken by Ryan Gandy or Lone Star, an Austin investment group, under the direction Dr. Tzachi Samocha, AgriLife Research. They conducted the survey to obtain market data and potential in Texas and to make an entrance strategy for supplying this retail market with a live bait shrimp product raised using aquaculture. The registered bait dealers selected for the study were based on their registration with Texas Parks and Wildlife, and Lone Star directly surveyed this market by using regional fishing maps which indicated established retailers which stocked live bait shrimp. A marine chart supplied by FISH-N-MAP Co. 2002 which listed all of the up to date major bait dealers in each bay system was used. The series of maps covered all primary, secondary and tertiary bay systems along the entire Texas coast from the Texas-Louisiana border to the Texas-Mexico border. The upper coast listed 49 retail bait dealers which handled live bait shrimp. Of these retail live bait dealers 37 were open year round and available for survey during this period. Of these 37 retailers 40.5% responded to the survey and provided data on the volume of sales and product characteristics desired. Retailers indicated on average shrimp count of 70 shrimp per pound was desirable. Presently they were purchasing these shrimp at a price of $4.18/ lbs not including labor and delivery costs from the boat to the retailer. Retailers indicated average weekly live bait shrimp sales during the Summer (April - October) of 1640 lbs/week/retailer. The winter (November - March) sales averaged 170 lbs per retailer per week. There was an average of 483 lbs of holding capacity per retailer. Of the retailers surveyed 80% maintained their stocks in a flow through holding tank system. In addition only 40% of retailers in this market owned their own boats. The mid-coast listed 23 retail bait dealers which handled live bait shrimp. Of these retail live bait dealers 15 were open year round and available for survey during this period. Of these 15 retailers 73.3% responded to the survey and provided data on the volume of sales and product characteristics desired. Retailers indicated on average shrimp count of 71 shrimp per pound was desirable. Retailers indicated average weekly live bait shrimp sales during the Summer (April - October) of 645 lbs/week/retailer. The winter (November March) sales averaged 159 lbs/week/retailer. There was an average of 382 lbs of holding capacity per retailer. Of the retailers surveyed 91% maintained their stocks in a flow through holding tank system. In addition only 45% of retailers in this market owned their own boats. The central-coast listed 17 retail bait dealers which handled live bait shrimp. Of these retail live bait dealers 11 were open year round and available for survey during this period. Of these 11 retailers 90.9% responded to the survey and provided data on the volume of sales and product characteristics desired. Retailers indicated on average shrimp count of 66 shrimp per pound was desirable. Retailers indicated average weekly live bait shrimp sales during the Summer (April - October) of 695 lbs/week/retailer. The winter (November - March) sales averaged 170 lbs/week/retailer. There was an average of 318 lbs of holding capacity per retailer. Of the retailers surveyed 80% maintained their stocks in a flow through holding tank system. In addition only 80% of retailers in this market owned their own boats. The Lower-coast listed 13 retail bait dealers which handled live bait shrimp. Of these retail live bait dealers 11 were open year round and available for survey during this period. Of these 11 retailers 90.9% responded to the survey and provided data on the volume of sales and product characteristics desired. Retailers indicated on average shrimp count of 67 shrimp per pound was desirable. Retailers indicated average weekly live bait shrimp sales during the Summer (April - October) of 273 lbs/week/retailer. The winter (November - March) sales averaged 83 pounds per week per retailer. There was an average of 68 lbs holding capacity per retailer. Of retailers surveyed 71% maintained their stocks in a flow through holding tank system. In addition only 40% of retailers in this market owned their own boats.

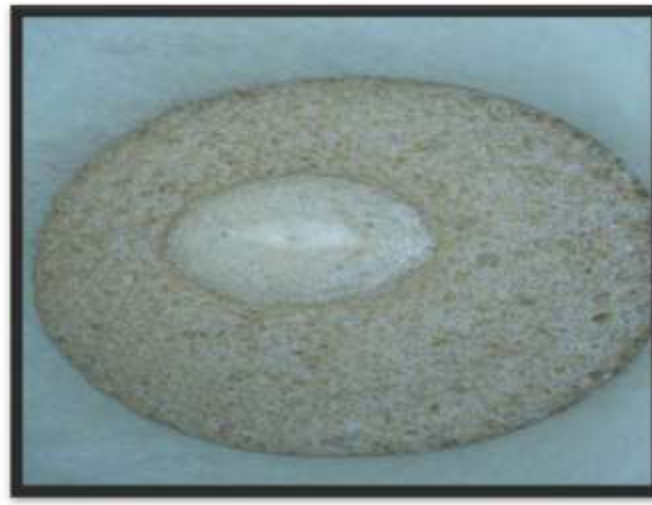
Texas Market Survey Discussion

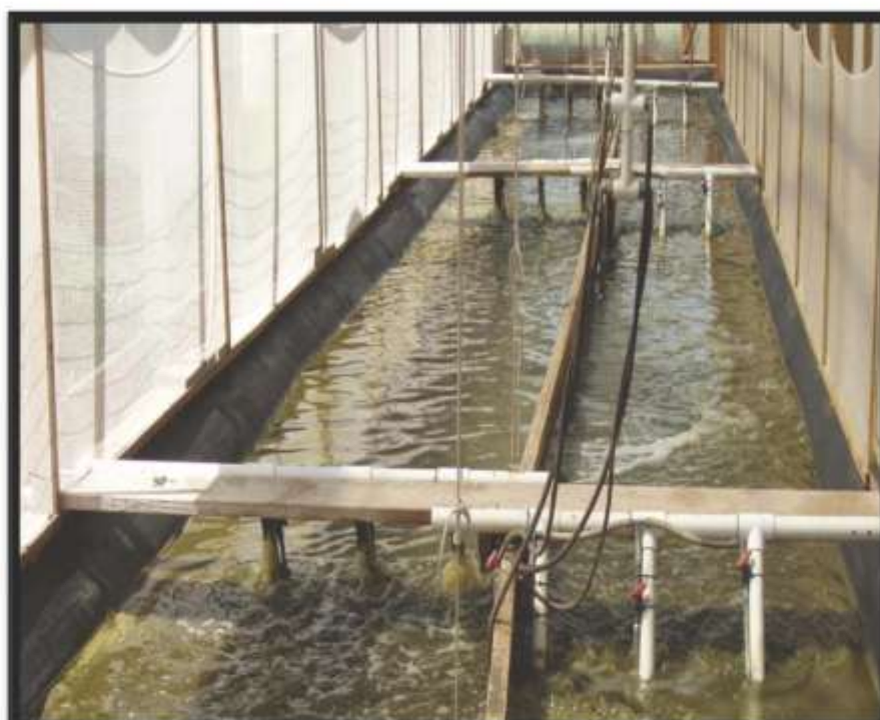
These survey data indicate that the winter period from November through March has no supply from the wild. During this period a farm raised product could enter the market un-contested by a wild product. A supply of 174,370 lbs of live bait shrimp could easily enter the market during this five month period and be sold. In addition all bait dealers indicated that they have never had enough wild caught shrimp during the winter months to fill the winter demand. Most retailers indicated that they could double their sales if more were available during the winter. This survey revealed that the summer demand from April through October the entire Texas market could absorb 1.36 million pounds of live bait shrimp if there were no wild catch available. Given the short term goals of regulatory agencies to remove wild shrimp trawlers from the bays this volume is attainable as the restrictions increase and the buy-back program continues. In the interim the wild supply is only available for two months in spring (April and May) and two months in Fall (September and October). In summer from June through August there is virtually no wild supply. During this three month period a farm raised bait shrimp could supply up to 500,000 lbs of live bait shrimp. In order to accurately target these periods the data generated on the four regions of the coast can be used to develop supply strategies that would allow a farm raised product to flow to market year-round. In the face of state restrictions on wild shrimp harvesters the market has the potential to broaden for a farm raised product as the wild supply dwindles. As a whole the Texas live bait shrimp retailers indicated their desire for a 65-70 count shrimp. These findings fit well within the cost effective production economics of potential Texas aquaculture producers which indicate a 70 count shrimp can be cultured from a PL_{10} in 90 to 150 days depending on density and culture technique. In addition these survey data indicate a need for developing better holding systems of bait retailers. This has the potential to generate increased revenues for the farm. Since, an average of 78% of the Texas retailers indicate they only use flow through systems and they experience large mortality due to the heat of summer, and aquaculture producers could also work to develop systems for installation to increase survival, develop strong relations with retailers and gain a foothold in this market. Bait shrimp are now selling for about $12/quart in Texas in 2008 and there never enough live bait according to recreational fishermen in Texas. This is therefore an prime area for an aquaculture producer to supply a strong niche market with an aquacultured product. Of course the bait shrimp would have to be native species.

Recent photos of the Texas AgriLife Research Station in Flour Bluff from Dr. Tzachi Samocha and Josh Wilkenfeld.











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FAO

University of Texas Marine Science Institute, Fisheries and Mariculture Laboratory. Web site: http://www.utmsi.utexas.edu/staff/gjholt/faml/index.asp.

1300 Port Street, Port Aransas, Texas 77373,
Dr. Joan Holt and Jeff Kaiser.
Tel. (361) 749-6749.
Email: joan@utmsi.utexas.edu.
jkaiser@utmsi.utexas.edu.

Laboratory emphasis on Aquaculture, Fisheries & Ecology, Physiology & Neuroendocrinology, and Ornamentals (marine finfish research, red drum, red snapper, cobia, flounder, marine ornamentals and more).

Where is FAML?

A mile west of the University of Texas Marine Science Institute's main building complex, the Fisheries and Mariculture Laboratory (FAML) occupies 30,000 sq. ft. of building on 10 acres adjacent to the ship channel. This facility includes seven large laboratories which provide for temperature and photoperiod control. The FAML complex provides facilities for research on spawning and rearing of marine finfish and crustaceans and affords unique opportunities for teaching and research using captive animals.

G. Joan Holt, Associate Director - Fisheries & Mariculture
Larval Fish Ecology/Marine Aquaculture
Studies of the early stages of marine fish; seagrass nursery habitat, life history of pelagic fishes, culture and conservation of coral reef fish

Izhar A. Khan, Research Scientist
Mariculture/Neuroendocrinology
Neuroendocrine control of puberty, sexual maturation, and spawning; induced breeding of captive broodstock fishes; toxicity of environmental chemicals.

Scott A. Holt, Research Associate
Larval Fish Ecology
Habitat utilization by larval and juvenile fishes; transport and settlement processes in fish larvae; sound production during courtship and spawning in adult sciaenids, movements and migration of tunas and billfish

Cynthia Faulk, Research Scientist Assoc.
Larval Fish Studies

Jeff Kaiser, Research Scientist Assoc.
Brood Stock Management

Cameron Pratt, Res. Sci. Asst.
Field Studies of Marine Fish

The University of Texas at Austin
Marine Science Institute
Fisheries and Mariculture Lab
750 Channel View Drive
Port Aransas, Texas 78373-5015
Phone: 361-749-6795, Fax: 361-749-6749
www.utmsi.utexas.edu

Fisheries and Mariculture Laboratory

Broodstock Development

Larval fish rearing and nutrition

Ecological Investigations

Marine Science Institute
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AQUACULTURE


ORNAMENTALS


PHYSIOLOGY &
NEUROENDOCRINOLOGY


FISHERIES &
ECOLOGY

Coastal Conservation Association of Texas Laboratory for Marine Larviculture (located at FAML, Port Aransas)

Juvenile cobia grow rapidly and are prime mariculture candidates.

Cobia larvae can ulitmately grow into a 100 lbs. adult.

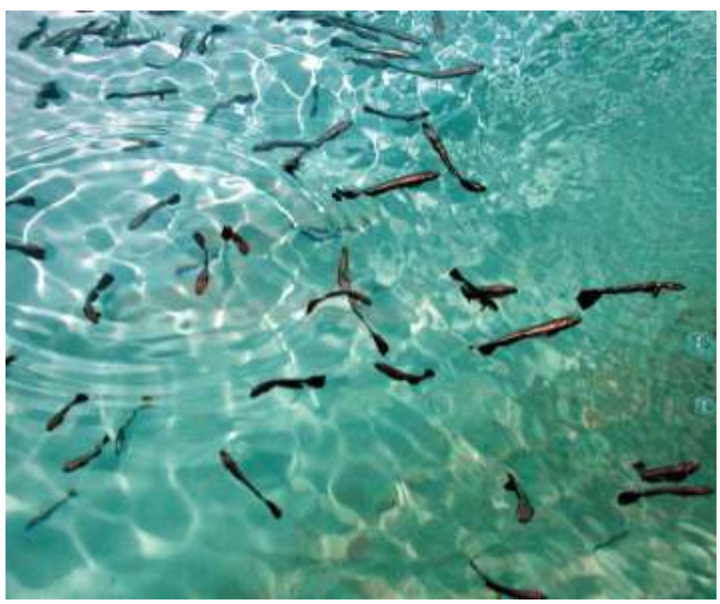
Research animals are closely monitored and kept in environments of only the highest quality

Fisheries and Mariculture Lab (FAML), Port Aransas (winter photo from Jeff Kaiser).

Research tanks at FAML are monitored several times a day, every day, without exceptions.

Indoor fish tanks at FAML.

Circular fish tank with biological filter. UTMSI, FAML (photos from Jeff Kaiser).



Cobia juveniles two weeks old. (photo from Dr. Joan Holt, FAML).

Marine tropicals and ornamentals

Example species the FAML has worked with include:

Lined seahorse *(Hippocampus erectus)* Dwarf seahorse *(Hippocampus zosterae)* Lemonpeel angelfish (*Centropyge flavissimus*) Peppermint shrimp (*Lysmata wurdemanni*) Jacknife (*Equetus lanceolatus*) Comet (*Calloplesiops altivelis*) Fire shrimp (*Lysmata debelius*) Cubbyu (*Equetus umbrosus*)

Jacknife is just one of several reef species that FAML has successfully reared in captivity.

Seahorse populations have suffered particularly severe declines in the last decade.

Some mariculture research is also conducted by researchers at the University of Texas Marine Science Institute, Port Aransas Marine Laboratory (UTMSI-PAML) at 750 Channelview Drive in Port Aransas.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CCA/CPL Marine Development Center Texas Parks and Wildlife Dept. 4300 Waldron Road, Corpus Christi, Texas 78418. Contacts: Dr. Robert Vega (Director). Robert Adami, Paul Silva. Tel. (361) 939-9238. Email addresses:
Robert.Vega@tpwd.state.tx.us.
Robert.Adami@tpwd.state.tx.us.
Paul.Silva@tpwd.state.tx.us.

TEXAS PARKS & WILDLIFE

Laboratory emphasis on stock enhancement of red drum and other marine species.

Statement of Intent

The CCA/CPL Marine Development Center (MDC) is located in Nueces County in the southwest sector of Corpus Christi near the west bank of the upper Laguna Madre. The facility is located on a 69-acre plot leased from American Electric Power Company (AEP) at the Barney Davis Power Plant Station. The site has the following purposes and objectives:

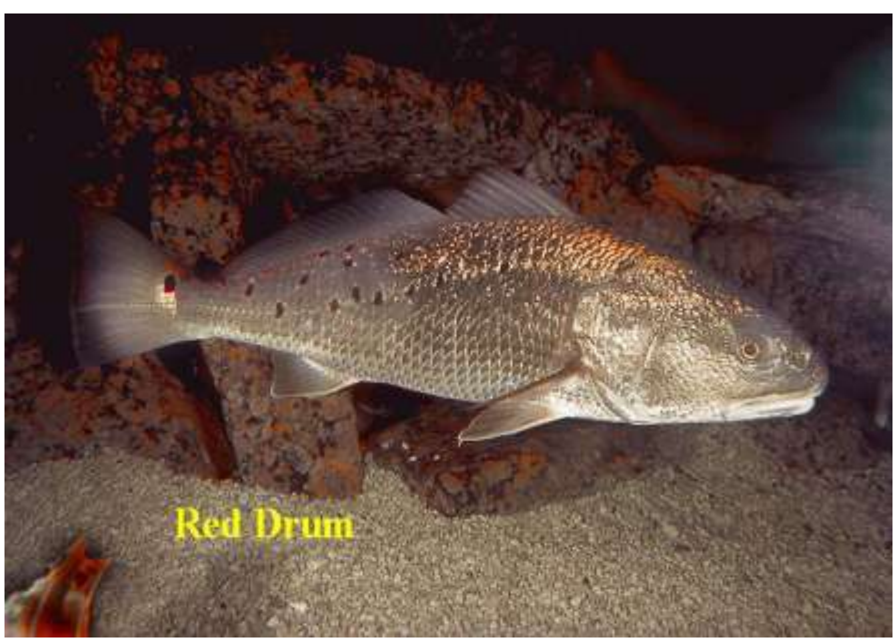
Purpose

- To increase recruitment of red drum and spotted seatrout to the sport fishery by releasing hatchery-produced fish into the wild.
- To provide hatchery-produced red drum and spotted seatrout for stock enhancement of Texas coastal waters from San Antonio Bay to the Lower Laguna Madre.
- To provide larval red drum for stocking rearing ponds at the Perry R. Bass Marine Fisheries Research Station (PRB) in Palacios, Texas.
- To conduct scientific research to strengthen the scientific basis for evaluating the fish stocking program's success.
- To provide education, interpretation, and recreation promoting awareness of resource conservation.

Objectives

- Effectively operate the hatchery to achieve annual fish production goals
- Plan and implement long-term maintenance and upkeep of the facility
- Provide a high quality hatchery-produced fish for release into the wild.
- Coordinate and conduct education related activities to promote natural resource and conservation awareness.
- Conduct scientific research to assess the performance of hatchery fish released into the wild
- Collaborate with fisheries managers to strengthen the viability of stock enhancement as a fisheries management tool

CCA/CPL Marine Development Center. Photo R. Adami



Red Drum (*Sciaenops ocellatus*). Photo –Robert Adami

Southern Flounder (*Paralichthys lethostigma*).

Texas Parks & Wildlife Fish Hatcheries for Marine Environment

Red drum and spotted seatrout are the most sought-after “recreational” fish species in bays and estuaries of the Texas Gulf, contributing approximately $250 million in annual revenue to coastal communities of the state. The agency implemented in the 1980s a stock enhancement program as a measure of conservation for “wild” fishery in Texas waters through annual release of millions of hatchery-produced red drum fingerlings. Texas' red drum stock enhancement program is one of the most visible marine stock enhancement programs in the country. To the recreational fishing community, the program has been economically and socially important because populations of red drum have increased in recent years. A combination of conventional fisheries management practices in conjunction with stock enhancement efforts have served as powerful tools for Texas resource managers to maintain sustainable fisheries. In Texas, stock enhancement has been an excellent tool for replenishing stocks suffering from over-fishing as well as from loss of critical nursery habitat. It has the potential to provide a source of new recruits in situations where a population is habitat limited, by growing juveniles large enough to bypass critical nursery-habitat bottlenecks that would otherwise prevent or severely constrain growth and survival.

Fish hatcheries are an important part of the agency's coastal fisheries management plan. The population of Texas is expected to double by the year 2030. Coastal waters will receive significant pressures from the expanded population and fisheries within coastal waters will be subjected to increased fishing pressure. A viable hatchery system can provide essential supplementation to moderate fish population fluctuations from year-to-year as affected by fisheries resource challenges in the future.

In addition, TPWD hatcheries serve a multifaceted role within the agency. Tens-of -thousands of visitors (e.g. general public, and students of all ages) come every year and are provided educational hatchery tours. Several thousand children participate in hatchery-sponsored fishing events. More than one hundred volunteers donate their time to the hatcheries. Hatchery personnel and volunteers are actively involved in conducting public outreach programs to teach the public about marine fisheries conservation issues.

Vision

Recent technological advances have greatly increased stock enhancement's potential. Advances in aquaculture technologies enable large numbers of high-quality, disease-free juveniles to be produced in hatcheries. An increased understanding of the ecological requirements of the receiving waters has improved hatchery-produced fish survival in the wild. Innovative methods used to measure growth and survival and monitor contribution to the fishery are promising. The rationale is to utilize this potential to provide the number, size and quality of fish required for meeting management needs via three (3) state-of-the-art fish hatcheries. Another goal is to ensure facility integrity through preventive maintenance, repair, renovation or replacement as required. In addition, elements of fingerling production, research, and outreach are to be combined for consideration that will greatly increase the magnitude of the hatchery program.

Current Status

TPWD operates three saltwater fish hatcheries and one regional office strategically located along the coast. There are 96 acres of production ponds, 57 captive broodfish tanks, 24 incubation tanks, and a number miscellaneous tanks available for culture activities. Stock enhancement is not a new strategy for replenishing depleted fish stocks, however, the approach that TPWD has taken to build the hatchery program most certainly is. The marine hatchery program began in 1982 as a cooperative effort between state and nongovernmental partners to construct the CCA/CPL Marine Development Center in Corpus Christi. One partner (Central Power & Light Company) donated 55-acres of land, and another (Coastal Conservation Association) provided funds to build the hatchery. TPWD obtained matching funds from the federal government to construct the facility, and provided staff and an annual operate budget. This same approach was used to develop and build the newest marine hatchery, Sea Center Texas in 1996. Dow Chemical Company provided 75-acres of land; Coastal Conservation Association and federal matching funds provided funds for facility design and construction. The coastal fish hatcheries annual program operating budget is $656,533 with a staff of 36 full-time state workers and 96 acres of ponds.

Annual production capacity at full operation – all 3 hatcheries:

Red drum = 34,000,000 fingerlings

Spotted Seatrout = 5,000,000 fingerlings

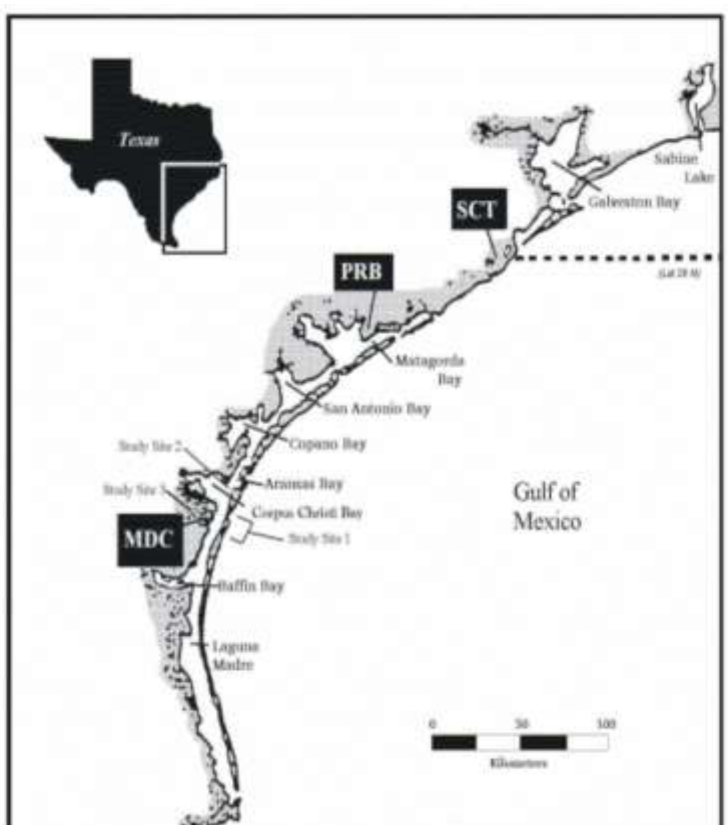
Number of red drum and spotted Seatrout produced to date:

Red drum = 542,909,630 fingerlings

Spotted Seatrout = 46,676,297 fingerlings

Information from David Abrego, Texas Parks and Wildlife Department Coastal Fisheries Division, Stock Enhancement Program, Sea Center Texas Facility Director

Fish Sources and Destinations of fish from TPWD stock enhancement hatcheries:



Improved technologies have provided significantly higher numbers of viable fry for rearing. Fish production quotas have been regularly achieved every year since 1997 when all three fish hatcheries were first collectively used for production. There is ample available rearing pond space to meet production demand. The primary limiting factor has been brood fish tank space.

The marine fish hatcheries have made a significant contribution to marine conservation recovery of ecologically and economically important recreational fisheries in Texas.

Cultural History

TPWD and the GCCA (new designation, CCA) developed a partnership in the 1970's to develop and build Texas' first red drum hatchery and production facility. The marine hatchery program began in 1983 as a cooperative effort between State and non-governmental partners to construct the CCA/CPL Marine Development Center. Central Power & Light Company (new designation, AEP) donated for use some 69-acres of land, and the Coastal Conservation Association provided funds to build the hatchery. TPWD obtained matching funds from the U.S. Fish & Wildlife Service Sport Fish Restoration Program for construction, staffing, and an annual operating budget for the facility. Initially, the hatchery consisted of the John Wilson building, a maintenance building, and ten two-acre ponds. Expansions led to the donation of an additional 39 acres, additional buildings including a visitor center, and additional ponds. No known archaeological sites are located on the property.

Facilities Program

The following are facilities at MDC:

• Land – 69 acres leased in 1981 for 99 years from CPL.

• Ben F. Vaughan Research and Development Center – visitor center, hatchery program leaders office, staff services office, 3 restrooms, 8 brood rooms containing 17 brood tanks, 2 aquarium rooms containing 8 saltwater aquariums, life support room, wet lab, storage room, 3 laboratories, 1 library (13,000 SF)

• Mechanical building – HVAC chiller unit, HVLP blower/generator room (864 SF)

• John Wilson – crew room, 3 offices, incubator room containing 8 incubator tanks, 2 restrooms, 2 storage areas (2,400 SF)

• Fish America – building housing 10,000 gallon fish tank, and 6 incubator tanks (1,200 SF)

• Garage and Shop – freezer, feed preparation room, maintenance area, tool room, generator room, restroom (1,800 SF)

• Perry R. Bass Spawning Building – 10 brood tanks (3621 SF)

• Storage Building (336 SF)

- Seawater pumping stations (2)
- 12 miles of hatchery roads and parking lot

Operational Program

FISH HATCHERY

Captive brood fish are subjected to a temperature and photoperiod maturation cycle (150 days). Once the fish begin to spawn, eggs are collected and incubated. Eggs hatch after 24 hours, and embryos develop into fish larvae after another two days. Feeding-stage larvae are transported to outdoor rearing ponds where they remain until they reach a body-length size of 30 mm. Fish larvae are also provided for stocking ponds at the PRB. A significant number of the fish cultured each year for Coastal Fisheries' stock enhancement program are reared at the MDC to include thirty percent (12 million) of the red drum and almost fifty percent (2 million) of the juvenile spotted sea trout. The MDC provides hatchery-produced fish used for stock enhancement of the lower Texas coast.

REVENUE/STAFFING

The site's FY 2002 operating budget and expenditures totaled $165,279. No revenue was collected, and visitation totaled 8,259 (2,799 adults and 5,460 youth). MDC was staffed by twelve full-time employees, and one position remained vacant most of the year. In addition, the hatchery program leader, staff service officer, and shrimp farm inspector occupy offices at the facility.

PRIORITIZED ACTION ITEMS

General Management Goals & Objectives

- Operate facility to meet annual fish stocking quotas as determined by Coastal Fisheries managers.
- Maintain, repair, and/or renovate facility to sustain long-term efficient of hatchery operations.
- Efficiently transport and distribute hatchery-produced fish to suitable habitats along the coast of Texas as directed by Coastal Fisheries managers.

- Educate the public about fishing, conservation of natural resources, habitat protection, and TPWD'S role in managing the fishery.
- Conduct research to strengthen the scientific basis for evaluating the program's success and prepare for the future needs of the fishery.
- Improve and update the visitor's center displays and aquarium.

• Continue cooperative efforts with groups interested in fish hatchery operations.

• Maintain the cooperative efforts of conservation groups and special interest groups.

Map showing location of CCA/CPL MDC lab in Flour Bluff.

Aerial photo of CCA/CPL MDC.

Marine Development Center Stats: (per David Abrego, TPWD, 2008) 39 acres in ponds. Staff of 16.

Sea Center Texas, Lake Jackson

Sea Center Stats:

36 acres, staff 17. High- tech fish hatchery. +120 million fish cultured to date. Visitor's Center features aquariums and dry exhibits that represent fishes and habitats that are indigenous to the Gulf of Mexico and Texas coast. 5-acre outdoor wetlands exhibit.

Red drum fingerlings for stock enhancement

Cobia (photo from Jeff Kaiser)

AgriLIFE RESEARCH
Texas A&M System

Texas A&M University, Dept. of Wildlife and Fisheries Sciences, Aquaculture Research and Training Center is located 9 miles west of the TAMU campus in College Station, near the Brazos River. It is supported by TAES and research grants from various sources. It has helped train many fine aquaculturists whom are practicing the trade today, and this research lab has done a lot in the area of fish nutrition research and over-wintering of red drum in shallow ponds and more recently work on pre-biotics looks very promising for the industry. Facilities Director is Dr. Delbert Gatlin, TAMU, Wildlife and Fisheries Sciences.

Tilapia. Photo from Del Gatlin

TAMU Aquaculture Research and Training Center outside College Station.
(Photos from Dr. Delbert Gatlin)

Hybrid striped bass (photo from Dr. Delbert Gatlin)

Texas A&M Corpus Christi has a mariculture department and offers advanced degrees. The Dept. head is Dr. David McKee and Dr. Joe Fox is also a professor in the department, as well the Harte Research Institute.

A. E. Wood State Fish Hatchery

507 Staples Rd., San Marcos, TX 78666 512-353-0572 Focus: Bass and catfish

Director: Robert Schmid

Web site:
http://www.tpwd.state.tx.us/fishboat/fish/management/hatcheries/aewood.phtml .

The facility is equipped with a fish health lab. Loraine Fries is the contact person for the lab http://www.tpwd.state.tx.us/fishboat/fish/management/hatcheries/fw_fish_lab/.

Description:

The A. E. Wood Fish Hatchery was originally built in 1949. It was named for A. E. Wood who served on the Texas Game & Oyster Commission, a forerunner of the Texas Parks & Wildlife Department. The hatchery was a mainstay of warm water fish production for Texas until 1984, when it was closed for renovation. After four years and $14 million, primarily from Federal Aid in Sportfish Restoration, Texas Parks & Wildlife Department reopened one of the most modern fish hatcheries in the United States.

The main hatchery building is named in honor of Robert J. Kemp, who served as director of TPWD's Fisheries Division for over 20 years. The 33,000square-foot building houses intensive culture operations. It includes a modern incubation room, shipping and holding troughs, and production raceways. The building also houses a complete laboratory capable of water quality testing, genetic identification, fish disease diagnosis and treatment, and law enforcement forensic techniques.

The outside portion of the facility consists of 50 plastic lined ponds that provide nearly 47 surface acres of water. There is also a 9.5-acre storage reservoir, two wastewater retention ponds and a zooplankton production pond. Water for the facility is obtained from the spring-fed San Marcos River.

The hatchery is responsible for raising millions of fish each year for stocking into the public waters of Texas. The staff is also active in performing research in many areas of aquaculture.

Aerial photo A.E. Wood, San Marcos, Texas. Photo from Jake Isaac.
(New Director in 2008, Robert Schmid)

TEXAS PARKS & WILDLIFE

TPWD, Perry R Bass Marine Finfish R&D Facility on Matagorda Bay

22 acres, staff of 3. (per David Abrego, TPWD, 2008)

Aerial of Perry R Bass Marine Finfish R&D Facility

National Fish Hatchery and Technology Center 500 E. McCarty Ln., San Marcos, TX 78666 512-353-0011, Fax: 512-353-0856.

Focus: Cultural techniques for endangered species

Contacts: Tom Brandt Joe N. Fries National Fish Hatchery and Technology Center 500 East McCarty Lane San Marcos, TX 78666 512-353-0011 ext 227 FAX 512-353-0856 E-mail: Joe_Fries@fws.gov.

Description:

The San Marcos National Fish Hatchery was the first warm water hatchery west of the Mississippi River. The hatchery, located near the headwaters of the San Marcos River, was opened around 1900. During the 1960's, the U.S. Fish and Wildlife Service (USFWS) donated the aging hatchery to Southwest Texas State University (SWTSU), San Marcos, which, in turn, donated 116 acres south of the city of San Marcos to the Service for the development of a new National Fish Hatchery and Cultural Development Center (Congressional Appropriations Act 83 Stat. 147, 29 October 1969). The Center, located at the intersection of Interstate Highway 35 and McCarty Lane, was dedicated in 1976 and the name was changed in 1983 to the San Marcos National Fish Hatchery and Technology Center.

Currently, the primary mission of the Center is to provide support for, and undertake research on, endangered, threatened, and species at risk. The Center houses Texas wildrice *Zizania texana*, Texas blind salamanders *Eurycea rathbuni*, San Marcos salamanders *Eurycea nana*, fountain darters *Etheostoma fonticola*, Devils River minnows *Dionda diablo*, Comal Springs riffle beetles *Heterelmis comalensis*, Peck=s cave amphipods *Stygobromus pecki, and* Comal Springs dryopid beetles *Stygoparnus comalensis*. Culture-related activities for these species are inherent to this mission. Major consideration is placed on assessment of biological issues related to the Edwards Aquifer and San Marcos and Comal springs.

Aerial photo National Fish Hatchery and Technology Center, San Marcos, Texas.

Heart of the Hills Fishery Science Center

Texas Parks and Wildlife Department 5103 Junction Hwy., Ing -3356
Web site: http://www.tpwd.state.tx.us/fishboat/fish/manageme

Bob Betsill, Director Second contact: Annette M. Sudyka Texas Parks & Wildlife HOH Fisheries Science Center 5103 Junction Hwy. Ingram, TX 78025 830/866-3356 ext 200 FAX 830/866-3549
E-mail: Annette Sudyka Annette.Sudyka@tpwd.state.tx.us

Focus: Freshwater fisheries research

Heart of the Hills hatchery, Ingram/Mountain Home, Texas

Description:

Heart of the Hills Fisheries Science Center (HOH) is located near Ingram. HOH is home to the Research Section of TPWD's Inland Fisheries Division. Their research improves fisheries management and explores what is not yet known about fish, their environment, and current and potential anglers. In addition to conducting independent applied fisheries research, they provide guidance and support for projects conducted by their fisheries managers and their hatcheries staff. The Fisheries Science Center is located on Highway 27 in Kerr County, Texas, approximately two miles south of the town of Mountain Home. The facility receives water from Stockman's Springs (also called Ellebracht Springs). Water temperatures range from 60º to 75ºF year-round, which allows investigations of both cold-water and warm-water fishes. The property covers 55.8 acres and includes 25 research ponds, laboratories, offices, and storage buildings.

Heart of the Hills hatchery, Ingram/Mountain Home, Texas

Texas Veterinary Medical Diagnostic Laboratory

TVMDL, College Station, Texas (Part of the TAMU System)

In the past this laboratory has provided support for the Texas Aquaculture Industry due to a special grant from the State Legislature to the TVMDL budget; however, the new TVMDL director decided to close the aquatics lab as of June 10, 2009. Apparently this was done without consulting anyone within the aquaculture industry and the TAA President wrote letters to stop the closing, but to no avail. As of 2010 the TVMDL laid off the 4 personnel that worked in this section and is sending all aquatic cases to other labs in other states. Therefore, there is no longer any aquatic animal diseases lab in Texas.

Texas Aquaculture Regulations

A detailed 138-page publication entitled “Updated Governmental Permitting and Regulatory Requirements Affecting Texas Coastal Aquaculture Operations” can be found for free download at the Texas Aquaculture Assoc. web site : http://www.texasaquaculture.org/Texas%20permitting.pdf.

The Texas Department of Agriculture (TDA) has the authority to regulate aquaculture facilities through licensing, fees, and marketing assistance such at their “Go Texan Program”. The TDA General Application for Aquaculture can be found on the TDA web site. The TDA Commissioner is Todd Staples.

Texas Parks and Wildlife Department (TPWD) has regulatory control over exotic species. **The Texas Commission on Environmental Quality (TCEQ)** adopted NPDES permitting rules for aquaculture discharges in 1997 and updated them when the US Environmental Protection Agency (EPA) adopted new rules for aquaculture in 2004 (calling them TPDES in Texas). Within the Texas coastal zones, all shrimp production facilities must be authorized by individual, state issued, TPDES permits. The TCEQ now regulates aquaculture farms under a “General Rule”. The TDA, TCEQ and the TPWD were instructed by the State Legislature to develop an MOU in 1997, for the coordination of the agencies on aquaculture regulatory matters. The TPWD assesses the suitability of a site for discharge and provides recommendations to the TCEQ during the permitting process. For facilities requiring permits, chemotherapeutic drugs should be limited to those either currently approved or authorized within an FDA Investigational New Animal Drug (INAD) Study. Rules adopted in response to the potential for native shrimp stocks to be affected by potential diseases in Pacific White Shrimp allows TPWD biologists to quarantine diseased shrimp, and require operators to immediately notify TPWD regarding any mortalities of farm-raised shrimp, require hatchery operators to have their shrimp certified as disease-free by a department-approved disease specialist, and require operators to show they possess or have applied for the appropriate TCEQ permit. However, no rules have been established to protect the farmed shrimp from feral, native shrimp populations, known to be carriers of a White Spot-like virus, or have there been rules established to keep imported or native frozen bait shrimp (found to contain active shrimp viruses) from being sold as bait on the Texas coast. The above two, among others, have been cited as potential vectors for virus disease transmission.

A great potential threat to both the wild shrimp fishery and aquaculture industry in the state was identified by shrimp pathologists a number of years ago, but nothing has been done by regulatory agencies to eliminate the threat. Imported shrimp on the retail supermarket selves in the US were sampled and found to contain shrimp viruses. Also frozen imported shrimp sold for bait and used in rivers and in coastal waters have the potential to carry viruses, and even the native shrimp caught and sold for bait may carry viruses. Shrimp processing plants that process imported shrimp have solid wastes and some of those solid wastes (shrimp parts), potentially containing viruses, are taken to composting facilities or landfills. If the wastes are not treated properly, they pose a threat to both wild shrimp and to farmed shrimp. The Taura Syndrome Virus hit South Texas shrimp farms in 1995 and again in 2004. The virus that hit in 2004 was found to be an Asian strain of TSV. One suspected vector for this virus was frozen imported shrimp, both for consumption and for bait. USDA Animal and Plant Health Inspection Service (APHIS) was given the information by the TVMDL at TAMU and APHIS may consider a risk assessment at some future time; however, at present other problems like Bird Flu and Homeland Security take priority.

Environmental Concerns, User Conflicts and Future Threats.

Environmental concerns of the Texas aquaculture industry have decreased due to prompt action by regulatory agencies and efforts by farms to manage natural resources wisely. First, discharges from aquaculture production facilities had the potential to discharge total suspended solids (TSS). Prior to regulations and permitting of certain shrimp farms in the coastal zone, there were incidents when TSS discharges caused turbidity and sedimentation problems in localized areas. The potential for TSS adverse impacts has been greatly reduced by the establishment of TSS effluent limitations into permits. In turn, the limitations have resulted in advances in wastewater management at all coastal aquaculture facilities and very effectively decreased the volume of the discharges. Among the advances were 1) re-circulation and reuse of wastewater and 2) constructed wetlands for sedimentation and polishing, often releasing water that is cleaner than it was when it was first pumped in from the intake. Flow through systems on some shrimp farms in 1994 used 4,500 gallons of water to produce each pound of shrimp. With the new technologies in place now, those farms use less than 300 gallons of water to produce each pound of shrimp, and most of that water is used to fill the pond and offset evaporation. Second, there were two accidental releases of the Pacific White Shrimp to Texas waters in the

1990s. A TPWD requirement that 3 screens with appropriate mesh sizes be placed on the farm effluents has effectively prevented any further releases. The potential ecological impacts of this type of introduction are no fully understood, but after 30 years of releases of the Pacific White shrimp in other areas of the world there have been no documented negative impacts. Thirdly, the presence of two viral diseases: Taura Syndrome Virus (TSV) and White Spot Syndrome Virus (WSSV) potentially pose a threat to native shrimp stocks and to farm raised shrimp. The native populations carry viruses (Baculovirus and a White Spot-like Virus) that potentially threaten shrimp culture operations on the coast. As of 2008 the viral problems in shrimp ponds on the Texas coast have not been a problem for several years. Biosecurity measures practiced by hatcheries and farms seem to be working and disease resistant strains of shrimp seem to be helping with the control of viral outbreaks. There was a WSSV outbreak last year in crawfish ponds in the state of Louisiana, but so far, the virus has been contained.

User conflicts in addition to those described above are primarily market functions. Imports of shrimp to the U.S. increased 76% from 1954 to 1993. Since the year 2000 there has been a 73% increase of shrimp imports, and there was a 47% increase since 2003. In 2004 the US imported 1.25 billion pounds of shrimp. The average price was $2.23/lb, down $0.27/lb from 2003. According to USDA statistics, the US import values for fish and shellfish were $10.9 billion in 2003; $11.2 billion in 2004; $11.9 bilion in 2005; $13.2 billion in 2006; and $13.5 billion in 2007. During this same period the US did not export as much seafood as it imported and resulted in a seafood trade deficit, ranked 17th in the US compared to all other products. According to USDA, the fish and shellfish deficits in the US from 2000 to 2007 were as follows: $-6.8 billion in 2000; $-6.4 billion in 2001; $-6.8 billion in 2002; $-7.5 billion in 2003; $-7.3 billion in 2004; $-7.7 billion in 2005; $-8.8 billion in 2006; and $-9.1 billion fish and shellfish trade deficit in 2007, and has remained about $9 billion since.

FAO (State of the World Fisheries and Agriculture, http://www.fao.org/docrep/009/A0699e/A0699e00.htm; 2007) estimated that due to a variety of factors, including overfishing, most wild fisheries were incapable of sustaining current production over the long term.

The development of aquaculture in Bangladesh, Brazil, Central America, China, India, Thailand and Viet Nam has substantially increased imports of shrimp and farm-gate prices of shrimp to the Texas farmer have dropped to about $2.00/lb on average, but varies with size. The imports have an impact on prices paid to Texas shrimpers and to Texas shrimp farmers. As supply increases from imports, market forces drive the price of all shrimp lower. Antibiotic concerns in shrimp from Asia closed the European shrimp market and much of that shrimp was sent to the US market instead in 2002 and 2003. The antibiotic problem has been eliminated and the European market is open again, but the economic viability of Texas shrimpers and Texas shrimp farmers in the future will continue to be affected in part by the amount of total shrimp available in worldwide markets.

When it was proven that the flood of imported shrimp (both wild caught and farm raised) negatively affected US shrimp prices, USDA Foreign Ag. Services Trade Adjustment Assistance Program included eligible US shrimpers and US shrimp farmers in benefits under the program for the production years 2002 and 2003. A $0.16/lb allowance was paid for the production year 2002, up to a maximum of $10,000 each producer and a $0.27/lb allowance was given for 2003. In 2004, more than $4.5 million in benefits went to the Texas harvest industry, but with the eligibility rules as they are, the program did not assist Texas shrimp farmers. Additionally, the US Dept. of Commerce's shrimp tariffs imposed on 6 countries (Brazil, China, Ecuador, India, Thailand and Viet Nam) found guilty of dumping shrimp on the US market have not been effective in raising prices of shrimp since the countries found guilty of dumping were quickly replaced by other countries producing and importing shrimp to meet the US demand (Indonesia, Malaysia, Mexico, etc.). Shrimp from some of the six countries found guilty went to other countries not on the list and were reboxed, repackaged and/or renamed, to end up in the US market. The Asian Tsunami hurt shrimp production in some Asian countries, but has not **noticeably** slowed the flow of shrimp imports to the US and USDOC tariffs were partially lifted in Oct. 2005. Any and all remaining shrimp tarriffs were lifted by USDOC in 2008. The US has consistently harvested around 176 to 200 million pounds of shrimp per year from the wild and about 50 million pounds of shrimp tails are harvested each year in Texas (43 million pounds from the Gulf of Mexico and 7 million pounds from Texas bays). With more and more shrimpers going out of business this production may fall, and no doubt will be replaced by imports.

Other potential use conflicts, such as with recreation and navigation, are minimal. The impacts of the traditional wild-caught shrimp fishery on natural resources is still in question. The effects of pulling trawls over sea bottoms is still being assessed and attempts to limit the fishery through license buy-back programs have been proposed in the past and implemented in some cases by regulatory agencies to control over-fishing. The impacts of shrimp aquaculture have not been fully evaluated either, but environmental impacts have been lessened in recent years. Hurricanes in the Gulf of Mexico and high fuels costs, as well as high insurance costs and risks of law suits by workers hurt on the job have severely limited the shrimping industry. High feed costs and fuel costs, coupled with low farm-gate prices for shrimp have severely limited the shrimp aquaculture industry and many US farms have gone out of business in 2007 and 2008. The potential for mutual exclusivity of the two industries provides resource managers with difficult social and economic parameters to consider. Both industries in Texas (the shrimp harvest industry and the shrimp aquaculture industry) have declined in recent years because of world market competition, lower shrimp prices, heavier regulations in the U.S., and higher operating costs. There seems to be no return of either industry in sight.

Industry Needs

Prices cycle up and down in the aquaculture industry due to supply and demand. Expansion of the aquaculture industry in Texas should continue in catfish as long as producers remain competitive with international markets and imports by keeping their costs under control, continue to improve upon efficiency, and take advantage of local infrastructure and economies of scale. The Texas industry needs to capitalize on the environmental compliance and establish direct market links to help insulate from imports and better utilize their proximity to markets. Fresh product niches should be located or developed, as well as organic market potentials. The industry needs to continue developing better diagnostic methods for diseases and better ways to prevent them, while continuing the development of disease resistant strains. Lastly, the industry needs to continue market promotion and support for U.S. farm raised aquaculture products and operations need to be diversified with multiple species to be able to adjust to ever-changing markets.

The Texas aquaculture industry has great potential in the future helping the U.S. offset part of its large seafood trade deficit. The U.S. needs the aquaculture industry. According to USDA the U.S. imported $13.5 billion of fish and shellfish in 2007 and only exported $4.37 billion worth of fish and shellfish in 2007, leaving a $-9.13 billion seafood trade deficit. In 2011 that trade deficit is over $10 billion. With the rising consumption of seafood worldwide, partly because of the health benefits, per capita consumption of seafood continues to increase. Wild fisheries cannot meet the rising demand. The total value of U.S. Aquaculture is $1.1 Billion and the U.S. industry supports a $167 million annual payroll. Aquaculture continues to be the fastest growing sector of U.S. agriculture.

The World Aquaculture Society met in San Antonio and drew approximately 3,500 participants from around the world. Trade show photo above.

Texas historically has had a strong aquaculture support organization, the Texas Aquaculture Association, and more information can be obtained about them and the industry on their web site at www.texasaquaculture.org.

TAA board and members in front of the state Capitol.

The Executive Secretary of the Texas Aquaculture Assoc., Donna Hanson at a TAA booth in a trade show venue.

TAA

Aquaculture Education in the State of Texas

Both the major “Flagship” Universities for the state of Texas (The Texas A&M University System and The University of Texas at Austin) provide a curriculum and advanced degrees in aquaculture. Other Universities within the state also provide some courses that are aquaculture oriented. Even some High Schools in the state offer aquaculture as part of their curriculum. San Antonio has a new Magnet Aquaculture high school which opened in 2011.

There is also a Marine Shrimp and Marine Finfish Culture Course offered annually by the Texas Sea Grant Program. Texas Sea Grant holds the annual Texas Shrimp Farming Short Course and Marine Finfish Culture Course in the fall at The University of Texas at Austin Marine Science Institute (UTMSI) and its Fisheries and Mariculture Laboratory (FAML) in Port Aransas, and at shrimp and fish farms on the Texas coast. The course is conducted in partnership with UTMSI and the Texas A&M University System’s Texas AgriLife Extension and Texas AgriLife Research, and in cooperation with Texas marine shrimp and finfish farms, and the Texas Parks and Wildlife Department (TPWD). The five-day course is designed for individuals interested in expanding or increasing the profitability of current mariculture businesses or starting new enterprises. It gives participants an opportunity to learn from more than a dozen respected specialists in the field of marine shrimp and finfish mariculture through lectures, laboratory demonstrations and field trips to commercial shrimp and finfish farms and research facilities. The 26th annual course will be offered Sept. 28-Oct.4, 2011. In exit evaluations, past participants have rated the course and its instructors as excellent. Participants receive 4 Continuing Education Units (CEUs) from Texas A&M University for completing the course. Agenda and registration information for the next course are posted on the Texas Sea Grant web site:

http://texas-sea-grant.tamu.edu. Look under coming events.

Aquaculture and Seafood-related Web Sites (the links will need to searched for on web browser)

Texas Growers

Austwell Aqua Farm.
Bowers Shrimp Farm
Brett Rowley's Koi Farm
Harlingen Shrimp Farm, Ltd
Johnson Lake Management Service
Lonestar Aquafarms, Ltd.
Silver Streak Bass Company
Southeast Texas Crawfish Farm
Southern Star (Leased by PetroSun)
Taste of Texas Shrimp Ranch
http://www.ifsolutions.us/#
http://www.watergardengems.com/

Texas Aquaculture Association Technical and Support Services

Booth Ahrens & Werkenthin; Austin, Texas

Important Aquaculture Bookmarks

Aquaculture Certification Council Aquaculture at NOAA Aquaculture Marketing Aquaflor for Channel Catfish Aquaplant Aquatic Network: Home Page Aquaculture Network Information Center (AquaNIC) Aquaculture News-Around the World Biosystems Analysis Group - Aquaculture Software Catfish Institute Catfish Farmers of America Current Seafood Wholesale Prices Empty Ocean/Empty Nets Fisheries Statistics & Economics Fish Information and Services Find the Aquaculture Species You Want Florida Tropical Fish Farms Assn Global Aquaculture Alliance Joint Subcommitte on Aquaculture Macrobrachium Hatchery Techniques National Aquaculture Association National Sea Grant NMFS (shrimp catches)

NOAA Fisheries
Oceanic Institute
Offshore Marine Aquaculture
Open Ocean Aquaculture
SeaFood Business
Shrimp News International
Southern Regional Aquaculture Center
State of the World Aquaculture and Fisheries Stirling *SUSTAINABLE MARINE AQUACULTURE: FULFILLING THE PROMISE;*

MANAGING THE RISKS, Report of the Marine Aquaculture Task Force, January 2007 (See Final Report)
Texas A&M University, Sea Grant Publications
Texas A&M University, Sea Grant College Program Texas Shrimp USDA Economic Research Service World Aquaculture Society

Regulations, Publications and Governmental Information

Aquaculture Licensing Forms
Conservation Reserve Enhancement Program - USDA
Crop Disaster Program
Environmental Protection Agency (EPA)
EPA Aquaculture Effluent Guidelines
FDA HACCP
Generic HACCP Plans
General Permit for Aquaculture
JSA - Aquaculture Effluents Task Force Home Page
LCRA
List of State Agencies
Matagorda County Econ. Dev. Corp
Seafood and Health
Sustainable Ag Business Planning Guide
(TCEQ) Texas Commission on Environmental Quality
Texas Aquaculture Administrative Codes
Texas Chapter 134~Regulation of Aquaculture
Texas Department of Agriculture
Texas Legislature Online
Texas Off-Shore Aquaculture Rules
Texas Parks and Wildlife
Texas Surface Water Quality Standards (TCEQ)
Texas Water Development Board
USDA Aquaculture Outlook
USDA-FAS Trade Adjustment Assistance for Farmers
USDA - National Organic Program

Other Aquaculture Companies and Equipment Suppliers

Aqualink Aquarium Systems Bell Creek Mfg. Inc. Broodstock Burris Mill and Feed CSIRO Marine Research DelStar Technologies, Inc. Diag Xotics Ewing Irrigation & Industrial Products (EMAIL) Fish H2O Fresh Choice Seafood Greenaqua Hihealth Shrimp House Manufacturing Co., Inc Itzasi Ocean Garden Ocean Spar Technologies, LLC R&B Aquatic Distribution Inc. Sea Farms Group Seafood Net Shrimp Anywhere Shoppa Farm Supply Wofford Electric & Pump Supply

Misc. Aquaculture & Seafood Web Sites

Aquafeed.com Aquatic Network Fish Info Service Gotradeseafood.com International Aquaculture WebRing IntraFish oneFish.org WorldCatch.com

Aquaculture Alliances, Associations, Organizations & Societies

American Fisheries Society (AFS) American Tilapia Association (ATA) Aquaculture Engineering Society (AES) Asian Fisheries Society (AFS) Asociación Nacional de Acuicultores de Honduras (ANDAH)

British Columbia Salmon Farmers Association California Aquaculture Association (CAA) Canadian Aquaculture Industry Alliance European Aquaculture Society (EAS) Ecuador's Camara Nacional de Acuacultura(CNA) Federation of European Aquaculture Producers Florida Tropical Fish Farmers Association(FTFFA) Fundacion Chile Global Aquaculture Alliance (GAA) National Aquaculture Association(NAA) National Shellfisheries Association(NSA) Norwegian Fish Farmers Association Striped Bass Growers Association Taiwan Tilapia Alliance Texas Aquaculture Association US Trout Farmers Association Virginia Fish Farmers Association World Aquaculture Society (WAS)

Aquaculture & Fisheries Research

Aquaculture at the University of Tasmania Aquaculture Research Unit at University of the North South Africa Asian Aquatic Resources Asian Institute of Technology Auburn University Department of Fisheries and Allied Aquacultures Australia's Department of Agriculture, Fisheries and Forestry Australia's Fisheries Research and Development Corporation Australia's National Fishing Industry Education Centre Australia's Cooperative Research Centre for Aquaculture Canada's Institute for Marine Biosciences Caribbean Marine Research Center Centre for Environment, Fisheries and Aquaculture Science (CEFAS) Consultative Group on International Agricultural Research (CGIAR)

International Center for Living Aquatic Resources Management (ICLARM) FishBase

International Food Policy Research Institute (IFPRI)

International Service for National Agricultural Research (ISNAR) Danish Institute for Fisheries Research Ecuador's El Centro Nacional de Acuicultura e Investigaciones Marinas

(CENAIM) European Commission - Fisheries Fisheries Research Services Food and Agriculture Organization (FAO)

Fisheries Department

- Focus: Aquaculture - new opportunities and a cause for hope
- Special Programme for Food Security (SPFS)

- Freshwater Institute
- Gulf and Caribbean Fisheries Institute
- Hawaii's Center for Tropical and Subtropical Aquaculture
- Harbor Branch Oceanographic Institute (HBOI)
- IFREMER
- Institute of Aquaculture at Sterling University
- Institute of Marine Biology of Crete
- International Fisheries & Aquatic Research (SIFAR)
- Israel's National Center for Mariculture
- Japan's National Research Institute of Aquaculture
- Mote Aquaculture
- Network of Aquaculture Centres in Asia-Pacific (NACA)
- National Institute of Water and Atmospheric Research Ltd - New Zealand
- North Sea Centre
- Norway's Foundation for Scientific and Industrial Research at the Norwegian Institute of Technology (SINTEF)
- Norwegian Institute Of Aquaculture Research (Akvaforsk)
- Norwegian Institute of Fisheries and Aquaculture Ltd. (Fiskeriforskning)
- Oceanic Institute (OI)
- Oregon State University's Pond Dynamics/CRSP Program
- Roslin Institute, Edinburgh
- South Australian Research and Development Institute
- Southeast Asian Fisheries Development Center (SEAFDEC/AQD)
- Taiwan Fisheries Research Institute
- Texas A & M Department of Wildlife and Fisheries Sciences
- Thad Cochran National Warmwater Aquaculture Center
- The Australian Aquaculture Centre
- The Cooperative Research Centre for Aquaculture
- University of British Columbia's Fisheries Centre
- University of Guelph's Aquacentre
- University of Ghent's Laboratory of Aquaculture and Artemia Reference Center
- University of Idaho Aquaculture Research Institute
- University of Maryland's Center of Marine Biotechnology
- University of Tasmania's School of Aquaculture

Regional Aquaculture Information

Acuicultura Rural a Pequeña Escala Arizona
Aquaculture Australian Aquaculture Centre
California Aquaculture Canadian Aquaculture
Delaware Aquaculture Resource Center

Economics of the Philippine Milkfish Resource System Florida Aquaculture Hawaii Aquaculture Havbruk - A Norwegian Aquaculture Resource Guide History, Status, and Future of Aquaculture in the United States Ichthica Malaysia Department of Fisheries Massachusetts Aquaculture White Paper Midwest Tribal Aquaculture Network Mississippi State University Extension Service Natural Energy Laboratory of Hawaii Negev Arava - an Israeli Kibbutz New Mexico Aquaculture North Carolina Aquaculture North Carolina Dept. of Agriculture's Aquaculture & Natural Resources

Division North Carolina State University-Extension Wildlife, Fisheries and

Aquaculture Northeastern Regional Aquaculture Center (NRAC) Nova Scotia Department of Fisheries and Aquaculture Pacific Regional Aquaculture Information Service (PRAISE) Peche et Aquaculture en Guinee Philippine Aquaculture Industry Philippines' Department of Agriculture Piscicultor - O maior site brasileiro de piscicultura Texas A&M University System Agriculture Program

Mariculture program Today Aquaculture Centre Malaysia Western Australia Fisheries

United States Federal Government Information Sources

Army Corps of Engineers

Coastal and Hydraulics Laboratory

Coastal Engineering Manual

Department of Agriculture Agricultural Research Service (ARS) Alternative Farming Systems Information Animal and Plant Health Inspection Service (APHIS) Economic Research Service (ERS) Economics and Statistics System Foreign Agricultural Service (FAS) National Agricultural Library (NAL)

Rural Development Salinity Laboratory State Department Travel Warnings & Consular Information Environmental Protection Agency (EPA) Aquatic Life Criteria EPA Effluent Guidelines Office of Ground Water and Drinking Water Office of Pesticide Programs Office of Water Office of Wetlands, Oceans, and Watersheds Fish & Wildlife Service Food and Drug Administration (FDA) FDA/CFSAN HACCP--Hazard Analysis and Critical Control Point Blue Book Foodborne Illness Education Information Center CFSAN Seafood Information and Resources Climate Diagnostics Center National Climatic Data Center (NCDC) National Hurricane Center National Marine Fisheries Service (NMFS) Fishery Market News Fisheries Foreign Trade Information United States Geological Survey (USGS) Water Resources of the United States Joint Subcommittee on Aquaculture

US State Government Information Sources

Florida Bureau of Seafood & Aquaculture Florida Department of Environmental Protection Louisiana Sea Grant Maryland Sea Grant Mississippi and Alabama Sea Grants Mississippi State Univ. Extension Service's Aquaculture Resources National Sea Grant Library South Florida Water Management District

Publications

Aquaculture Asia
Aquaculture International
Aquaculture Magazine
Blackwell Science CRC
Press

Elsevier Science Fish
Farming International
Fishfarmer-magazine.com
Fish Farming News Iowa
State Press Maryland
Aquafarmer National
Academy Press Northern
Aquaculture Panorama da
Aqüicultura Revista AquaTIC
SeaFood Business Shrimp
News International The
Aquaculture News

Aquaculture Mailing Lists

Aqua-L Shrimp
Mailing List Tilapia
Mailing List

Additional Aquaculture Information Resources

Amazon.com - Aquaculture Books Aquatext Excite.com News Wire Search for "Aquaculture" Fishing for Information "Global aquaculture: a giant in the making" by James Muir International Aquaculture WebRing NRAES Publications List: Aquaculture National Sea Grant Depository ProgressiveFarmer.com The Rosenstiel School Library Search Adobe PDFs - query "aquaculture" World Aquaculture World Resources Institute Article "Farming Fish: The Aquaculture Boom"

Aquaculture & Seafood Conferences

Aquaculture China 2002 AquaVision 2002 European Seafood Exposition Heighway Events - International Exhibition Organisers International Boston Seafood Show 2002 Exhibitors International West Coast Seafood Show Recirculating Aquaculture Conference

Seafood Processing Europe
Singapore Seafood Exhibition

Abalone, Clams, Oyster, Pearl, Mussel & Scallop Culture

Abalone Farm in Mexico Biosphere
Clams Blue Pearls Cedar Creek
Shellfish Cedar Key Clams Chilean
Scallop Culture Coast Seafoods
Fishtech Frank M Flower & Sons
Island Scallops Orchid Island Clams
Pacific Marine Farms Pearl
Seaproducts Sea of Cortez Pearls
Seapa Oyster Baskets Taylor
Shellfish Farms The Great Eastern
Mussel Farm

Algae & Plankton Culture

Acadian Seaplants Limited Addavita Limited Applied Photosynthetics Arizona State University's Photosynthesis Center Bowling Green State University Center for Algal Microscopy and Image Digitization Cyanotech Earthrise Spirulina Microgaia Provasoli-Guillard National Center for Culture of Marine Phytoplankton Spirulina Tesgofarm Group University of Texas Culture Collection of Algae

Catfish Farming

Alabama Catfish Producers
AquaPro Catfish Bargaining
Association Catfish Institute Delta
Pride Catfish

Harings Pride Catfish
SouthFresh Farm
Southern Pride Catfish

Hybrid Striped Bass

Fins Technologies
Kent SeaTech Pure
Water Farms

Macrobrachium

http://www.aquacultureoftexas.com/

Marine Fish Culture

Aquaculture Center of the Florida Keys
Ardag Ltd. Marost Mote Aquaculture Pan
Marine ASA Prodemar Selonda Group Venø
Fishfarm http://www.oceanfarmsa.com/

Salmon Farming

Alf Lone Fiskeoppdrett Aquafarms Aquascot
AquaSeed Corp. Aqua Gen Atlantic Salmon of Maine
Buckman's Creek Brithish Columbia Salmon Farmers
Association British Columbia Salmon Marketing
Council Chilean Seafood Exchange Fiskekultur Fjord
Seafood Grieg Seafood Landcatch Marine Farms
Marine Harvest Salmon Hydro Seafood New Zealand
King Salmon Company

Pacific Star Prince William Sound Aquaculture
Corp. Salmon: Spirit of the Land and Sea
Salmon Aquaculture Review Final Report
Scottish Quality Salmon Scottish Salmon Stolt-
Nielsen Stolt Sea Farm True North Salmon
Ventisqueros

Shrimp Farming

Aquafuture Corporation
Aqualab
Aqualider Maricultura
Arizona Shrimp Company
Atlantis Aquacultura
Bluewater Aquaculture
Ceatech
ContiGroup Companies
Corporación Santa Rosa
Corporacion Vandar
Costapac
CP Food Report on Black Tiger Shrimp in Thailand
El Rosario
Empagran
Exporklore
Gazadco
Grupo Granjas Marinas
High Health Aquaculture
Images of Ecuadorian Shrimp Aquaculture
Indian River Aquaculture, LLC
Maricultora del Golfo
Maricultura del Pacifico
Marine Maricultura
OceanBoy Farms Inc.
Sahlman Seafoods
St. Petersburg Times article: Harvesting shrimp a jumbo headache
Shrimp Farming in Texas
Shrimpfarming.org
Super Shrimp Mexico
UVic Shrimp Aquaculture Research Group
Wood Brothers Shrimp Farm

Tilapia Farms & Tilapia Farming

AmeriCulture Aqua Malta Aquasafra Canadian Tilapia Estação de Piscicultura Aquabel Fazenda Santa Isabel Fingerlakes Aquaculture Fishgen Grupo El Chao Jamaica Pride Kloubec Aquaculture Lake Harvest Aquaculture Ltd. Living Waters Tilapia Farm Minaqua

Profile - New Generation Cooperatives, Minnesota Association of Cooperatives Mississippi State University Extension Service: Tilapia Nam Sai Piscicultura Aquabel Rain Forest Aquaculture Regal Springs Sde Eliyahu Sea Grant Tip Sheet Series: Tilapia The Tabtim Fish Tilapia Culture in Brazil Tropical Tilapia

Trout Farming

Branch River Trout Hatchery Clear Springs Foods Coldwater Farms Eridi Rossi Silvio Idaho Trout Processors Company Pure Springs Trout and Walleye Farm Troutlodge Trout Production in Western North Carolina

Miscellaneous Aquaculture

5-D Tropical Alevinos.com.br Blue Ridge Koi Hatchery Delaware Valley Fish Company Ekk Will Farming Yabbies

Fazenda Vale do Rio Claro
Flowers Fish Farm Freshwater
Farms of Ohio Greenwater Fish
Farm Heymann Aquaculture
Hofer Forellen Hunting Creek
Fisheries Icy Waters Longshan
Eel Farm McKenzie Fish Co.
Moana Aquacultura Mt. Parnell
Fisheries Perch Research
International Piscicultura FB
Piscicultura São Pedro Projecto
Pacu Seawater Farms Silver Eel

Cage Manufacturers, Cage Culture, Cage Equip. & Materials

Ardag Red Sea Mariculture, Ltd.
Atlantic Extrusions Corporation BF
Products Carmanah Christensen Net
Works Corelsa Egersund Net Euro
Gear Fablok Mills Farmocean
International Fusion Marine Future SEA
Technologies Gulf Marine Institute of
Technology Helgeland Holding InterNet
Istazi Kropf Aquaculture Lift-Up Marine
Construction Memphis Net & Twine
Nor-Mær Ocean Spar Technologies
SeaCage.com WaveMaster

Aquaculture Supply Companies

AGK Kronewitter AREA Aquacenter Aquaculture
Systems & Equipment Aquaculture Supply Aquafauna
Bio-Marine Aquatecno Aquatic Eco-Systems C+H
Aquaculture Catvis Fish Farming Trade Directory
Florida Tropical Fish Farmers Association Store
Forestry Suppliers Fukuina Keeton Industries

Aeration & Oxygen Generation Equipment

Aeration Industries Aeromix
Systems AerResearch Air-Aqua
Enterprises Air-O-Lator Corp. Air
Products PLC AirSep Big John
Aerators Commmon Sensing
FisH2O Fresh-flo House
Manufacturing Kasco Marine
Linn Geraetebau Mazzei MG
Generon On Site Gas Oxygen
Generating Systems OxyGuard
Oxymat Pioneer Sanitaire
SeQual Technologies Sino-Aqua

Water Quality Monitoring, Metering & Testing

Airak Aquadyne Atago Campbell Scientific CHEMetrics Common Sensing Craig Ocean Systems Dosatron International Dosmatic International Fondriest Environmental GAVISH Agricultural Control Systems GLI International Geo Scientific Hanna Instruments Hydrolab LaMotte OMEGA Engineering Orion Research Point Four SingleChips Spectrum Laboratories Turner Design YSI

Pumps, Engines & Generators

Alita Air & Water Pumps Amarillo Gear Americas Generators Crisafulli Delta Pumps Mid Atlantic Pump And Equipment Moving Water Industries Pentair Pump Group Pump.Net

Fish Pumps, Fry Counters & Live Haul Tanks

Aquaneering
Aquascan
Enviromental Technologies
Grade-right
Inventive Marine Products
Jensorter
P.R.A. Manufacturing
Vaki

Lab Equipment & Chemical Supply

AML Industries Argent Fisher
Scientific LECO Leica Precision
Weighing Balances

Filtration Equipment & Filter Material

A-1 Aquaculture Americo Manufacturing
Co. Aquaculture Systems Technologies
Baker Hydro Biofilters.com BubbleBead
Filtration Hydrotech Jacuzzi Brothers
Marine Biotech Osmonics Parkson
Corporation QuikSand® Filters Water
Management Technologies

Tank Manufacturers, Materials, Valves & Fittings

Alchem Industries A-PLAST |
Hovedside Aquafarms2000 Casco
Group Chem-Tainer Industries
Dolphin Fiberglass Products E-
Com Plastics Fabco Plastics
Haogenplast Peterson Fiberglass
Laminates Plastics.org
PlumbingProducts.com Red Ewald
Red Valve Solar Components
Spears Manufacturing

Additional Recirculating Aquaculture System Equipment

Applied Aquatics Aquacare
Aqua Logic Aquipro Aquanetics
Blancett Fluid Flow Meters
Clepco Del Industries Emperor
Aquatics HESY Hyland
Equipment Company MGD
Technologies Marine Biotech
Mega Fisch Northeast Controls
Nutech-O3 Pentair Aquaculture
Trio3 Industries Upscale Water
Technologies

Recirculating Aquaculture System Resources

Evaluation of Recirculating Aquaculture Systems PRAqua Proceedings From 1991
Workshop On Commercial Aquaculture Using Water

Recirculating Systems
The Fish Barn at N.C State
The Sterner Aqua Group

Environmental & Wastewater Engineering

American Academy of Environmental Engineers
American Council of Engineering Companies
American Water Works Association Axsia Beckart
BioMatrix CH2M HILL Environmental Data Interactive
Exchange (edie) Environmental Dynamics Enviroquip
Goble Sampson Associates Green Pages
Hydromantis Integrated Engineers ITT Flygt

Flygt USA - Mixers Kinetico LAS International Landia Lemna USA North Carolina State's Dept. of Biological and Agricultural Engineering Notre Dame's Center for Environmental Science & Technology Orenco Systems Pollution Online Prism-USA Sanitaire Corporation University of Florida Water Reclamation Facility University of Queensland's Advanced Wastewater Management Centre Wastewater World Wide Water and Waste Water Water and Wastewater Equipment Manufacturers Association (WWEMA) WesTech Engineering Zenon Environmental

Water Resources

American Water Resources Association American Water Works Association Aqueous International Water Association (IWA) The Groundwater Foundation Water Environment Federation Water Online

Aquaponics & Hydroponics

American Hydroponics Aquaponics.com CropKing General Hydroponics Hydrofarm S & S Aqua Farm Bioponics System The Growing Edge Magazine Tom's Greenhouse

Greenhouses & Buildings

API Insulated Building Panels AT Plastics Clamshell Buildings ClearSpan DynaGlas Plus

Klerk's Plastic Products National Greenhouse Manufacturers Association Photobiology Online Sprung Instant Structures SPS International Tyco Plastics Agricultural Films Universal Fabric Structures US Global Resources Van Besouw Coated Fabrics Van Wingerden Greenhouse Company Warner Shelter Systems Limited

Construction & Farm Equipment

Case Caterpillar Contech Construction Products Ritchie Bros. Auctioneers Equipment Trader Online Hino Trucks Hitachi John Deere Kawasaki ATV Komatsu LSR Machinery Trader Reynolds International Rock and Dirt Online Spectra Precision

Farm Construction & Civil Engineers

American Society of Civil Engineers An Introduction to Acid Sulphate Soils Cadalyst CADdepot.com CADinfo.NET EARTH Earthwork Cut and Fill Quantities Calculation Software iCivilEngineer.com Pond Construction Smith & Loveless Water 101 Soil Survey Manual Soil texture triangle: hydraulic properties calculator Sweets.com theBlueBook.com Coastal Engineering Page

US Army Corps of Engineers
Pumping Stations

Pond Liners & Biological Substrates

Agru/America, Inc. Association of the Nonwoven Fabrics Industry Colorado Lining International Cooley Group

C.W. Neal Corp. Environmental Fabrics Environmental Protection GeoChem GEOfabrics Geosource Geosynthetica.net Industrial Fabrics Association International Integra Plastics Meridian Mats Permalon Polyfelt Poly-Flex Seaman Corporation Solmax International Synthetic Industries Watersaver Company Webtec

Aquaculture Feeds

Aller Aqua Agribrands do Brasil Aquafeed.com Arasco Balanceados BioMar Burris Mill & Feed Charoen Pokphand Foods Cargill Clements Farm Service Coppens International Corey Feed Dana Feed Freedom Feeds Martin Mills Moore-Clark

Nelson & Sons Nicovita
Nutreco Nutron PT.
Bestari Indonesia
Rangen Shur-Gain
Zeigler Feeds

Larval Feeds & Feed Supplements

Aqion Aquatic Lifeline Brine Shrimp Direct Florida Aqua Farms Global Aquafeeds Innovative Aquaculture Products INVE Manual on the Production and Use of Live Food for Aquaculture Reed Mariculture Salt Creek Sanders Brine Shrimp ShrimpActiva

Feed Ingredients

Archer Daniels Midland Ajinomoto American Feed Organization American Soybean Association American Soybean Association - Singapore Regional Office Amerol Corp. AquaSearch Balchem Corporation Bentoli Central Soya Cenzone Chelated Minerals International FF of Denmark Grupo Sipesa Hooton & Company IFOMA Industrial Grain Products International Ingredient Company International Nutrition

Monsanto Omega Protein Prince Agri Products US Feed Grains Council USDA Briefing Room - Soybeans and Oil Crops

Feed Testing & Nutrition Research

Mycotoxins in Feed Grains and Ingredients Mycotoxicology Newsletter Neogen New Jersey Feed Lab Nutrient Requirements of Fish Nutrition, Feeds, and Feeding of Catfish Romer Laboratories The Fish Nutrition Research Lab - University of Guelph VDS Vicam

Feed Distribution Equipment

AKVA AKVAsmart ARENA Arvo-Tec Betten Maskinstasjon Feed Trays Faivre Feeding Systems GaelForce Marine Technology Sweeney Feeders

Feed Manufacturing Equipment

Alfa Laval Amandus Kahl Group Anderson Buhler Buhler USA Continental Agra Equipment Contra-Shear Nanrong Sprout-Matador Verner Lorenzen Wenger Wijnveen

Genetics & Breeding

AquaGen AquaGene Aquaculture Genetics RCGB Aquatic Stock Improvement Co. GenoMar NMT - Instructions for Tagging Shrimp with VIE tags PIC International Group Transgenic Tilapia University of California Tilapia Genome Lab

Aquatic Health

Alpharma Antec International Aquatic Health AVC Aqua Health (Canada) Ltd. Aquaculture Vaccines Limited Aquatic Diagnostic Services AquaVet Aqion Bayotek International Diagxotics General Principles of Fish Health Management Intervet Norbio Schering-Plough Shrimp Diseases The Aquaculture Health Page VESO Vikan AkvaVet

Biological Additives

ABI Advanced Microbial Systems Alken-Murray American Biosystems Applied Biochemists Aqua-Bio Aqua-In-Tech Aqua Biotechnology Aqualogy BioRemedics Bacta-Pur

Balanced Aqua Systems
Biobugs.com Bio-Genesis
Technology BioMagic
BioSynthesis Epicore
GreenAqua Ultra Bio-
Logics United-Tech

Chemicals

Agripac Argent Chemical
Laboratories Bio-Cide
International Ceba Specialty
Chemicals Citrobio Halamid®

H.J. Baker & Bro.
InterBio

Seafood Processing Information Resources

Codex Alimentarius Commission Fish and Fishery Products Commercial Fish and Shellfish Technologies and Food Science & Technology

(CFAST) at Virginia Tech Control of Food Safety Hazards During Cold-Smoked Fish Processing International Association of Fish Inspectors Microbe Inotech Labs, Inc. Processfood.com Processing and Marketing Aquacultured Fish (NRAC Fact Sheet No. 140) SeafoodNIC

University of California (Davis) Compendium of Fish and Fishery Product Processes, Hazards, and Controls

US Guidelines and Regulations USDC Seafood Inspection Program USFDA/CFSAN Seafood Information and Resources USFDA/CFSAN Food Compliance Program: Domestic Fish & Fishery Products

Seafood Processing & Packaging Equipment

AFOS Alkar
American Delphi
Aqua-Pak

Atlantic and Gulf Baader
Bonar Plastics Cabinplant
International Cablevey
Capital Controls Group
Cardinal & Detecto Scales
Cox Technologies Danfoss
International Doran Scales
Enviro-Pak Fibergrate
Fishmore Fischtechnik
Freezing Systems Frick
Frigid Units Frigoscandia
FTC Sweeden Gel Ice
Intercomp Company Intralox
IRAS Kerian Machines
KOCH Supplies Laitram
MPBS Industries Marel
Melbutech Optimar Pisces
Industries Polar Pack Pols
Processing Technology
Russell Harrington Cutlery
Sæplast Scalemasters
Scanvaegt International
Sealed Air Semi-Stål
Sensitech Sipromac
Stálvinnslan Star
Refrigeration Ltd Techpak
Trio Industrier

XPERTO Refrigeración Industrial

Ice Making Equipment

A-1 Refrigeration Berg
Chilling Systems
Geneglace North Star
Sunwell Technologies
Turbo Refrigerating

Seafood Processors, Wholesalers & Distributors

Alpha Group Anova Aquastar Cannon
Fish Company ConAgra Seafood
Contessa Cuisine Solutions Darik
Enterprises Ducktrap River Fish Farm
E.Frank Hopkins Empire Fish Egersund
Fisk Fishery Products International (FPI)
Fleming Companies Fortuna Sea
Gorton's of Gloucester High Liner Foods
JJ Helland Morey's National Fish and
Seafood Ocean Fresh Ocean Garden
Products Pacific Seafood Group Pan
Fish Group Polaris Seafood Red
Chamber Roberts Røkeri Royal
Supreme Seafood Sea Harvest SeaPac
of Idaho Slade Gorton Springs Smoked
Seafoods Starfish Sea Products

Stavis Seafoods
Supersea Sysco
Corporation Trident
Seafoods Trimarine
Wanchese

Seafood Marketing

Australian Seafood Industry Council Fish Info Service (FIS)
Florida Bureau of Seafood & Aquaculture Marketing Garry
Alan Design Gotradeseafood.com Greenfield Consulting
Group

H.M. Johnson and Associates Hawaii Seafood Buyers' Guide Illinois Fish
Farmers Cooperative iseafoodXchange Joseph W. Slavin & Associates
Marine Products Export Development Authority of India (MPEDA)
Minneapolis Grain Exchange (MGE) National Fisheries Institute (NFI)
PEFA.com Sea-Ex Seafax Sea Fish Seafood.com Seafood Choices
Seafood Market Analyst Seafoodnet.com Seafood Network Information
Center SeafoodNow.com SeafoodRecipe.com Seafood Steward
SimplySeafood.com Urner Barry WorldCatch.com World Seafood Market

Food Industry Resources

American Institute of Baking Epicurious European
Food Safety Authority Regulations
FoodEngineeringMag.com

FoodExplorer
Food Marketing Institute
FoodlineWeb
Food Online
Food Processors Institute
Food Quality
Food Safety at Iowa State University
Food Standards Agency
Food Trader
GM Food News
Institute of Food Technologists
International Foodservice Manufacturers Association
National Restaurant Association
Organic Consumers Association
Processfood.com
UF/IFAS National Food Safety Database
US FDA / Center for Food Safety and Applied Nutrition (CFSAN)
Food and Cosmetics Compliance Programs

Software & Calculators

ABE Volume Calculator
Aquaculture Simulation and Database Management
Agricultural Software Consultants
Aqua Assist Pty Ltd
AquaCAD Pond Design
AquaSense
Australian National Fishing Industry Education Centre - Software
Autodesk
BOSS International
CRSP Biosystems Analysis Group
Decision Support Tool For Aquaculture
eFunda
Engineering Software Center
FishMakers
FishMonger
Free Ammonia Calculator
Hawaii Aquaculture Module Expert System
Island Science
Martindale's 'The Reference Desk'
Calculators On-Line
Novatlantique
Pond Manager
Samakia
SmartFish Systems
Spratt's Simulation of Aquaculture Production

Superior Systems
The Fluid Flow Calculations Website
Unit Converter
Water Environment Federation - Conversion Factors, Constants, and Basic Formulas

Business, Management & Communications Resources

Aquaculturejobs.com Capital Factors GO Translator Learn Spanish OANDA Currency Converters Travelocity Worldtimezones.com

Trade, Logistics & Distribution Resources

Agribuys.com
Trade Compass

Agricultural Sites of Interest

@griculture Online Agriscape AgroInfo American Farm Bureau Archer Daniels Midland Cargill Committee for the Promotion and Advancement of Cooperatives Farms.com Farmbid.com FarmChina.com Farmsource.com Green Beam HortNet INFOAGRO Venezuela Instituto Interamericano de Cooperación para la Agricultura (IICA) National Council of Farmer Cooperatives New Agriculturist The Co-operative Information Superhighway University of Florida's Institute of Food and Agricultural Sciences (IFAS) University of Wisconsin Center for Cooperatives

Aquarium Links & Suppliers

AquaLink Fish Link Central
Inland Aquatics Oceans, Reefs
& Aquariums Reefs.org The Krib
Thiel Infobase WhatAFish.com

Aquatic Plants

Dr. Wastewater's Duckweed Application Page
Freshwater Flora & Fauna IFAS Center for Aquatic
Plants The Charms of Duckweed The Lemnaceae
Tropica Aquarium Plants Tropical Pond & Garden

Cichlids

Cichlid News Magazine Cichlid Press Cichlid
Research The Cichlid Room Companion The
Cichlid Center The Cichlid Fishes of Lake
Malawi, Africa

Satellite Imagery, Maps & Weather Centers

DeLorme Maps and Mapping Software EarthSat
Intellicast International Weather Satellite Images
MapQuest Maptech Space Imaging Spot Image The
Weather Channel Wisconsin University's Realtime
Satellite Image

Geographic Resources

Africa Online Caribbean-On-Line
Eco Travels in Latin America

Latin American Network Information Center
Latinet.com Lonely Planet

Ocean Resources

@ Sea NOAA
Ocean Planet

Fisheries Resources

FAO Fisheries Department Fishery Country Profiles World
Fishing Companies

Sustainable & Innovative Agriculture/Aquaculture Systems

Appropriate Technology Transfer for Rural Areas (ATTRA) Bioshelters Environmental Turf Solutions Geo-Heat Center Global Network of Environment and Technology Green Pages International Arid Lands Consortium International Crops Research Institute for the Semi-Arid Tropics Living Technologies Scientific American Article: Irrigating Crops with Seawater Sustainable Agriculture Initiative (SAI) United Nations Commission on Sustainable Development United Nations: Integrated Biosystems

Aquaculture & Hunger Relief

Aquaculture, poverty impacts and aquaculture by Peter Edwards International
Hunger & Poverty Relief Programs
Farmesa Sifar.org: Aquaculture and Poverty

International Hunger and Poverty Relief Organizations & NGO's

ACDI/VOCA Basic Food Citizens Democracy Corps Community of Science Cooperative for Assistance and Relief Everywhere (CARE) FAO/GIEWS - Food Supply Situation and Crop Prospects in Sub-Saharan

Africa Food for the Hungry Idealist.org Intermediate Technology Development Group (ITDG) International Executive Service Corps (IESC) OneWorld.net Oxfam International Peace Corps ReliefWeb Save the Children The Hunger Project The Hunger Site The HungerWeb World Bank: Resources and Support to Alleviate Poverty World Food Programme

Development Banks & Development Resources

African Development Bank Asian Development Bank (ADB) Asia-Pacific Economic Cooperation Caribbean/Latin American Action Commerce Business Daily (CBDNet) Commonwealth Development Corporation (CDC) Compañía Española de Financiación del Desarrollo (COFIDES) Conapri - Venezuelan Investment Office Danish International Investment Funds (DANIC) Deutsche Investitions- und Entwicklungsgesellschaft mbH (DEG) Directory of Development Organizations European Bank for Reconstruction and Development European Development Finance Institutions(EDFI) European Investment Bank (EIB) Export-Import Bank of the United States International Institute for Sustainable Development Institute of International Finance Inter-American Development Bank (IADB)

Sustainable Development FONTAGRO - Regional Fund for Agricultural Technology Inter-American Investment Corportation

International Development Network International Finance Corporation (IFC) International Fund for Agricultural Development (IFAD) Institute for International Development (IID) IPAnet Multilateral Investment Guarantee Agency (MIGA) Overseas Development Institute

Overseas Private Investment Corporation (OPIC) Seed Capital Network Sida Swedfund International AB Swiss Organisation for Facilitating Investments(SOFI) UK's Department for International Development (DFID)

Fisheries Management Programme

United Nations Capital Development Fund Development Programme (UNDP) Economic and Social Development

United States Agency for International Development (USAID) United States-Asia Environmental Partnership United States Trade and Development Agency World Bank

United Nations Development Business Online

Environmentalists on Sustainable Fisheries & the Impact of Aquaculture

Aquaculture Impacts on the Environment Empty Oceans, Empty Nets Environment News Service: Aquaculture May Be Fishing for Trouble Fish as food: aquaculture’s contribution Factory Farming - Seafood Production International Development Research Centre Global Aquaculture Alliance (GAA) Greenpeace Industrial Shrimp Action Network Natural Resources Defense Council Oceans of Trouble

Appendix A through C on Offshore Aquaculture: Appendix A Offshore Aquaculture and literature review for background on Open Ocean

Aquaculture and environmental impacts, Compiled by Granvil Treece.

The following is the results of a literature search for assessing effects of offshore aquaculture. Most of the literature has found that sitting of a project is the key step in protecting the environment and some of the literature makes recommendations for sitting. For example:

- Proper depth and strong currents (mean velocity about 30 cm/s or ~ 1⁄2 knot) are important to fish culture to prevent organic solid wastes from accumulating on the seabottom and expedite the aerobic (oxygen based) assimilation into the natural biota.

- Insensitivity to dissolved nitrogen wastes (such as those excreted by the fish) means that small marine plants (phytoplankton, sometimes referred to as algae) will not be influenced by any fish farming. In the case of the Strait of Juan de Fuca (and much of Puget Sound) off Washington State there is always sufficient nitrogen for algae growth; rather it is ambient light and to a lesser degree water temperature that regulates plant growth. Too much plant growth is called eutrophication, but productivity and standing stock of phytoplankton in the Strait is relatively low due to mixing of the cells above and below the surface (euphotic) layer. See study findings publication that cites Rensel Associates and PTI 1991; Mackas and Harrsion 1997 for peer reviewed literature regarding this topic as well as issues dealing with harmful algae (Anderson et al. 2001, Rensel and Whyte 2003). In general, phytoplankton growth in marine water bodies is limited by the availability of light and/or nitrogen, and the availability of phosphorus is less critical than it is in freshwater bodies (Parsons et al. 1973).

- A detailed literature review of the relationship between harmful algal blooms, eutrophication, and fish farming in coastal waters of Scotland, indicates that fish farming is unlikely to have any large-scale impact on the occurrence of harmful algal blooms. Such blooms appear to be more common in pristine than in enriched waters, and that they occur independently of fish farming activities. (Rydburg et al. 2003).

New Hampshire OOA -http://ooa.unh.edu/.

Most of the literature reviewed thus far has found no detrimental effects of offshore aquaculture if the project was properly sited in an area with proper depth and adequate currents. Proper sitting to protect the environment is only part of the process. Navigation, commercial fishing, sports fishing and other activities offshore must also be considered during site selection.

Puerto Rico Offshore Environmental Observations

- Maximum Feed/Day. 600 pounds. Time: 18 mos.
- Water Depth: 95 feet. Current: 20-30 Cm/sec Max.
- No Inorganic N detected upstream or downstream.
- Total organic N: No difference in sediment, has stayed the same as control at about 4.5%.
- Benthic Fauna: Abundance of macroinvertebrates at control site only marginally different ($P<0.05$) with station at bottom center of cage. Species diversity and evenness remained unchanged at all other sampling sites.
- Fish: 37 species vs four species before project. Schools of jacks, Decapturus and Caranx, cobia, barracuda.
- Invertebrates: Spiny lobsters, crabs, urchins, conch, pearl oysters.

Hawaii Offshore Environmental Observations

- Maximum Feed/Day. 4000 pounds. Time: 3 years.
- Water Depth: 130 feet. Current: 10-20 Cm/sec.
- Inorganic N: No systematic changes for nitrite or nitrate at any station but some measurable change at cage rim for ammonia after feeding, reduced to 5 micrograms/liter, at 100 meters but no change at 400 meters.
- Total Organic N: % of organic N in sediments _?
- Benthic fauna: Change to 4-5 times higher biomass of detritivores under cage, 80 m less, 400 m with no change.
- Fish: 24 species, large schools of jacks (Decapturus and Caranx), Seriola, sand bar sharks, filefish.
- Invertebrates: Tunicates, sponges, bivalve mollusks.

Dr. Charles Helsley's (personal communication, June 2006) team monitored the sea floor under a fish cage (heavily stocked with Moi in 20032004) in Hawaii for accumulations of food or waste that might harm water quality. They also surveyed the surrounding waters. Excess food didn't appear to be a problem as the huge cage attracted about 10,000 wild fish that gobbled any leftovers. Helsley detected only a stream of ammonia --a basic component of fish waste -- coming from the cage. The stream was not detectable 1,000 feet away.

In another report “Results of Water Quality and Benthic Monitoring Around the Moi Cages Offshore of Ewa Beach, Oahu”, the following synopsis of results from the water quality monitoring of the two stage HOARP operation tested moi culture in submerged cages of Oahu. Sea parameters of interest to the Dept. of Health (salinity, temperature, oxygen saturation or % O2, acidity or pH, phosphates, silicates, nitrates, ammonium, total phosphorous, total nitrogen, and water clarity or turbidity) were measured at a number of positions near the cage, and a few stations in the far field. None of these parameters seem to be significantly changed as a result of the cage being present, except for NH4. Observations near the cage yielded elevated NH4; about 3 hours after feeding, out to a distance of several cage diameters, but essentially gave background levels in the far field. During phase III, the current program, they have been focusing more on the far field. In the immediate vicinity of the cage they continued to find elevated NH4, but they have not found any systematic changes that can be related to the presence of the cage beyond about 200 meters. They concluded that the cage is having little effect on the surrounding waters at distances of more than a few hundred meters.

Observations Relative to Specific Criteria

(Based on Hawaii Administrative Rules, Title 11, Department of Health, Chapter 24,Water Quality Standards)

Total # of observations – 373

Parameter/Mean/Not more10% of time/Max.value(times)
Total Nitrogen mg N/L/ 150/250/>150 to 250 (2) Ammonia Nitrogen mg NH_4/L/ 3.5/8.5/ > 8.5 to 69 (9) >3.5 < 8.5 (32) Nitrate + Nitrite N mg (NO_3+NO_2)/L/ 5.0/14.0/ always < 5 Total Phosphorus mg P/L/ 20.0 /40.0/ >20 <31 (1) > 40 (0) pH 8.2+/-0.05; Temperature $\pm$ 0.5°C from ambient; Salinity 35+/-0.5; D.O. >80%

Helsley et al. 2003.

- No samples had values in excess of allowable values under the NPDES permit
- NH4+ is the only nutrient that is ever above background
- NH4+ is only above background very near the cage for a few hours about two hours after feeding

Summary of Environmental Observations

- Inorganic nitrogen concentrations are not changed significantly except at the net.
- Organic nitrogen in sediments no change at levels below 1000 pounds of food per day
- Benthic communities will shift to more detritivores at higher levels of organic N.
- Fish and large invertebrate species diversity and biomass will increase near and on offshore cages.
- Oxygen levels and benthic appearance have not changed and support biota under cages.

One benthic study on polychaete infaunal communities around a Hawaiian mariculture operation showed benthic population effects from offshore cages were apparent. They found low species richness resulting from the disappearance of ambient polychaete species and depressed community abundance reflecting the effects of fish mariculture on the benthic community. They concluded that such effects could be diluted by an open-ocean location (Lee, H.W., J.H. Bailey-Brock, and M.M. McGurr. 2006. “Temporal changes in the polychaete infaunal community surrounding a Hawaiian mariculture operation”. Marine Ecology Progress Series. Vol. 307: 175-185. Jan. 24, 2006).

The University of New Hampshire-OOA project (Larry Ward and Ray Grizzle) produce a yearly environmental report based upon samples taken from around the experimental farm. This monitoring program could serve as a baseline for projects in the Gulf of Mexico (personal communication, Dr. Michael Chambers, UNH, June 2006). According to Dr. Chambers his experience in the Gulf of Mexico on a platform was that the marine ecosystems outside the cage quickly established and consumed any extra feed or nutrients from the cage. This included urchins, barnacles, crabs, polycheates, and numerous fish species. A large scale, commercial farm will have a greater effect on the environment, so cage depth, size, biomass, spacing and feeding strategy will be important factors to consider.

The UNH-OOA project concluded the following:

NH Inner Shelf is Heterogeneous -Composed of Muddy
Sands, Gravels, Bedrock

- Benthos Typical of NH Inner Shelf Environments

Impact of Aquaculture Activities To Date -No
Impact on Organic Content of Sediments -No
Impact on the Benthic Infauna

The Kona Blue Water Farms, OOA group recorded offshore impacts from their commercial open ocean fish farm off Unualoha Point, Kona, Hawaii. Their web site has a number of studies posted http://www.blackpearlsinc.com/3_4.shtml. The permits that were obtained are posted, as well as feasibility and impact studies which could be used as examples.

Additional impacts have been recorded by the following Project:

Mariculture in the Stait of Juan de Fuca.
http://www.wfga.net/sjdf/index.html.

Finfish mariculture has existed in the Pacific Northwest for over thirty years, but for the past 15 years most effort has focused on culture of Atlantic salmon in protected, inshore pens. The Strait of Juan de Fuca (the "Strait") is a large area with sparse development in some regions and several apparent advantages for mariculture using offshore fish culture technology. The culture could be with salmon or marine fish using surface or submerged net pen systems. The latter are preferable for aesthetic considerations but in some locations the former may be more suitable for technical reasons.

This website provides an overview of pertinent hydrographic conditions and possible impacts of marine or salmonid finfish culture in the Strait for commercial harvest or marine fish stock rehabilitation.

Circulation studies, current and wave meter deployments, acoustic Doppler current profiles and phytoplankton assessments were conducted in three different regions distributed throughout the Strait near the southern shore. Results were compared to existing inshore fish farms nearby and analyzed with a new simulation model that accounts for growth and metabolic oxygen demands of caged fish and the response of phytoplankton to nutrients and grazing.

Previously undetected and persistently lower sea surface temperatures were observed in satellite imagery for the central Strait region, especially during the summer and early fall.

Surface-layer water temperature was positively correlated with dissolved oxygen concentration during the same season. Accordingly, there could be significantly reduced dissolved oxygen content of surface waters of the central Strait during this period. Eastern and western areas of the Strait may be marginally better for fish culture on this account, depending on fish species cultured.

They concluded that low or no impact marine fish mariculture is technically feasible in the Strait. However, the high energy environment and challenging conditions will necessitate revised and novel management techniques to insure successful operations.

The study was sponsored in part by funding from NOAA Office of Oceanic and Atmospheric Research. Many individuals and organizations contributed in kind support, including the Washington Fish Growers Association and members, The Makah Tribal Nation, and several residents of Clallam County Washington who aided in field work and sampling.

Selected References cited by the Mariculture in the Strait of Juan de Fuca study are:

Oceanographic Changes in Puget Sound and the Strait of Juan de Fuca during the 2000–01 Drought. 2003. J. A. Newton, E. Siegel and S.L. Albertson Canadian Water Resources Journal: 28

Effects of the Juan de Fuca Eddy and upwelling on densities and distributions of seabirds off southwest Vancouver Island, British Columbia. 2003. A.E. Burger 2003 Marine Ornithology 31: 113-122.

What Determines Seasonal and Interannual Variability of Phytoplankton and Zooplankton in Strongly Estuarine Systems? Application to the semi-enclosed estuary of Strait of Georgia and Juan de Fuca Strait. 2000. M. Li, A. Gargett and

K. Denman Estuarine, Coastal and Shelf Science 50, 467–488

Nash, C.E. (editor). 2001. The net-pen salmon farming industry in the Pacific Northwest. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-49, 125 p.

Review of Potential Impacts of Atlantic Salmon Culture on Puget Sound Chinook Salmon and Hood Canal Summer-run Chum Salmon Evolutionarily Significant Units. Waknitz et al. 2002

Pathways and Management of Marine Nonindigenous Species in the Shared Waters of British Columbia and Washington. R. Elston for PSWQA, USEPA and Dept. of Fisheries and Oceans

Dungeness Bay Bathymetry, Circulation and Fecal Coliform Studies. 2003. Rensel Associates Aquatic Sciences for the Jamestown S'Klallam Tribe, Sequim Washington and the U.S. Environmental Protection Agency, Seattle, Washington. 94 p.

Effluent Limitations Guidelines and New Source Performance Standards for the Concentrated Aquatic Animal Production Point Source Category, Final EPA rule 40 CFR Part 451. Available at: http://epa.gov/guide/aquaculture/.

Code of Conduct for Responsible Aquaculture Development in the United States Exclusive Economic Zone

For years academic experts starting with Dr. Don Weston at the University of Washington Oceanography Department have pointed out that there are fundamental and important differences between fish culture wastes and wastes produced by municipal and industrial discharge operations. In his landmark 1986 publication on floating fish farm impacts Dr. Weston pointed out that:

- Water flow rates through commercial net- pens are massive, comparable only to major rivers and far exceeding that seen from industrial and municipal waste discharge. The large volume of flow means that measurable effects in the water column at more than a modest distance (e.g., 30 m) are hard to detect.
- The vast majority of wastes from net pens are of an organic nature (i.e., carbon based) and do not include the toxic materials homeowners and some industries flush down their drains or apply to their properties.

Since Dr. Weston published this work there has been rapid and sweeping improvements in the industry including:

- Reduction of waste feed loss by better management (feedback monitoring systems, human-managed automated feeding, improved instrumentation such as dissolved oxygen monitoring tools).
- Improvements in pen construction and operation including tensioning of “gravity” cages so they simulate the “offshore” style cages in strong water current areas.
- Relocation of sites from poorly flushed areas to well-flushed channels and bights
- Improvements in impact monitoring and use of surrogate indicator measures of the health of the sea bottom (e.g., total organic carbon, redox measurement, etc.).
- Improvements in feed quality and assimilation of nutrients.

The performance standards for net pens off Washington State are as follows:

(This is a distillation of parts of a publication by Rensel [2001] available on the Internet).

- The Department of Ecology (University of Wash.?) elected to manage the pens by allowing a sediment impact zone within the “footprint” of the pens. Outside the 100’ perimeter, performance standards would have to be met.

• The primary cause of the sediment effect was the natural decomposition and breakdown of the fish feces and waste food, mostly carbon compounds that are oxidized through bacterial decomposition. This process requires oxygen, but if the deposition rate exceeds the assimilation rate, the process may become anaerobic and slows down.

• Given the above, carbon monitoring was selected as a reasonable approach to grossly monitor conditions in the benthos. Total organic carbon (TOC) is measured from core samples of the upper 2 cm of sediment, after hydrolyzing carbonates from inorganic forms such as from bivalve shells.

• Carbon (TOC) data was available from a multitude of unaffected, reference sites throughout Puget Sound. This database was used to estimate background conditions, by parsing it into differing silt/clay content categories (e.g., finer sediments naturally have higher contents of carbon) within geographic subregions. By comparing to reference conditions, the relative "health" of the sea bottom at net pen sites could be estimated. Total Organic Carbon "Triggers" or endpoints were defined for each silt and clay category through this process.

• Monitoring of sediment TOC is required at seven stations at each permitted net pen farm in Puget Sound. Four of these stations are located at a distance of 100' from the perimeter on each side of the farm. This distance was not selected arbitrarily, but was derived from observations of well-managed and sited farms in Puget Sound. Three replicate sediment samples are collected at each station (Fig. 4). No further monitoring is required if sediment TOC is not statistically elevated above the TOC trigger corresponding to the observed percent fines at each 100' station. If the measured TOC is significantly higher than the corresponding trigger value, then repeat sampling is required in the following summer with the collection of five replicates of benthic infauna samples at each station that may have failed the TOC trigger, as well as at a suitable reference location. Benthic infauna (i.e., invertebrate) enumeration analysis is required for any station at which elevated TOC is observed during the second round of sampling.

• Each farm is required to manage its production such that there are no significant negative effects on benthic resources beyond the boundary of this sediment impact zone. Washington State Administrative code states that biological resources in sediments are considered adversely impacted if the mean numbers of crustaceans, mollusks, or polychaetes in the test sediment are reduced to significantly less than 50% of the number of animals belonging to the same taxa living in an undisturbed reference sediment. A one tailed t-test at a = 0.05 for five replicate samples is the basis of the test. The overall Puget Sound sediment standards are being revised and upgraded, with a probable shift to species diversity as an end point rather than species abundance (B. Betts, WDOE Sediment Management Unit supervisor).

- Should any of the test stations around the pens have results showing a violation of the general benthic abundance rule mentioned above, the farm managers must prepare a plan showing how compliance will be achieved.

- Benthic conditions at each of the four orthogonal 100’ SIZ stations must be photographically documented periodically and whenever sediment samples cannot be collected and analyzed in conformance with the requirements stipulated in the Puget Sound Protocols and the permits.

Optimum Conditions for Cage Farming

There must be natural shelter from storms and large waves, water depth in the range 15 to 50 meters and consistent tidal water exchange. Water flow should average speed greater than about 5 cm/s but this is not fixed. Rather it is dependent on stocking density and total biomass (total weight of fish) on a particular site.

Suitable conditions occur along the fjiordic and channel coastlines of British Columbia, Canada, Chile, Norway and Scotland and this is the reason that salmon farming has been so successful in these countries. Similar conditions exist in many other countries, though to a lesser extent. Where they do occur, such as in Greece, Japan, parts of Australia and in Washington and Maine, USA, cage farming of several species of fish is now established.

Environmental Effects and Regulation

The background for regulation of Washington State aquaculture:

In the mid 1980s, amidst boom in Atlantic salmon culture worldwide, the Washington State Departments of Ecology and Fisheries commissioned a synthesis and review of the known effects of salmon net pen culture, which resulted in a milestone literature review by Dr. Donald P. Weston of the University of Washington (Weston 1986). This document was widely acclaimed as the best-available review and interpretation of the literature at the time and is still a useful and pertinent document in many regards. Immediately after the issuance of the report, Dr. Weston, in concert with the state resources agencies and interested parties, prepared the Interim Guidelines (SAIC 1986), which helped guide agency management and monitoring efforts for nearly a decade. The Washington Department of Natural Resources adopted the Interim Guidelines as legal requirements of their aquatic lands leases. The requirements were detailed, but may be summarized as having the following primary attributes:

- Depth and velocity minimums were established, depending on size of annual fish production
- Pens could not be located near protected special habitats for fish & wildlife, invertebrates, (e.g., clam beds, herring spawning areas, marine bird and mammals)
- Pens were either not allowed in “nutrient-sensitive” areas subject to nitrogen-limitation of algal growth or strictly limited to minor production amount in transition areas.
- No un-pelletized (raw) feed or tributyl-tin net treatments were allowed
- Only non-lethal predator control, such as exclusion nets, were permitted
- Antibiotic use and fish transfer reports were required
- Hydrographic and bathymetric studies at proposed sites were required before initial permitting, although existing pens were allowed.
- Prescriptive water column monitoring was required during the algal growing season and benthic sampling of infauna, chemistry and grain size were required along with SCUBA diving surveys for observation of waste feed, feces, and bacterial growths.

There were no “end points” to this Interim Guideline monitoring, i.e., no regulatory threshold values or criteria were promulgated to determine if too much enrichment or impact was occurring. The idea was to amass a database so that future regulations could be based on more detailed fact.

Other studies done specifically for Washington State fish mariculture:

About 1990 a Programmatic Environmental Impact Statement for net pens was prepared by consultants for several state agencies under direction of the Washington Department of Fisheries. The work was peer-reviewed by leading fisheries and oceanographic authorities, included the best available technical information and was drawn in part from studies published in technical appendices (Parametrix et al. 1991). The purpose of the PEIS was to clarify the known technical impacts of net-pen rearing, to aid the site permitting and monitoring process. Aesthetic impacts were also considered in this effort. The results were transferred and adapted for use by the State of Maine but have evolved slightly differently in subsequent years (Normandeau Associates and Battelle. 2003).

The results of the 1980s and 1990s impact monitoring work in Washington State:

The Department of Ecology assembled all available monitoring information and hired an independent environmental consulting company (Stripland Environmental Associates) to assist them to quality control and analyze the data. Some of the data was discarded for technical or quality control reasons. It was found that most all measurable or significant impacts, as measured by infauna analysis and carbon content on the seabottom occurred within 30 m of typical commercial net pens, sometimes much less. This was unexpected, as prior studies by independent, academic workers had focused on one particularly large site in Clam Bay that was the world's largest array of pens and this pen system generated impacts much further away. This atypical system was subsequently reduced greatly in size and reconfigured to match the site-specific carrying capacity. The Department used the relevant monitoring data to construct a two stage benthic monitoring and performance standard system, as described below.

Regarding water column monitoring, some of the sampling was found to be of little value and was discarded. This included nutrient impact sampling, because the results appeared too variable and not really of consequence as commercial pens were all located in water naturally replete with nitrogen and phosphorus. Dissolved oxygen monitoring up and downstream of pens was discontinued as all data (and thousands of data from Maine) showed that measurable effects only occurred a few meters downstream of the pens. In practice, most fish farmers continued to monitor and record dissolved oxygen for their own use in managing their farms during the summer and fall periods.

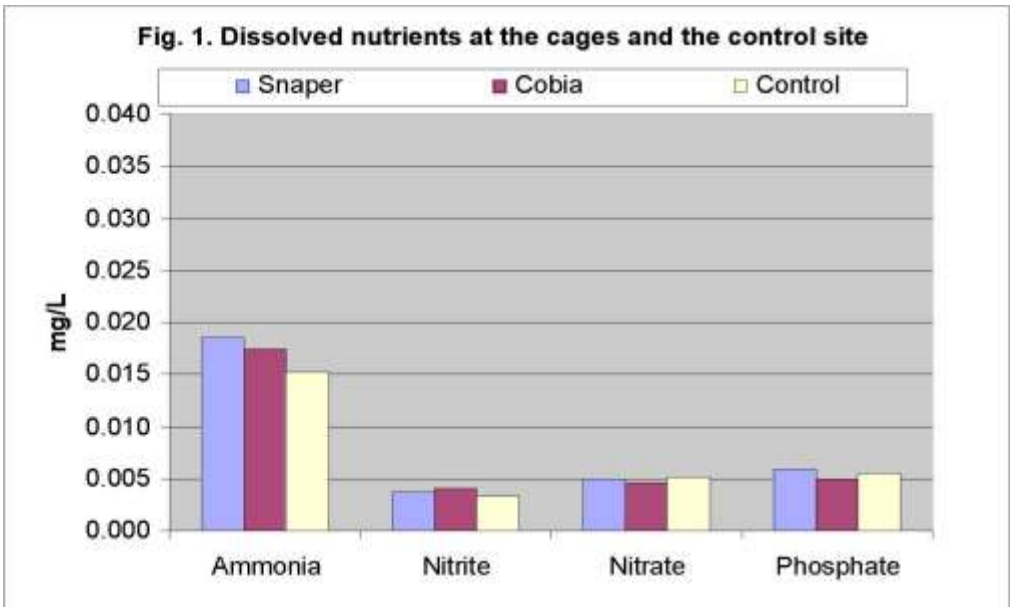
Federally authorized discharge permits issued:

Washington State was the first U.S. state to authorize NPDES permits for fish culture in 1996, using the studies and analyses discussed above as a firm scientific basis. In 2001 the permits were revised after a review of the first five years of data to include the measurement of copper (a trace metal used in animal nutrition and as an antifoulant on some of the nets) beneath and near the pens.

In 2005, all existing commercial net-pens met or exceeded performance standards that the Department of Ecology had in place.

Dr. Dan Benetti (Univ. of Florida) states "The amount of nutrient output from offshore cages properly managed should be negligible, as shown by data gathered from projects in Hawaii, Puerto Rico, New Hampshire and the Bahamas". In his opinion, as long as the broodstock fish are well managed, are from the same genus and species and at least 25% of the fish are replaced every year, there should not be negative effects. Broodstock from the same genus and species from a different geographical area could actually bring more desirable genetic diversity to the offspring. It could be a plus in avoiding inbreeding. Exotic species must not be considered! He further states that cage culture allows a continuous exchange of water (OVER 600 MILLION GALLONS OF DAILY WATER EXCHANGE IN OFFSHORE CAGES DEPLOYED IN AREAS AT THE RIGHT DEPTH AND CURRENT VELOCITY) that reduces stressors associated with water quality, thus allowing higher fish density without environmental problems. LESS DISEASE OUTBREAKS AND PROBLEMS SHOULD BE EXPECTED IN THE OFFSHORE ENVIRONMENT BECAUSE OF THE EXCELLENT WATER QUALITY ASSOCIATED WITH THE OFFSHORE ENVIRONMENT. POTENTIAL APPLICANTS FOR PERMITS TO CONDUCT

OFFSHORE AQUACULTURE OPERATIONS MUST SHOW PROOF THAT THE FINANCIAL REQUIREMENTS OF THE OPERATION CAN BE MET EVEN BEFORE APPLYING FOR SUCH PERMITS.



The above figure was provided by Benetti, showing dissolved nutrients at Snapper, Cobia and Control cages.

Offshore Aquaculture Benthic Impacts Reported: (from Riedel and Bridger 2004)

1. Mattsson and Linden (1983). Species composition changed up to 20 m away from mussel farm.
2. Brown et al. (1987). Species composition changed up to 15 m away from cage edge.
3. Gowen et al. (1988). Species composition changed up to 30-40 m away from cages.
4. Lumb (1989). Impacts restricted to within 50 m of cage edges and dependent on seabed type.
5. Ritz et al. (1989). Macrofaunal community under the farm adopted an undisturbed condition 7 weeks post harvest of farm stock.
6. Kupka-Hansen et al. (1991). Species composition changed up to 25 m away from cages.
7. Weston (1990). Farm effects on sediment chemistry evident up to 45 m from the farm; species composition changed at least to 150m away from cages.

8. Johannessen et al. (1994). No influence of fish farming could be detected 250 m away from cages.
9. Krost et al. (1994). Affected area extended 3-5 m from the fish farm margin.
10. Wu et al. (1994). Impacted area extended to 1000 m with industry using trash fish as feed and poor water flushing exists.
11. McGhie et al. (2000). Farm wastes largely restricted to area beneath sea cages; most of the sediment organic input from feces; and 12-month fallowing period sufficient to return site to pre-farm oxic conditions.
12. Morrisey et al. (2000). Large temporal and spatial variabilities depending on water velocities; recovery times estimated between 3-12 years.
13. Dominguez et al. (2001). No affect on physical and chemical sediment characteristics due to fish farm operation in high average water current velocity (6 cm/s) site.

Full citations for the above 13 references can be found in : Bridger, C.J. (editor) 2004. “Efforts to Develop a Responsible Offshore Aquaculture Industry in the Gulf of Mexico: A Compendium of Offshore Aquaculture Consortium Research”. Mississippi-Alabama Sea Grant Consortium Pub. MASGP-04-029. 200 pp. (Chapter 6, Environmental Issues Associated with Offshore Aquaculture and Modeling Potential Impact. p 95-108, by Ralf Riedel and C.J. Bridger. Citations found on pages 105-107.

OTHER OFFSHORE AQUACULTURE IMPACT DISCUSSIONS:

Fish farming will result in increased nutrients in the surrounding environment. However, most studies to date have concluded that aquaculture sited in preferable locations for optimal fish health will not result in increased abundance of phytoplankton species (Parson et al. 1990; Pridmore and Rutherford 1992). In fact, Arzul et al. (2001) reported inhibited phytoplankton growth when in the presence of excretion from selected finfish species (sea bass and salmon). These results were in stark contrast to the excretion from shellfish species (oysters and mussels), which stimulated phytoplankton growth rates.

Numerous authors have discussed the mechanics and relationships involved in modeling benthic impacts from fish farm wastes (e.g., Hargrave 1994). Complex hydrodynamic models have been developed for specific regions (Panchang et al. 1997), but are unlikely to be general. DEPOMOD is a more generic, end-user benthic impact model developed for the Scottish cage culture industry (Cromey et al. 2002) using changes in species population composition to determine impacts. SEI (The Simulation for Environmental Impact) is another model created by Riedel and Bridger, 2003), further described by them in Riedel and Bridger, 2004, p.98-101.

Good site selection was one method discussed as a potential way to reduce the impacts of total organic carbon under cages. Fallowing or setting aside a farm for the duration of several months to a year was cited as another way to reduce impacts.

OTHER OFFSHORE AQUACULTURE IMPACT DISCUSSIONS:

PICES Meeting. Yokohama Japan S8: FIS/MEQ (Oct. 13-22, 2006)
Aquaculture and sustainable management of the marine ecosystem

Co-Convenors: Toyomitsu Horii (Japan), Jie Kong (China) and Michael B. Rust (U.S.A.)

"Activities associated with aquaculture can result in both positive and negative impacts on the marine ecosystem. The environmental, ecological and genetic capacities of the marine environment need to be considered to maintain sustainable aquaculture development and a healthy wild ecosystem. At various levels of aquaculture production, environmental hazards can be assessed and management measures developed to minimize those hazards to the marine ecosystem and/or their probability (risk) of occurrence. PICES WG 18 has begun to consider environmental and ecological impacts associated with aquaculture. These include ecological hazards associated with nutrient release, escaped or released cultured organisms (predation, competition), and the potential for disease transfer. In addition, the escape of genetic selected species used for aquaculture may have harmful effects on the genetics of wild populations of native species. Genetic risks should be evaluated based on potential impacts to biodiversity and ecosystem conservation using proper evaluation techniques. These techniques should be consistent among researchers where possible. Moreover, it is necessary to consider the influence on ecosystem and genetic diversity when artificially produced seedlings are released for stock enhancement or rebuilding. To promote responsible aquaculture in a healthy marine ecosystem, it is critical to continuously evaluate and manage the aquaculture activity. Clearly defining the potential hazards to the ecosystem, assessing the probability that hazards will occur and implementing mitigation strategies to reduce or eliminate hazards can facilitate this oversight. The goal of this session is to identify and establish evaluation techniques and models for potential hazards which aquaculture exerts on genetic diversity, ecosystem function and/or the marine environment. The potential for standardization of methods and models that deal with interactions between aquaculture and wild organisms will also be explored."

Details of this meeting are available on the Internet at
http://www.pices.int/meetings/annual/PICES15/scientific_program.aspx?session= S8#S8.

Concerns about Offshore Aquaculture from Agencies, NGO's, Environmentalists, Media, and the Public at Large

- **Species**

–Native Species Only

–Non-use of Genetically Modified Organisms (GMO)

–Domestication to minimize disease concerns

- **Hatchery**

–Probiotics

- **Growout Systems**

–Advanced Technology
- Exposed Areas
- Strong currents and depth for effluent dispersion
- **Feeds**

–Efficiency
- Saturation of Oxygen increases FCR
- Fish are more efficient than terrestrial (don't fight gravity)

–Reduction of Fishmeal
- Pelletized diets with reduced fishmeal content
- Best Management Practices (BMP) development
- **Environmental Assessment**

–Water Quality Parameters Monitored

- Water Column
- Benthos
- Biodiversity
- **Addressing industry needs and issues/concerns from agencies, NGO's, press and public at large: native species; no GMO's; probiotics; only FDA approved chemicals (except food additive eugenol); adv. growout technology; exposed sites offshore; high efficiency feeds, low FCR, reduce use of fish meal; no drugs, chemicals, ATB's, hormones, pigments - all natural, "organic"(?); environmental monitoring H_2O/benthos**

Other discussions of environmental effects of offshore aquaculture found on the Internet (both negative and positive) are as follows and serve as further examples of the type of literature and information that is out there:

“REVIEW AND SYNTHESIS OF THE ENVIRONMENTAL IMPACTS OF AQUACULTURE. Scottish Executive Publications. 14 June 2006

CHAPTER TWO THE DISCHARGE OF WASTE NUTRIENTS AND THEIR INTERACTION IN THE WIDER MARINE ENVIRONMENT

SOLID WASTES FROM CAGE FARMS AND EFFECTS ON SEDIMENTS

2.1 The major particulate effluent from a cage farm consists of fecal material and uneaten fish feed. The amount of feces and feed will depend not only on the digestibility of the food, but also on a range of other environmental and husbandry factors such as temperature and disease status. Feeds are fish meal/oil based, but they also contain a wide range of components including wheat, soya meal, crustacean meal, vitamins, amino acids, minerals and pigments.

2.2 Modern diets are easily assimilated and give good feed conversion ratios (FCR: product produced per unit feed), which has reduced waste inputs to the environment per unit production. Economics are also important, as overfeeding is most likely when the value of the product is high and the cost of the feed is low, with greater care being taken of an expensive feed product. In the early years of the Atlantic salmon farming industry, feed losses were thought to be up to 20% of total feed input. It is now generally accepted that feed losses have been reduced to less than 5% in well-run farms. This is important, as fish feed is extremely energy-rich, causing much greater organic enrichment than feces on a weight for weight basis.

2.3 The solids emanating from cage farms consist of a range of particle sizes and densities, with a range of settling velocities. These particles are affected by water currents that may vary with depth. The resulting dispersion may cause settlement well away from the farm, but usually the highest deposition rates are in the immediate vicinity. The eventual site of deposition will depend on local bathymetry, water movement, and flocculation (clumping of finer particles to form larger, more rapidly settling particles). Bacteria may break down slow settling particles, leading to the release of nutrients into solution. A variety of computer models have been used to track particles to the bed in an effort to predict the zone of organic enrichment. On reaching the seabed, these particles may become incorporated into the sediment or may be resuspended by near-bed currents, thus further dispersing them away from the cages.

2.4 Addition of organic wastes to sediments immediately causes an oxygen drain as bacteria degrade them. The dissolved oxygen concentration at any point in the sediment is dependent on the rate of its uptake, either to fuel aerobic metabolism, or to re-oxidize reduced products released by anaerobic bacteria deeper in the sediment. When the oxygen demand caused by the input of organic matter exceeds the oxygen diffusion rate from overlying waters, sediments become anoxic and anaerobic processes dominate.

2.5 Animals burrowing in sediments that receive normal detrital inputs have a diverse fauna with many species and include a wide range of higher taxa, body sizes and functional types. As organic inputs increase, this diversity also initially increases as the enhanced food supply provides opportunities for the expansion of existing populations and the immigration of new species. However, deterioration of the physical and chemical conditions in the sediments progressively eliminates the larger, deeper-burrowing and longer-lived forms favoring smaller, rapidly growing opportunist species. With increasing inputs, the surface sediments become anoxic and only a small number of specialist taxa can survive, mainly small annelid and nematode worms, which may flourish in huge numbers. Where anaerobic processes occur close to the sediment surface, this may become covered in dense white mats of sulphide oxidizing bacteria Beggiatoa sp. High flow rates, bringing a continuous supply of oxygen to the sediment surface, do allow the survival of infauna even when the sedimentary surface layer is anoxic but, where sediments suffer oxygen deficiency for even relatively short periods of a few hours, e.g. caused by slack water, large sections of the benthic macrofauna are eliminated. Ultimately, increasing levels of sedimentary oxygen demand bring about anoxia in the lower levels of the overlying water column leading to the elimination of all higher life.

2.6 Organic degradation rates for labile materials such as are present in waste feed (e.g. lipids and protein) are broadly similar in both anaerobic and aerobic sediments but less labile organic material degrades much more slowly in aerobic sediments. The small worms that dominate enriched sediments significantly enhance the degradation rate of organic materials by mechanisms that are not yet fully understood. Thus, if these are excluded by a severe lack of oxygen in the sediment the rate of organic breakdown is reduced. This enhances organic accumulation through negative feedback.

2.7 The rate at which sedimentary ecosystems recover following the removal of cages or the cessation of farming is of considerable interest, particularly as the fallowing of sites and rotation of cages has now become recommended practice in many areas. In a Scottish study of benthic recovery, communities adjacent to the cages returned to near-normal (with respect to unimpacted stations) 21–24 months after farming ceased, but to date no study has looked at recovery processes over a sufficiently long period to be certain about recovery times.

Summary

2.8 Particulate organic wastes from cage farms have a profound effect on the benthic environment and recovery, on cessation of farming, may take several years. Impact on the seabed is the most obvious pollution effect from fish farms and measures of this effect are the main method of regulating and controlling the size of fish farms such that the local environment is not overwhelmed. However, severe effects are generally confined to the local area (a few hundred meters at most) and the total area of seabed used for this purpose is insignificant in terms of the total coastal resource. Recovery of the seabed after farming is variable, but in Scottish waters may take around 2 years.

Research Gaps

2.9 Although the gross effects of fish farming on sediments are relatively well understood, much remains to be done regarding the dynamics of waste input, responses from the sediments in terms of the interactions between microbial and macrobiological processes, how these influence the chemistry of the sediments, and the physical processes of oxygen supply, sediment resuspension and mixing by water currents. These interactions take place against a background of seasonal changes and the 2 year farming cycle that results in great variation in the supply of organic materials to sediments. In addition, interannual variability in biological factors, such as the supply of invertebrate larvae, probably has effects that are not as yet well understood. These aspects are important as they affect: 1) our understanding of the assimilative capacity of sediments with respect to farm wastes; 2) the ways in which chemical contaminants in sediments are redistributed to the wider environment and; 3) the ways sediments consume oxygen and release dissolved nutrients into the water column.

DISSOLVED NUTRIENT INPUTS AND EFFECTS ON PHYTOPLANKTON

Introduction

2.10 Fish farms undoubtedly contribute to the pool of plant nutrients in seawater. Fish excreta and decaying food contain or release ammonia and salts of nitrate and phosphate. In pristine coastal waters the nutrients are typically present only in small amounts, but are important because they support the growth of seaweeds and the much smaller floating algae that comprise the phytoplankton and which can be properly seen and identified only with microscopes. Additional nutrients enter the sea from acid rain and from rivers enriched with (treated) urban sewage, farmyard waste and drainage from fertilized soils. In the north and west of Scotland, however, fish farms are the most important extra source of nutrients in most lochs and voes.

2.11 Phytoplankton, it has been said, are "the grass of the sea", the basic food on which animal life and fisheries depend. Whenever there is sufficient light, planktonic algae increase in numbers by absorbing mineral nutrients and converting solar energy into organic matter. They are eaten by equally microscopic single celled creatures, the protozoa, as well as by pelagic crustaceans, the size of seeds, termed zooplankton. In turn these zooplankton provide food for larger animals and thus for fish. Live and dead plankton sinks towards the seabed and provides the main source of food for animals living there.

2.12 However, nutrient enrichment can have negative consequences. Most of these are comprehended by the widely accepted EU definition of eutrophication, which is "the enrichment of water by nutrients especially compounds of nitrogen and phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms and the quality of the water concerned".

2.13 The undesirable consequences of eutrophication include:

* Increased abundance of micro-algae, perhaps sufficient to discolor the sea and be recognized as a bloom or "Red Tide";

- Foaming of seawater;
- Killing of free-living or farmed fish, or sea-bed animals;
- Poisoning of shellfish;
- Changes in marine food chains;
-

* Removal of oxygen from deep water and sediments as a consequence of the sinking and decay of blooming algae.

2.14 The main concerns relating to the marine aquaculture industry in Scotland are that the discharge of plant nutrients from finfish farms:

* Has led to an increased occurrence of algal blooms.
* Has disturbed the natural ratios of nutrient elements in seawater so favoring the occurrence of toxic species over harmless algae.
* Has made potentially toxic algae more poisonous.

2.15 **This part of the report presents the scientific background and reviews the evidence relating to these charges. Our conclusion is that, except perhaps in a few enclosed waters, enrichment by fish farm nutrients is too little, relative to natural levels, to have the alleged effects.** However, we cannot, as we would wish, support this conclusion with data from series of measurements of nutrients, phytoplankton, algal blooms, and the presence and toxicity of harmful species, made at key sites over the several decades that span the development of the current fish farming industry. The future collection of such data, and its scientific analysis, should be made a priority.

Phytoplankton growth and harmful algal blooms

2.16 Under conditions of plentiful light and nutrient supply, many types of planktonic algae reproduce at an increased rate, potentially doubling their abundance every few days. The peaty waters of many sea-lochs, and the turbid sea in regions of strong tidal streams, are too dark for algal growth except near the sea surface. In many lochs, however, river discharges lower near-surface salinity and create a distinct and well-illuminated upper layer. Adding nutrients to this layer, either in river water or by way of fish excreta, can create ideal conditions for algal blooms. Even here, however, algal population increase can be offset by zooplankton grazing or by dilution with seawater containing less phytoplankton.

2.17 Some types of algae, usually slow growing, deter their potential predators by means such as the formation of jelly-like masses, or the making of chemicals that make the algae taste or smell bad to their potential consumers. Should nutrient enrichment coincide with certain physical conditions, and other, poorly understood factors, it may be the growth of a noxious species that is stimulated, leading to a failure of this grazing control and the creation of a Harmful Algal Bloom. According to the editorial in the scientific journal Limnology and Oceanography (Volume 42, 1997). "The last two decades have been marked by an extraordinary expansion in the nature and extent of the marine phenomena we now call "harmful algal blooms". For years, the term "red tide" was used to describe many of these outbreaks, but in time, that term became less and less appropriate ... Not all red tides are harmful, and many blooms that cause negative impacts are not red and in fact, do not discolor the water at all. Some blooms are associated with potent toxins in the causative algae, while others cause problems simply because of high algal biomass. Some are of concern at exceedingly low cell densities .... Blooms of seaweeds or macroalgae also cause harm, in many cases as a result of the same environmental forcing that regulate microalgal blooms. The search for a term that encompasses these diverse phenomena was doomed to fail, but, for better or worse, "harmful algal bloom" is now used by scientists and government officials throughout the world, with HAB the obligatory acronym."

2.18 In most Scottish waters, the increase in daylight during spring stimulates phytoplankton to make a Spring Bloom with the aid of mineral nutrients formed during the winter from the decay of the previous year's plankton. The algae, termed "diatoms", are normally the most important members of this bloom, which is in some places sufficiently dense to make the sea brown in color. Even when the Spring Bloom is enhanced by nutrient enrichment, it is not normally harmful, because the diatoms get eaten and thus provide food to fuel the pelagic ecosystem for much of the rest of the year. In addition to the nitrates and phosphates needed by all algae, diatoms also need dissolved silica to make the glassy material that forms the walls of their cells. When the supply of this nutrient becomes exhausted, diatoms cease to grow, and, if nitrates and phosphates remain, other algae may succeed the diatoms. Amongst these are flagellates, characterized by one or more whiplash-like organelles named from the Latin, flagellum. The tiny flagellate Chrysochromulina polylepis formed extensive and persistent blooms that caused widespread fish kills in Scandinavian waters in 1988.

2.19 Dinoflagellates have two flagella, arranged in characteristic fashion: one circles the waist of the cell, and spins it, the other trails lengthways and acts as a propulsive screw or propeller. The dinoflagellate formerly called Gyrodinium aureolum, but recently renamed as Gymnodinium mikimotoi, typifies harmfully blooming algae. G. mikimotoi seems to have been introduced into European waters in the 1960s. Where dinoflagellates are abundant, typically in late summer, the sea becomes dark brown or red-brown and sometimes appears oily

- the classic signs of a Red Tide. These have sometimes been associated with the death of seabed animals. In Loch Fyne in September 1980, a Red Tide of the dinoflagellate G. mikimotoi killed salmon in ponds supplied with water from the loch.

2.20 Other harmful algae are associated with 'shellfish poisoning', in which toxins produced by the algae are accumulated in mussels, oysters, scallops, etc., that feed by filtering phytoplankton from water. Paralytic shellfish poisoning (PSP) is caused by a dinoflagellate formerly called Gonyaulax tamarensis and now Alexandrium tamarense. Humans eating intoxicated shellfish suffer numbness, headache, nausea, and diarrhea, leading to paralysis and death in extreme cases. PSP has been known in southeastern Scotland for several centuries. Species of the dinoflagellate genus Dinophysis are responsible for Diarrhetic Shellfish Poisoning (DSP), which involves rapid onset diarrhea and vomiting (but is not fatal). Finally, Amnesic Shellfish Poisoning (ASP) has been known to science and medicine only since its discovery in 1987 in eastern Canada. Nausea and diarrhea occur when humans eat intoxicated shellfish, leading in extreme cases to hallucinations, short-term memory loss, and death. The toxin seems especially persistent in scallops in Scotland. The causative algae are diatoms, mainly species of the genus Pseudo-nitzschia, and thus disprove the general rule that 'diatoms are good and flagellates are bad'. A common feature of all the shellfish poisonings is that potentially harmful levels of toxin can be found in mussels or scallops even when the causative algae are not abundant.

Harmful algal blooms in Scottish waters

2.23 The major concern relates to algal toxins accumulating in shellfish. Although toxicity monitoring prevents harmful consequences to humans, the occurrence of toxicity results in substantial economic loss through closure of shellfisheries. At first glance, it indeed seems that these types of HAB have grown more common and widespread during recent years, but this may be the result of greater spread and intensity of toxin monitoring rather than a real increase in the frequency of occurrences of HABs. It is unfortunate that there are no sites in fish farming regions that have been regularly and continuously sampled for phytoplankton amount and type since the 1960s, as this would allow a sound judgment to be made concerning whether toxic organisms had increased. However, information about phytoplankton is available from various sources and for particular places and years. This evidence, sporadic as it is, does not show conclusively that there has been a widespread increase in the abundance of most of the types of organisms responsible for harmful blooms. Despite increased numbers of fish-farms, which might be expected to provide a better detection network for harmful blooms of Gyrodinium aureolum and flagellates, there would seem to have been a decline in reports of such blooms.

2.24 On the east coast, present-day PSP levels seem to be no worse than those reported for 1968-1990. The apparent spread of toxicity (as opposed to that of the organism) to the Northern isles and the West-North-Hebrides region may have been a result of wider monitoring, a genuine spread of the causative organism, or a spread of toxicity or of toxic strains amongst existing populations. There is no evidence that Alexandrium tamarense is becoming more abundant either at new or traditional sites: it remains an organism that can give rise to significant toxin in shellfish at low concentrations of the dinoflagellate.

2.25 Dinophysis acuminata and other DSP-causing species have always been widely distributed in Scottish waters, and, with the exception of a Red Tide in Loch Long in 1994, there seems no evidence of an increase in abundance. As with Alexandrium tamarense, D. acuminata and related species can cause DSP when present in relatively small numbers, although the occurrence of outbreaks of DSP seems to be more sporadic and localized than that of ASP. DSP may have been endemic in Scottish waters for much longer than revealed by systematic monitoring for the toxin.

2.26 The greatest puzzle relates to ASP. Pseudo-nitzschia spp., formerly known as Nitzschia spp., has been common, and sometimes abundant, in Scottish waters for as long as records exist. Widespread toxicity was discovered soon after the commencement of extensive monitoring in 1999. Common sense suggests that this is too much of a coincidence, and that toxicity likely existed in years prior to 1999, an argument supported by sporadic records from occasional sampling in 1997 and 1998. But did ASP occur in Scottish waters long before 1997? If it did not, what has changed within the populations of Pseudo-nitzschia spp.? If it did, why are there no records of occurrences of the signs and symptoms of ASP amongst either Scottish or other European consumers of Scottish scallops?

2.27 Experience elsewhere may be relevant. In Mexico, although Red Tides have been known to occur in coastal waters for a long time, it is only in the last decade that ASP, DSP and PSP have become a cause for concern. A lack of regular monitoring of these waters - PSP analysis only taking place regularly in shellfish destined for export to the USA - suggests that where shellfish poisonings occurred in the past, they may have either been ignored, tolerated without permanent remark, or ascribed to bacterial contamination of the shellfish rather than to the effects of algal toxins.

2.28 On the one hand, then, the available data can be read as 'no change'. On the other hand, it must also be said that these data do not conclusively exclude

the possibility of a real increase in the frequency of Scottish HABs, and especially in ASP, generally, and PSP in the Northern Isles. What could account for such increases?
2.29 We now turn to three specific hypotheses commonly espoused regarding finfish aquaculture in relation to eutrophication and harmful blooms.

Hypothesis 1: plant nutrients from finfish farms have led to an increased occurrence of algal blooms

2.30 Scientists would prefer to address this charge with extensive data obtained in fish farming regions before and during the development of the industry. In Japan, for example, many years of observations in the Inland Sea have documented an increase and then decrease in the number of Red Tides as urban and industrial discharges first increased and then were controlled. In Scotland we do not have such time-series. Instead, there are two main sorts of indirect evidence.

2.31 The first derives from many site-specific studies carried out for purely scientific reasons and largely before the main growth of salmonid farming. These studies give a good picture of seasonal changes and spatial variation in coastal phytoplankton, either under natural conditions or under nutrient enriched conditions in the Firth of Clyde and its lochs. A study of Loch Hourn between 1988 and 1990, during the establishment of a farm in the inner part of the loch, showed a small but detectable increase in nutrient but no significant effect on the biomass or the 'balance of species' of the phytoplankton. A comparison between the nutrient-poor Loch Creran between 1972 and 1982 (before local fish farming) and in the nutrient-enriched Loch Striven circa 1980, shows that human-generated nutrients do cause larger blooms. The extra nutrients in Loch Striven derive largely from wastewater and agricultural inputs to the Clyde and associated rivers, and greatest winter concentrations in Striven were more than twice those in Creran. Although phytoplankton abundance was highly variable in both lochs, and sometimes less in Striven than in Creran, the largest blooms in Striven were much larger than those in Creran at the same time of year.

2.32 The second sort of evidence derives from the application of mathematical models, which allow the theoretical effect of adding nutrients to sea-lochs or coastal waters to be estimated. Two types of model have been employed:

- simple 'screening' models that represent the contents of a loch or voe or coastal water as a box or bath full of water, exchanging contents slowly with the outside sea;
- sophisticated and complex models that aim to represent more accurately the water flows in coastal seas and some of the variety of organisms that make up the marine community.

2.33 Both types of models are sets of equations. The equations of screening models are simple, and can be solved 'on the back of an envelope'. The equations of the sophisticated models are complex and difficult, and can only be solved by computers, using programs that require years of effort to render error-free. Additionally, both types of model make assumptions about some of the numbers used in the calculations and about the best way to describe the processes represented in the model. Because of such assumptions, the models are best viewed as sets of hypotheses about the workings of marine ecosystems, rather than completely realistic descriptions thereof. In general, it is wise not to rely too much on results obtained from a single model.

2.34 Prediction of the bulk effect of human-generated nutrients on phytoplankton in small water-bodies - those of the size of a sea-loch - involves calculation of the Equilibrium Concentration Enhancement (ECE) of nutrients. The ECE is the extra concentration that would occur if a steady input of nutrients were to be balanced by steady removal by seawater exchange. Use by algae is ignored. The procedure used by the Fisheries Research Service (FRS) then compares the ECE with concentrations of total nutrients at a reference site (Loch Linnhe). The procedure of the Comprehensive Studies Task Team (CSTT) considers the potential for conversion of the ECE plus background nutrients into phytoplankton: lack of light, or losses caused by dilution or grazing, can prevent such conversion. The reliability with which the yield of phytoplankton from nutrients can be predicted is improved by results from a recent SNIFFER-funded study carried out by Napier and DML and by ongoing work in the EC project OAERRE. An unresolved issue is how to take account of the dissolved organic nutrients naturally present in seawater. Both procedures depend on good estimates of the flushing rates of water in lochs and voes, and a number of Scottish and European projects aim at improving methods for such estimation. Application of the FRS procedure shows that a few sea-lochs and voes are strongly enriched with nutrients to a level where they may exceed Environmental Quality Standards. At most sites, however, relative levels of enrichment are low.

2.35 The ECE procedure can also be applied to larger water bodies, such as the Minch, and allows apportioning of observed nutrient concentrations to known sources. Depending on assumptions made about flow in offshore water, nutrients from west coast fish farms may contribute between 1 and 10% of summer concentrations in the Minch, which is one of the regions most impacted by ASP. However, nutrient levels here are most strongly influenced by inputs from the Atlantic Ocean, human-controlled discharges into the Irish Sea, and poorly understood loss processes. More sophisticated ecosystem models also predict that nutrients from fish farms make a relatively minor contribution to algal production in Scottish coastal waters.

2.36 All told, it may be concluded that the present level of fish farming is having a small effect on the amount and growth rate of Scottish coastal phytoplankton, but that this effect should not be a cause for concern, except in a few, heavily-loaded, sea-lochs.

Hypothesis 2: plant nutrients from finfish farms have disturbed the natural ratios of nutrient elements in seawater so favoring the occurrence of toxic species over harmless algae.

2.37 Despite many studies of algal growth in the laboratory, science is still far from understanding what controls the 'balance of organisms' in the plankton. Some broad aspects of the balance can be predicted. Those algae associated with eutrophication, Red Tides, and substantial blooms (G. mikimotoi, Phaeocystis pouchetii, and toxic flagellates) do seem to be stimulated by nutrient enrichment and favored by increases in ratios of nitrogen or phosphorus to silicon, but suitable physical conditions and lack of grazing must also be invoked to explain their blooms. In contrast, explanations for the fluctuations in abundance of the species of Alexandrium, Dinophysis and Pseudo-nitzschia causing the shellfish poisonings, remain speculative. The scientific literature contains little unequivocal evidence that the populations of these algae are stimulated, relative to other species, by nutrient inputs or by changes in nutrient ratios. In addition, as already mentioned, there is no clear evidence that their populations have increased in Scottish waters. Of course, absence of evidence is not the same as evidence of absence of effect.

2.38 The perturbing effect of fish farm wastes on nutrient element ratios can in most Scottish cases be shown to be small. Typical farm waste has a ratio of nitrogen (N) and phosphorus (P) of about 11:1, close to natural ratios in seawater and well within the acceptable range of ratios of 7:1 to 30:1. Thus, even where farms substantially enrich lochs or voes, they should not dangerously disturb the

N:P ratio. However, farm waste contains little or no silicon (Si), so can increase N:Si ratios, especially during summer when background levels of nutrients are often low and the Spring Bloom has already drawn down silicate. Therefore, there may be some heavily enriched lochs or voes where the "safe" N:Si limit of

2.5:1 is exceeded locally, especially in the waters of the Northern Isles where nitrate is enriched by inflow from the North Atlantic. However, ECE calculations show that broad-area effects should be small and more sophisticated models show that the ratio of flagellates to diatoms is not much increased by the addition of fish farm nutrients. The concept of safe nutrient ratios is examined in Tett, P. & Edwards, E. (2002) Review of Harmful Algal Blooms in Scottish coastal waters, forthcoming report to SEPA, Stirling.

Hypothesis 3: plant nutrients from finfish farms have made potentially toxic algae more poisonous

2.39 Laboratory experiments show that providing algal populations with an unbalanced mixture of nutrient elements can result in an increase in the toxin content of individual cells. However, some papers report more toxin under nitrogen starvation, others, more under phosphorus starvation. A wise precaution, until more is known, would be to avoid exposing potentially toxic algae to additional nutrient stress, defined as any substantial perturbation of nutrient element ratios. The N:P ratio of fish-farm waste is typically about 11:1, close to optimal, and thus fish-farm perturbation of N:P ratios in Scottish waters is unlikely to stress algae. In contrast, the N:Si ratio may be substantially increased during summer in lochs and voes that are heavily loaded. Would this change stress cells of Pseudo-nitzschia spp. brought into the loch in natural exchange of seawater, causing them to increase their content of the domoic acid responsible for ASP? Or might it instead suppress the diatom in favor of flagellates or dinoflagellates? In any case, the effects should be local and uncommon, and the ECE calculations reported above suggest that fish farm nutrients should not result in nutrient stress in coastal waters in general.

2.40 The FRS monitoring program allows toxin levels in shellfish to be compared with the abundance of the causative algae in water taken nearby. The ratio is highly variable for all three kinds of shellfish poisoning. Variation might be caused by changes in the toxin content of the algal cells, or result from differences in rate of capture of the cells, and accumulation of their toxins, by mussels and scallops. Algal populations might differ genetically between locations. Toxicity might change from year to year as a result of genetic re-assortment during sexual reproduction at intervals of several years. Although these suggestions can help explain apparent changes in levels of toxicity, and although fish farm nutrients seem unlikely to have a widespread effect on algal toxin content, only the development of new methods will allow the claim to be convincingly refuted. Such methods would ideally demonstrate the presence of the toxin in single algal cells.

The influence of fish farm nutrient discharges on sea loch assimilative capacity

2.41 One critical factor determining the carrying capacity of the coastal zone is oxygen availability. Oxygen is supplied through the sea surface and is transported throughout the water column by turbulent diffusion. The activities of the animals and plants and bacteria within the water column and sediments consume oxygen by the process of respiration. If respiratory demand exceeds turbulent supply, oxygen concentrations will fall and may become depleted. Even a modest reduction in oxygen concentration can affect fish and other marine animals. At most sites in Scotland, oxygen supply in surface waters is not a limiting factor. Those sites with problems tend to be located at the head of lochs where tidal currents are lowest. Such sites may experience oxygen problems during warm calm periods.

2.42 Oxygen demand is controlled, amongst other things, by the rate of supply of organic matter, some of which is provided by production of phytoplankton. Nutrients may influence oxygen demand by stimulating primary production, which in turn may be ultimately consumed by bacteria and grazing animals. Whether nutrient inputs have an influence on the carrying capacity of a coastal system depends, therefore, on whether environmental conditions exist for the phytoplankton to uptake and make use, photosynthetically, of the nutrients. In many sea lochs, because of dissolved and suspended material, light cannot penetrate to more than 10-15 m or so. Consequently the zone within the water column where phytoplankton can photosynthesize is relatively shallow and the average illumination experienced by phytoplankton is low. Modeling studies suggest that phytoplankton production is relatively insensitive to changes in nutrient supply as in many areas; production is limited by light rather than by nutrients. Thus, except where special conditions exist, i.e. where nutrients are introduced into a shallow and well-illuminated surface layer, nutrient discharges are unlikely to have a significant effect on capacity for fish farming.

Summary

2.43 Modeling studies have shown that a few sea loch sites are strongly enriched with nutrients to such a level that they might exceed environmental quality standards but, in the main, enrichments are low. It is concluded that the present level of fish farming is having a small effect on the amount and growth rate of Scottish coastal phytoplankton and that this effect should not be a cause for concern except in a few, heavily loaded sealochs.

2.44 The perturbing effect of fish farm waste on nutrient element ratios in most Scottish cases can be shown to be small. Typical farm waste has a ratio of nitrogen to phosphorus that is close to natural ratios. However, there is a possibility that because of the absence of silicate in fish foods there may be a danger of exceeding the "safe" N:Si limit of 2.5 locally at heavily enriched sites in summer when background nutrient levels are low and silicate has been drawn down by the Spring Bloom. However, modeling studies suggest that broad area effects should be small. Similarly there is no convincing evidence to suggest that changes in nutrients as a result of fish farm inputs ratios is likely to stress potentially toxic species to cause them to increase their toxicity.

2.45 Except perhaps in a few enclosed waters, enrichment by fish farm nutrients is too little, relative to natural levels, to have the various effects alleged. However, we cannot, as we would wish, always support this conclusion with data from series of measurements of nutrients, phytoplankton, algal blooms, and the presence and toxicity of harmful species, made at key sites over the several decades that span the development of the current fish farming industry.

Research Gaps

2.46 Further studies of phytoplankton abundance and species composition in some lochs originally studied before 1984 and now the site of major fish farms;

2.47 A few key coastal sites should chosen to bring together long-term programs of monitoring of nutrients, phytoplankton and algal toxins, and the historic and future data collected in this way should be subject to statistical analysis and compared with predictions from mathematical models; the sites should represent a range of loadings by fish farms;

2.48 Inflows of nutrients from the Atlantic Ocean and the Irish Sea should be monitored in winter and summer; such inputs are likely to change because of climate change as well as changes in nutrient enrichment of the Irish Sea;

2.49 Better understanding is needed of water movements within sea-lochs and voes, between them and coastal waters, and in coastal waters;

2.50 Studies of the biology, toxicology and ecology of Scottish populations of harmful algae, especially of Pseudo-nitzschia spp;

2.51 Development of methods capable of detecting the presence of toxins in small samples of phytoplankton - present methodology relies on analysis of shellfish tissues, and can thus provide only indirect information about toxic algae;

2.52 Better understanding of the role of pelagic protozoa in coastal waters, lochs and voes; these organisms may be crucial in preventing the development of algal blooms, yet especially sensitive to pollution with metals or pesticides;

2.53 More information on rates of loss of nutrients from Scottish continental shelf and sea-loch waters, especially concerning the process of denitrification which takes place in organically enriched sediments and which probably removes a substantial part of nutrient-N;

2.54 Continued development of simple, robust models that can predict 'undesirable disturbance to the balance of organisms and the quality of the water' as a result of inputs of nutrient and organic matter by fish farms.

ENVIRONMENTAL ASPECTS OF SHELLFISH CULTURE

2.55 Primarily small companies conduct shellfish cultivation in Scotland, the estimated first-sale value of the industry is around Â£5 million, not including the revenue from managed wild stocks. The recent trends are for increased overall production, an increase in the total number of operational businesses, but a slight decrease in the number of operational sites.

2.56 The main species cultivated, all bivalve molluscs, in descending order of tonnage produced are: the blue mussel, Mytilus edulis; the Pacific oyster, Crassostrea gigas; the queen scallop, Aequipecten opercularis; the king scallop, Pecten maximus and the native oyster, Ostrea edulis. Production is dominated by that of the blue mussel, both production levels and farm gate prices have risen over several consecutive years with a further substantive increase in production reported for 2001 with the expansion of cultivation in the Shetland Isles. Production of Pacific oysters has shown a smaller but consistent increase in recent years.

2.57 All these species are filter feeders, extracting the food they require naturally from the water column. Juveniles for on-growing are supplied from hatcheries (oysters) or collected from wild populations. For the blue mussel, spat can be collected in abundance and is not a limiting factor. During the grow-out phase the shellfish receive no additional feed or medication; as the cultivation processes are close to the natural mechanisms they are inherently sustainable.

2.58 There are, however, two major environmental considerations key to the sustainability of Scottish shellfish production. All bivalve mollusc production areas are classified under The Food Safety (Live Bivalve Molluscs and Other Shellfish) Regulations 1992, and areas are classified A, B or C depending on the number of fecal coliforms. The industry is, therefore, highly dependent on the maintenance of good water quality. The second major constraint on many businesses is the prevalence and duration of closures on harvesting caused by the presence of algal toxins. Most notably, with respect to mussel growers, prolonged closures caused by the presence of Diarrhetic Shellfish Poison (DSP), have threatened to close companies in north-west Scotland over the last two growing seasons. There have also been seasonal closures caused by the presence of Paralytic Shellfish Poisons (PSP). The scallop cultivation industry has been affected similarly by prolonged and widespread closures, since 1999, because of the detection of the toxin that can cause Amnesic Shellfish Poisoning (ASP). The first reports of AST (domoic acid) in king scallops from Scottish waters were coincident with the inclusion of ASP in the biotoxin monitoring program, raising the possibility that it may in fact have been present prior to this. However, as ‘shucking’ or preparation of the scallop for table, leaving only the gonad and adductor mussel, removes 99% of the toxin burden in the scallop, it is unsurprising there were no reports of ASP illness.

2.59 There has been some speculation as to whether there is a link between the nutrient input from fish cultivation and the occurrence of the toxins causing DSP, PSP and ASP in shellfish from Scottish waters. There is no obvious spatial correlation between recent HAB events in Scotland and fish cultivation sites. For example AST (the Amnesic Shellfish Toxin) can be found in scallops from offshore fishing areas as well as from those in sea lochs and the factors controlling the prevalence, duration and distribution of phytoplankton blooms, are clearly operating on a much larger scale. From laboratory study of toxin production in known AST-producing algal strains, it is clear that a change in nutrient ratios, or more specifically the limitation of a specific nutrient, can effect toxin production (see previous section).

2.60 The environmental impacts of shellfish farming in Scotland are generally considered to be minimal. Some studies on the impact of mussel culture have reported a build up of sediments, fecal and pseudo-fecal matter, which caused organic enrichment and a reduction in the diversity of macrobenthos beneath the farm. Other studies have concluded mussel culture had little impact and thus the extent of any impact is closely linked to the site-specific water movements. There are some objections to mussel cultivation on the basis of the visual impact of the floats supporting the culture ropes, although the widespread use of low profile, grey or black floats minimizes the effect. Oyster culture, as conducted in Scotland, has to be considered benign, with a limited visual impact of trestles, only visible at low tides. The tonnage of the other species cultivated is still minimal.

2.61 There is awareness, however, of the need to monitor the carrying capacity of shellfish production waters, particularly in terms of phytoplankton availability. Well-documented studies from other countries have shown that intensive mussel cultivation can result in a significant negative correlation between mussel condition and the annual standing mussel stock; an indication the system is exploited to capacity. In such situations, intensive mussel cultivation will presumably be having an impact on other suspension feeders and throughout the food web. Current models for shellfish cultivation predict and optimize exploitation capacity but there is scope for studying nutrient flux, habitat degradation and deposition below suspended systems.

2.62 To avoid pronounced shifts in coastal processes, conversion, and not dilution, is promoted as the common sense solution to the issue of the additional nutrient loading that results from fish cultivation. By integrating ‘fed’ aquaculture with inorganic and organic extractive aquaculture (seaweed and shellfish), the wastes of one resource user become a resource (fertilizer or food) for the others. Asian countries, which account for more than two thirds of the world’s aquaculture production, have been practicing integrated aquaculture for centuries, whereas Western countries and the more rapidly expanding parts of the Asian aquaculture industry tend to focus on high value, high production monoculture.

2.63 The potential benefits of integrating seaweed / shellfish and finfish cultivation, with the aim of mitigating the effects of the latter are now recognized and being researched in Scotland. There have been several studies investigating the potential benefits of cultivating mussels alongside Atlantic salmon in Scottish sea lochs. Shell and tissue growth of mussels associated with salmon farms were found to be significantly augmented, but the variation of growth rates between lochs was greater than that within lochs, underlining the need for a better understanding of the interaction of site specific characteristics, primary productivity and carrying capacity at an ecosystem level.

2.64 There is now a consensus that at least 80% of the total nitrogen lost from fish farms is available for uptake by marine plants (both phytoplankton and macroalgae) and that fish excreta and waste fish food provide well-balanced nutrients for algal growth. As macroalgae can take up nitrogen from seawater at rates sufficient to support increases in biomass of up to 9–10% a day, they are regarded by some as important, renewable, biological nutrient scrubbers. As such, the potential benefits of their integration to fish cultivation sites is worthy of further attention.

2.65 The use of non-native species is one aspect of the cultivation of non-fish species that could potentially have negative environmental impacts. In some scenarios the risk of introducing disease to native species is of as much concern as any deleterious impacts of the species introduced.

Summary

2.66 The cultivation of non-fish species has few measured, negative environmental impacts, and those that have been recorded are restricted to the vicinity of the farm site. As this type of culture extracts nutrients from the marine system, carrying capacity considerations should be focused on the extent to which the environment can supply these nutrients. It is likely that the cultivation of non-fish species can, to some extent, help reduce nutrient inputs from other activities including fish culture.

Research Gaps

2.67 A fuller understanding of the interaction of suspended-culture mussel populations with other components of the ecosystem, in terms of their scope for growth (phytoplankton availability), their impact on other suspension feeders in the food web and the potential for nutrient release from accumulated biodeposits is required.

2.68 Such studies should be linked to the development of models to assist in calculation of appropriate stocking densities for each bivalve cultivation area and the identification of sites where mussel cultivation could be practiced to advantage.

2.69 Fuller study of the potential benefits of integrating aquaculture species is required, using a combination of nutrient extracting species on site with nutrient enriching species, with a view to increased productivity in the former and a net reduction in nutrient release from the latter.

2.70 There is a need to improve our understanding of the mechanism of toxification and depuration of AST in commercially valuable species such as the king scallop. There is little information at present on the levels and mechanisms of production of domoic acid in Pseudo-nitzschia species isolated locally, the reason for prolonged toxin retention in king scallops or the potential impact of the AST on shellfish physiology, fecundity and recruitment.

Algal introductions to European shores with 10 parts; Pan-European quantitative survey of introductions; Impact on native communities; Demography of introduced species; Propagule pressure by vectors: Fouling, Ballast waters and AQUACULTURE (oyster aquaculture); Life history and biochemical characters of some invasive species; Hierarchical sampling of selected introduced species; Genetic analysis of selected introduced species; Economic impact; Modeling and risk management; Screening protocol; OBJECTIVES: To explain the underlying ecological causes of the introduction, establishment and development of seaweed invasions on European shores; To generate a baseline dataset on the present status of seaweed introductions to European shores, and of future susceptibility to further introductions/invasions.; To elucidate the genetic structure of various populations of selected invasive seaweeds in Atlantic and Mediterranean Europe; To evaluate the economic impact of existing seaweed invasions on a European scale; To carry out risk assessment and propose a screening protocol for invasive macroalgae to be used in coastal management.

The contract has provided resources for the identification of the semiochemicals involved in the location of salmon hosts by sea lice and in the location of mates by reproducing sea lice with a view to developing monitoring and control of lice for use in integrated pest management strategies. Sea lice are the major disease affecting farmed salmon and the industry requires substantial and costly manpower to control this health problem. Although a number of veterinary medicines are now available to treat infections the industry is continually threatened with massive welfare problems and stock losses. In addition, resistance problems to medicines recently introduced are apparent and management practices for the prevention and control of resistance are required. In order for a sustainable integrated pest management strategy for sea lice to be put in place a key set of criteria is required. Firstly populations of lice must be monitored on a regular year-round basis both in the vicinity of the fish and elsewhere in the estuary. Monitoring of sea lice populations is seen as an essential tool in understanding the dynamics of lice infection and for providing knowledge for when to treat fish. Secondly the use of veterinary medicines must be kept down to an absolute minimum to satisfy environmental and public concerns and for the prevention of resistance and its control once it develops. This project provides the means to fulfill both of these criteria by using natural chemical signals, semiochemicals, that regulate important interactions of the louse (host location, mate location). Such cues, once identified, can be used in traps for the routine daily monitoring of lice numbers in estuaries, in baited targets for lure and kill approaches or in push-pull strategies to remove lice from the salmonid host without the use of veterinary medicines. This project is unique in attempting to identify chemical cues in the aquatic environment, which are of significance to sea lice life cycle strategies.

REVIEW AND SYNTHESIS OF THE ENVIRONMENTAL IMPACTS OF AQUACULTURE CHAPTER THREE EFFECTS OF DISCHARGES OF MEDICINES AND CHEMICALS FROM AQUACULTURE

SEA LICE MEDICINES

3.1 A recent review of the availability and use of chemotherapeutic sea lice control products identified eleven compounds representing five pesticide types being used internationally on commercial salmon farms in the period 1997 to 1998. These included two organophosphates (dichlorvos, azamethiphos); three pyrethrin/pyrethroid compounds (pyrethrum, cypermethrin and deltamethrin); one oxidizing agent (hydrogen peroxide); three avermectins (ivermectin, emamectin and doramectin) and two benzoylphenyl ureas (teflubenzuron, diflubenzuron). Of these, six compounds were available for use in the UK (dichlorvos, azamethiphos, cypermethrin, hydrogen peroxide, ivermectin and emamectin). Dichlorvos and ivermectin are not known to be used in Scotland, and hydrogen peroxide, which degrades rapidly to water and oxygen, is not considered to be a hazard to marine life.

3.2 This report concentrates on four compounds currently licensed for use as sea lice medicines in Scotland: the bath treatments, azamethiphos and cypermethrin; and the in-feed treatments, emamectin benzoate and teflubenzuron. Of these, cypermethrin and emamectin benzoate are most widely used and are, therefore, considered to present the greatest environmental risk. Bath treatments involve the discharge of dissolved medicine into the water column after the treatment period. In-feed treatments are ingested by the fish and then excreted over a period of time with most of the losses occurring to the sediments rather than the water column.

Azamethiphos (Salmosan)

3.3 Currently azamethiphos use for sea lice control on salmon farms is limited and will probably continue to decline as the use of in-feed treatments increases. At present, azamethiphos is most often used in conjunction with cypermethrin treatments when lice numbers necessitate control measures but farms have reached their discharge consent limits for cypermethrin. Field studies in Scotland using deployed mussels and lobster larvae indicate that effects on marine organisms in the vicinity of treated cages are unlikely. A dispersion and toxicity study undertaken in the Lower Bay of Fundy, New Brunswick, at sites displaying a range of dispersive energy conditions concluded that azamethiphos presented a low to moderate environmental risk. The risks of short or long term adverse environmental effects resulting from the use of azamethiphos for sea lice control are considered to be low as toxicity values are well above both concentrations predicted following sea lice treatments and Environmental Quality Standards (EQS).

Cypermethrin (Excis)

3.4 Cypermethrin is widely used for sea lice control in Scotland and a considerable amount of information is available on its dispersion, fate and ecotoxicity. Dispersion modelling and field based studies focussing on single treatments indicate that cypermethrin released following a bath treatment will be rapidly diluted in the receiving environment, with the majority adsorbed onto particulate material, which settles to the sea bed. This absorption process takes several hours by which time the discharge plume is spread over a wide area. Sediment concentrations are, therefore, generally so low as to be undetectable. Both water column and sediment cypermethrin concentrations predicted following single releases are lower than Environmental Quality Standards (EQS), and are therefore unlikely to result in toxic effects. However, a recent study concluded that even a single cage application of cypermethrin has the potential to create a plume of up to 1 km2 that may retain its toxicity for several hours. In that study, water samples collected up to 5 hours post-treatment were toxic to the benthic amphipod, Eohaustorius estuarius, causing immobilisation during 48 hour exposures. This has potential ecological implications because, in reality, cypermethrin treatments involve multiple releases daily, usually over several consecutive days. The potential for cypermethrin concentrations to exceed water and sediment EQS is, therefore, increased during multiple treatment events. Consequently the environmental risk associated with cypermethrin use is greater. SEPA account for this by setting 3 hour and 24 hour EQSs. The dispersion, fate and cumulative effects of multiple treatment releases on the marine environment remain unknown and require further investigation.

3.5 Sediment associated organisms are most likely to be affected by cypermethrin as it binds strongly to organic particles and solids, and is rapidly adsorbed by sediments. Such particle binding ameliorates toxicity by reducing bioavailability. For example, the tissue concentrations of cypermethrin in Daphnia have been examined as a proportion of sediment concentration and were found to decrease with increasing organic carbon content, indicating decreases in bioavailability. This was a freshwater study, but has implications for the organically enriched sediments below fish farm cages in terms of cypermethrin bioavailability and toxicity to benthic invertebrates.

Emamectin benzoate (Slice)

3.6 Emamectin benzoate use for sea lice control is increasing in Scotland and, in many loch systems, strategic treatments are being undertaken simultaneously at several farm sites. There is very little information available on the environmental fate and ecological effects of emamectin benzoate in the marine environment.

3.7 The organisms most likely to be affected by emamectin benzoate are those closely associated with the sediment as emamectin has low water solubility and a high potential to be adsorbed and bound to suspended particulate material. Much of the emamectin reaching the sediments will be associated with particulate material in the form of fish feces and uneaten fish food. Emamectin remains in the sediments for a considerable period of time having a half life (i.e. the time taken for the concentration to diminish by 50%) of around 175 days.

3.8 Benthic communities in the organically enriched sediments below fish farm cages are generally dominated by small worms, which play a vital role in remineralizing waste products. A recent study on the effects of emamectin benzoate on infaunal polychaetes indicated that predicted sediment concentrations are unlikely to adversely affect polychaete communities below fish farm cages. Sediment emamectin concentrations causing significant mortality to the capitellid worms that typically dominate sediments beneath fish farms were also considerably higher than the EQS.

3.9 Emamectin benzoate water column concentrations are expected to be considerably lower than sediment concentrations and are unlikely to pose a risk to planktonic organisms. Results from laboratory toxicity tests support this conclusion, with acute toxicity values orders of magnitude higher than the maximum allowable water concentration of 0.22 ng L-1.

3.10 The environmental risk of emamectin benzoate to the marine environment is considered to be low to moderate. However, there is relatively little information available on the toxicity of this chemical to marine benthic invertebrates in particular, and little is known about the potential long-term impacts of this chemical on the marine environment.

Teflubenzuron (Calicide)

3.11 Discharge consents are being granted for the use of teflubenzuron as a sea lice medicine in Scotland, but it is not being widely used, primarily because it is not effective against adult sea lice. There is very little information available on the environmental fate and ecological effects of teflubenzuron in aquatic environments. The specific mode of action of teflubenzuron means it is highly toxic to aquatic crustacean invertebrates, but low in toxicity to fish, mammals and birds. As with emamectin benzoate, it is likely that the sediments will act as a sink for teflubenzuron and so sediment associated organisms are more likely to be affected by this chemical.

3.12 To our knowledge, there are no data on the toxicity of teflubenzuron to marine invertebrates in the published literature and the suitability of sediment quality standards in particular, are unknown. A recent study, investigating the toxicity of sea lice chemotherapeutants to non-target planktonic copepods, determined acute toxicity values for planktonic marine copepods exposed to teflubenzuron that are orders of magnitude higher than water column EQS.

3.13 Teflubenzuron is predicted to be only directly toxic to crustacean invertebrates in marine ecosystems. However, the potential exists for indirect effects such as increases in primary productivity and changes further up the food chain. Direct and indirect ecosystem-level effects of the structurally similar benzoylurea insecticide, diflubenzuron, have been observed in freshwater mesocosms in the USA. Monthly and bimonthly applications of 10 µg L-1 diflubenzuron reduced zooplankton abundance and species richness, causing algal biomass to increase because of decreases in invertebrate grazing. Significant declines were also observed in juvenile bluegill biomass and individual weight, probably because of decreases in invertebrate food resources.

3.14 It is difficult to predict the ecological risk of teflubenzuron to the marine environment because of the current lack of information. Results from field studies referred to in SEPA's environmental risk assessment suggest that the use of teflubenzuron for sea lice control may present a moderate to high environmental risk. It seems unlikely that teflubenzuron will be widely used for sea lice control in Scotland, but if use does increase, investigation into the potential long-term impacts of this chemical on the marine environment is recommended.

ANTIMICROBIAL COMPOUNDS

3.15 Antimicrobial compounds such as oxytetracycline, oxolinic acid, trimethoprim, sulphadiazine and amoxycillin are administered to farmed salmon as feed additives to treat bacterial infections. In general, salmon farming is one of the least medicated forms of agriculture; compared with factory beef, poultry and pork production, antibiotic usage in fish farms is small and continues to decline. Antibiotics are not used on a continual, long-term basis as they often are in other types of animal husbandry. Rather, they are used intermittently for short periods (5 to 14 days) to control outbreaks of disease.

3.16 Most antimicrobial compounds readily associate with particulate material and residues are often found in the organically enriched sediments below farms that have treated fish with antibiotics, although the area of sediments containing measurable residues is generally very localized.

3.17 Concerns relating specifically to antibiotic usage by the aquaculture industry are:

- Development of drug resistance in fish pathogens
- Spread of drug resistant plasmids to human pathogens
- Transfer of resistant pathogens from fish farming to humans
- Presence of antibiotics in wild fish

* Impact of antibiotics in sediments on: rates of microbial processes; composition of bacterial populations; relative size of resistant sub-populations.

3.18 The environmental risk of antimicrobial compounds used by the aquaculture industry is considered to be very low. Antibiotic usage in aquaculture is insignificant compared with agricultural use and, because of the development of vaccines, continues to decline.

METALS

3.19 Of the metals present in fish farm sediments, elevated concentrations of copper and zinc have been reported in Scotland and Canada. The principal sources of these metals are antifoulant paints and fish feed.

Metals in antifoulants

3.20 Antifoulant products are painted or washed onto fish farm nets and structures to slow the build up of fouling organisms. Currently, 19 of the 24 antifoulant products registered for use in Scottish aquaculture are copper based, either as copper, copper oxide or copper sulphate. These copper-based products exhibit effective antifouling activity against barnacles, tube worms and most algal fouling species. Two types of antifoulant paint (water based or spirit based) may be applied to fish farm nets at washing sites remote from the farm. When the nets are placed back in the water at the farm, copper can be released from the paints, producing metallic slicks. It is likely that copper is also released in soluble and particulate form from paint on the metal cage structures.

3.21 The use of copper-based antifoulants is likely to increase and there may be reason for concern because of the accumulation of copper in sediments below fish farms, and its potential toxicity to benthic organisms.

Metals in fish feed

3.22 Metals present in fish feed are either constituents of the meal from which the diet is manufactured or are supplemented as a mineral pre-mix for perceived nutritional requirements. The meal constituents, together with the mineral premixes, are composed of various trace and heavy metals, providing copper, zinc, iron, manganese, as well as cobalt, arsenic, cadmium, fluorine, lead, magnesium, selenium and mercury. Concentrations of copper and zinc in feeds produced for Atlantic salmon range from 3.5 to 25 mg Cu kg-1 and 68 to 240 mg Zn kg-1. However, the estimated dietary requirements of Atlantic salmon for these elements are 5 to 10 mg Cu kg-1, and 37 to 67 mg Zn kg-1. Therefore, it would appear that the metal concentrations in some feeds are unnecessarily high as they exceed salmon dietary requirements.

3.23 Sediment copper and zinc concentrations measured at fish farms surveyed by the SEPA West Region in 1996 and 1997 were compared with proposed sediment quality criteria to assess the potential for adverse effects caused by elevated metal concentrations. Sediments directly beneath the cages and within

30 m of the farms were severely contaminated by copper and zinc at 7 of the 10 farms surveyed, with "probable" adverse effects predicted on the benthic invertebrate community at these sites.

3.24 The long-term ecological implications of high metal concentrations in fish farm sediment are unknown. Sediment biogeochemistry and physical characteristics influence the accumulation, availability and toxicity of sediment contaminants such as trace metals to benthic invertebrates. Even when metal concentrations in sediments substantially exceed background levels, metal bioavailability may be minimal and adverse impacts may not occur. Organically enriched fish farm sediments characteristically have a high biological oxygen demand and negative redox potential; conditions leading to sulphate reduction. Under these conditions, metals such as copper and zinc are less likely to be biologically available. However, disturbance of the sediments by strong currents or by trawling could cause the sediments to be redistributed into the water column, leading to re-mobilization of the metals so that they become available for uptake. It is possible that elevated copper and zinc concentrations, in combination with high levels of other potentially toxic substances such as sulphides and ammonia, could represent a significant barrier to the recolonization of benthic sediments when fish farm sites are fallowed. Sediment chemical remediation when a fish farm site is fallowed, in particular, degradation of organic material and reductions in sulphide concentrations, may increase metal bioavailability in the sediments, and might also result in the release and further dispersal of metals away from fish farm sites.

Summary

3.25 There is currently insufficient information available to determine the long-term effects of medicine and antifoulants use. Further research is required into the effects of these products over the long term, particularly where multiple sources enter the same marine area. In the short term, the environmental risk is considered to be low if sea lice medicines and antifoulants are used according to regulatory guidelines but, in the case of antifoulants, more information is required relating to their use by the aquaculture industry.

Research Gaps

3.26 The following concerns and areas for future research relating to these chemicals and their potential environmental impacts have been identified:

* More information is required on the toxicity of emamectin benzoate, teflubenzuron, copper and zinc to benthic organisms commonly found Scottish sea lochs.

* More information is required on the long-term effects of cypermethrin, emamectin benzoate, copper and zinc on sediment associated organisms. In particular:

* What proportion of the chemicals, particularly the metals, present in fish farm sediments is bioavailable?
* Is there potential for these chemicals, particularly the metals, to accumulate up the food chain.
* What happens when a site is fallowed and the sediment biogeochemistry changes?
* Do the chemicals that have accumulated, and are possibly not biologically available in the organically enriched sediment, become bioavailable as chemical remediation occurs? Are they released, and do they disperse over a wider area? Do they prevent recolonization of impacted sites?
* More information is required on the dispersion, fate, and potential long-term effects of multiple cypermethrin treatments (at single and multiple farm sites) within a loch system.
* More information is required on the potential effects of concurrent emamectin treatments at several farm sites within a loch system.
* Antifoulant usage by the aquaculture industry should be quantified.
* Copper and zinc concentrations, speciation, and toxicity in fish farm sediments needs to be investigated.
* Better understanding of salmon metal dietary requirements is needed to reduce metal concentrations in feed and consequent metal input into the marine environment.

CHAPTER FOUR DISEASE IMPACTS ON WILD AND FARMED STOCKS

4.1 Cage farms may cause ecological effects stemming from the release of parasites and pathogens. It is, however, difficult to find diseased animals in the marine environment – such animals quickly succumb to predation. It is, therefore, not easy to be confident about the frequency or significance of transfer of pathogens to wild stocks.

4.2 One example involved a monogenean parasite of salmon Gyrodactylus salaris, which was transferred from resistant Baltic salmon populations to Norwegian populations lacking resistance as a result of movements of farmed fish stocks in the mid-1970s. This resulted in the extinction of many wild populations. Restrictions in the movement of live material between countries are enforced but this parasite still presents a significant potential threat to wild stocks in Scotland. Although aquaculture represents a possible method of transmission it is thought that inadvertent transfer by anglers represents a more significant risk.

4.3 Sea lice infestations are endemic in most salmonid culture areas and, in recent years, declines in wild salmonid populations have led to the widespread belief that there is a link between farming and this decline. In Scotland, the main focus has been on the marked population declines of wild sea trout Salmo trutta, particularly in the north-west where salmon culture is concentrated. On their first visit to sea in the spring of the year following hatching, sea trout may be confronted with very high concentrations of infective sea lice larval stages and quickly become infested with lice. Although these fish may choose to return to fresh water to avoid the parasite it is likely that many are severely compromised. A burden of only 10 adult lice is thought to be sufficient to cause mortality, especially in immature fish already under stress.

4.4 The position is less clear with wild Atlantic salmon Salmo salar, also in general decline. Smolts of this species migrate directly to the ocean without remaining in the coastal or estuarine zone, as is the case with sea trout. It was previously thought that wild salmon would not be exposed to the same degree of infestation owing to the limited period of contact. However, it is now suggested that, particularly in long sea loch systems with several fish farms, salmon may receive sufficient infestation to compromise their survival. This hypothesis is not easy to test, as it is difficult to catch salmon smolts in coastal waters, particularly in such a way as to protect the fish from skin/scale damage that may remove any early lice stages present. However, researchers in Norway have recently made significant progress in this area using a fishing net with an aquarium in the cod-end designed to minimize damage to the fish. The results from a co-operative research project between the Institute of Marine Research, Bergen, Norway and the University of Bergen indicate that more than 86% of the wild postsmolts of Atlantic salmon migrating out of the Sognefjord, and between 48.5% and 81.5% of the postsmolts from the Nordfjord were killed as a direct consequence of sea lice infections during the spring of 1999. The surviving fish were probably weakened because of the infection. Only two fjords were investigated at that time, but it seems probable that postsmolts from other fjords also experience the same problem and there is every likelihood that a similar situation may exist in some of the longer sea lochs in Scotland.

4.5 Although the relationship between sea lice infection and the decline of wild populations is striking, and is additional to the widespread decline of migratory salmonids in areas without fish farms, there is as yet no absolute proof of a causal link. In spite of this, and owing to the increasing body of supporting (although as yet inconclusive) evidence, the burden of opinion has recently begun to swing in favor of accepting the likelihood that lice from farms constitute a direct threat to wild salmonids.

4.6 Lice infestation has always been a significant economic and health problem for the industry and has tended to be tackled site-by-site, company-by-company. Most large salmon producing countries now recognize the value of an integrated approach to lice management. The main features of strategies to reduce lice numbers include:

* Regular monitoring of lice numbers
* Coordinated chemical treatments between farms sharing the same water body

- Single generation sites
- Fallowing of management areas to break lice cycles
- Treatment of lice in the spring when lice numbers are low

4.7 These features were adopted in Scotland in 1999 as part of the industry's National Sea Lice Strategy.

4.8 In the past, fish farmers had access to only a few treatment agents. A consequence of this limited group of medicines was reduced efficacy, caused by resistance. There are, however, several new lice treatment agents on the market that are proving more effective in reducing lice numbers on farmed fish.

4.9 Even with greater access to effective sea lice treatment agents it is uncertain that total lice numbers can be brought down to low enough levels to fully protect wild salmonids. This is a consequence of the continuously increasing numbers of fish entering culture: the numbers of farmed fish far exceeds the collective size of wild populations. Any decrease in lice numbers occurring through a lowering of acceptable lice levels on farmed fish is likely to be compensated for through future increases in production. Given that there will always be economic and environmental constraints on the frequency of therapeutic application, it would appear that if lice from salmon farming are a major contributor to declines in wild populations, we will have to await a much more radical solution e.g. a totally effective vaccine.

4.10 In Scotland, the farmer controls lice burdens and the data collected on lice burdens remains commercially sensitive and not generally available, except confidentially through Area Management Agreements (AMA). AMAs are aimed primarily at tackling sea lice and bring fish farming, wild fisheries and regulatory interests together. There are currently 7 such AMAs in Scotland.

4.11 It is likely that the burdens of lice acceptable to the farmer are higher than the levels probably required to minimize effects on wild fish. The situation in Norway is different in that state veterinarians on a regular basis monitor lice levels and, when lice levels rise, treatment is compulsory.

4.12 The use of non-chemical methods of lice control (e.g. cleaner wrasse) remains widespread in Norway but is little used in Scotland. Recent commercial scale trials of wrasse use in Scotland as part of an integrated lice management program have shown positive economic benefits with a concomitant decrease in the use of chemical treatments.

4.13 With the exception of sea lice, there appears to be little significant transfer of parasites between farmed Atlantic salmon and wild populations – in fact reverse transfer is more apparent. Little research has been reported on the parasitic interactions of other cultured species and wild populations.

4.14 The potential for bacterial and viral diseases to be transmitted from farmed fish to wild is real. Furunculosis (caused by the bacteria Aeromonas salmonicida) is believed to have been re-introduced to Norway via cultured-fish imports from Scotland in 1985 causing severe damage to both farmed and wild populations. Furunculosis is no longer a problem in fish farming owing to effective vaccination programs.

4.15 During and since the major outbreak of infectious salmonid anaemia (ISA) in several Scottish fish farms in 1998–1999 there have been several claims of a threat to wild populations. The presence of ISA in wild populations was confirmed in Scotland (Scottish Executive Press Release, 04/11/99) but it is not clear whether this was a consequence of the outbreak in farmed stocks nor is it clear what impact the disease had on wild populations. Fisheries biologists have also expressed concerns about the possibility of Infectious Pancreatic Necrosis virus (IPN) transfer between farmed and wild stocks. IPN is widespread in some farming areas and it appears that it can be passed to wild stocks. However, very few samples have been analyzed from wild populations and further monitoring is required to determine the degree to which transfer is occurring and whether it has significance for wild populations.

Summary

4.16 Wild salmon and sea trout are at risk from infective larval sea lice that may be associated with marine salmon farms. Salmon are most at risk in long fjordic systems where they have to pass several farms during their migration to sea. The transfer of other parasites from farmed to wild fish is not thought to be a major problem at present. The introduction of the parasite Gyrodactylus salaris from Scandinavia would probably devastate the Scottish wild salmonid population although it is not thought that transfers relating to farming represent the only or greatest risk of introduction. The potential exists for transfer of infectious diseases such as Infectious Salmonid Anaemia (ISA) and Infectious Pancreatic Necrosis (IPN) from farmed to wild stocks but the real level of risk is not quantifiable given present knowledge.

Research Gaps

4.17 Research to quantify the factors responsible for the transmission of lice between farms and wild fish. Improvements in understanding the mode and rate of transmission are essential in providing information on the relationships between infection of wild populations, lice burden on farms and separation distances between migratory fish routes and fish farms. This type of research would also bring greater understanding of the mechanisms by which farmed fish become infected with sea lice from wild populations and from other farms. This would help to determine the reasons why some sites have much fewer lice problems than others do and, therefore, assist in the selection of better sites for salmon culture.

4.18 Further work is required to determine the factors affecting the risk of transmission of a variety of fish diseases between farmed and wild populations.

CHAPTER FIVE ESCAPES FROM FISH FARMS AND POTENTIAL EFFECTS ON WILD POPULATIONS

5.1 Salmon escape from cage farms owing to accidents of weather or operation, through poor maintenance of nets and other equipment, through inappropriate specification of containment equipment for the exposure characteristics of the site, or through damage from seals. Although there have been improvements in containment technology and husbandry practice, the absolute number of escapes may remain high as a consequence of expansions in the industry.

5.2 Escapes from farms are obviously not desirable for the farmer as stock is lost and future insurance costs may be increased. There are also detrimental effects on the environment.

5.3 The genetic and ecological effects of escapes on wild populations are complex subjects and only the most important aspects will be summarized here. The fundamental problem arises because wild salmon and their farmed cousins have very different levels of genetic variability. Wild salmon have a high level of genetic diversity both within and between populations. Between populations variability is driven by selection for the particular river (or part of a river) that they originate from and these differences are maintained by their accurate homing ability as they return from the sea to breed. Thus there are many distinct populations of salmon with a relatively low rate of mixing between them. Farmed salmon arise from relatively few wild strains and thus show lower overall variability. Although some breeding programs seek to maintain genetic variability within populations by ensuring that large numbers of broodstock are used, this is not always the case so some reared strains are lacking in variability. Large numbers of broodstock are required to ensure that relatively rare genetic components are not lost from the population. For example, several thousands of broodstock are thought to be required to maintain the evolutionary viability of a wild population.

5.4 Breeding programs for farmed fish exert very different pressures than natural selection does in the wild. Farmed fish are selected, intentionally or otherwise, for high growth rates and for the particular environment that exists in culture situations: high stocking densities, easy access to food, reduced stress during handling and isolation from predation. Reproductive success is generally unimportant, as is the ability to find food and avoid predators. These factors are, however, under intense selection pressure in the wild. Thus farmed fish are much less fit for survival in the wild than wild salmon. However, it is likely that if farmed fish escape early in their life cycle, those fish that survive to adulthood will have at least learned to catch prey and avoid predation but they may not be any more reproductively competent.

5.5 When farmed fish escape they can breed with wild fish. It is possible that the immediate offspring of such crosses may benefit from hybrid vigor but this is not passed on to the next generation owing to the phenomenon of outbreeding depression leading to much lower fitness and productivity.

5.6 It is quite easy to see that even where escaped fish are reproductively inferior i.e. less able to participate in breeding or having poorer quality or fewer gametes (eggs and sperm), large numbers of escapes may dwarf local wild populations which may only have relatively few breeding adults in any one year. Wild fish have some protection from such events owing to their life cycle: it takes a minimum of 2 years post-hatching for salmon to go through the freshwater phase, migrate to sea as smolts and return the following year as grilse but some fish will spend more than one year at sea thus spreading the progeny of a particular year's hatch out over several future years. Thus, it is possible for a wild population to recover after some catastrophe that affects the progeny of any one year and this factor undoubtedly contributes to the success of the species (although there appears to be a general decline in the proportion of fish who have spent more than one year at sea). However, continued escapes, if maintained over several years can have very serious effects on wild populations.

5.7 To put the problem in context, if 1% of the farmed population escapes each year then, for the west coast of Scotland only, that will amount to over 200,000 fish (in 2000), which vastly exceeds the total catch of the wild population. The total wild catch for the fish farming regions - North West, West, Clyde Coast and Outer Hebrides – was 8,459 salmon by all methods in 2000. This is probably in the region of 15% of the wild population and so it is easy to calculate that a 1% loss from aquaculture exceeds not only the catch from wild fish but also probably the total adult population in this region. The actual reported loss from escapes in 2000 for the whole of Scotland was 411,433 salmon, although more than half of this came from one incident in the Northern Isles.

5.8 It has been argued that the wild populations that might be affected by escapes from fish farming are themselves already affected by often inappropriate restocking and transplanting programs that have been practiced by fishery managers and owners for many years. Where restocking or "stock improvement" programs are based on only a few broodstock, even where the broodstock were taken from the local population, then serious reductions in effective population size can be introduced i.e. a loss in genetic diversity. Where strains for distant rivers have been used it is likely that the phenomenon of outbreeding depression will occur with reduced fitness especially in the second and subsequent generations. Thus, it is argued that some of the negative effects of escaped farmed salmon are already present as a consequence of some fisheries management programs.

5.9 Although this argument is valid, it does not negate the need to prevent or minimize further escapes of farmed salmon. Given that stocking with salmon has released orders of magnitude fewer fish into the wild than farm escapes, escapes of the scale currently experienced will inevitably increase the degradation of genetic diversity already present, with potential losses of genes that are important for the fitness of populations in the wild.

5.10 Various options are available to minimize loses of escaped salmon. The most drastic is complete containment and this is the only option open where losses cannot be countenanced, for example, in experimental stations where transgenes have been introduced. Complete containment, i.e. culture in tanks with multiple safety measures on the effluent water, is currently rare except for the most juvenile life stages as a consequence of economics. Another option is to ensure that escaped fish cannot breed. This is done successfully with trout by inducing a chromosomal abnormality called triploidy. The females of these fish are essentially sterile and this is desirable for trout as it prevents early sexual maturation thus ensuring that resources are not wasted in producing unwanted gonadal tissue. Triploidy can also be induced in salmon and female triploid salmon are sterile. However, these fish show reduced performance and are generally unsuitable as a culture organism.

5.11 Improvements in containment of caged fish will likely continue as net technology develops but this may be compensated for by the probable increase of sites with a greater degree of exposure. While such sites are certainly of benefit for other reasons there must be rigorous precautions taken to minimize escapes e.g. by ensuring that net strength is over-specified and that cages and moorings are adequate for extreme weather conditions. With sufficient data, it is possible to make estimates of weather extremes likely to occur within a given time period, e.g. 50 years, and this could be used to derive containment specifications. Once the correct specifications are determined it is crucial that the appropriate inspection, preventative maintenance and replacement management regimes are implemented.

5.12 Management of predators is also important as if seals attack farmed stock in cages there is a high risk of damage to the net. Sites seem to vary as to the degree that seals present a problem and farmers have three basic strategies: 1) acoustic deterrents are transducers placed in the water that are programmed to emit high powered sounds of a frequency that is unpleasant to the seals thus excluding them from the immediate area; 2) the use of a second net designed to keep seals from gaining access to the fish net (not regularly used for large cages); and 3) maintaining the fish net at high tension thus preventing seals from being able to bite through to the fish. Each of these measures is often supplemented with occasional shooting of "rogue" seals. Shooting is, however, relatively inefficient as it is often difficult for farmers to identify the particular rogue seal.

5.13 Although the above measures probably have no ecological impact on seal populations, which are thriving nationally, the use of acoustic deterrents has been questioned because of the potential problems caused for cetaceans. Cetaceans – dolphins, porpoises and whales – are much more sensitive to acoustic noise and a high pitched sound that might inconvenience a seal might cause pain to a cetacean. Thus it is likely that powerful acoustic deterrents exclude cetaceans from a large area. A Canadian study indicated that killer whales were excluded from a 10 km radius of such a device. This has obvious implications for exposed sites where sound transmission distances might be considerably greater than in enclosed sea lochs. Thus although effect seal management is crucial in maintaining the containment integrity of fish cages, acoustic deterrents have other environmental impacts diminishing their usefulness. At present there is insufficient information on coastal marine noise from other sources to easily quantify the degree of extra hazard to cetaceans.

Summary

5.14 Escapees from fish farms may interbreed with wild population resulting in losses of genetic variability, including loss of naturally selected adaptations, thus leading to reduced fitness and performance. Non-local genes have been introduced into wild salmonid populations for over a century, as a consequence of restocking programs intended to increase population sizes. However, the effect of these programs is probably insignificant compared with that caused by farm escapes simply owing to the large scale of escapes in comparison with the wild populations. Escapes from salmon farms, therefore, constitute a major threat to wild populations. Current methods to reduce fish farm escapes by reducing net damage from predators include the use of acoustic deterrents to exclude seals from the farm area. While these probably have no great consequence for seal populations they may exclude whales, dolphins and porpoises from a much larger area owing to their greater sensitivity to underwater acoustic noise.

Research Gaps

5.15 Continued surveillance of the presence of escaped fish in wild populations and quantification of the effects in terms of population fitness.

5.16 Improvements in marking or tagging fish to enable easy identification of escapees.

5.17 New methods for reducing fertility of farmed fish.

5.18 Improved containment technologies, including technologies for reducing the costs of operation of fully contained systems.

5.19 Assessment of the effects of seal scarers on cetaceans.

CHAPTER SIX SUSTAINABILITY OF FEED SUPPLIES – INCLUDING RESEARCH ON PLANT MEAL SUBSTITUTION

6.1 Fishmeal and fish oil are key constituents of pelleted diets for the intensive production of carnivorous species. World capture fishery production has flattened out (against a background of increasing fishing effort) at around 86–94 million tons of which around 23–33 million tons have been used annually for the production of fish meal and oil over recent years (Table 6.1). The main species used in the manufacture of these products include anchovies, sardines, pilchards, capelin and sandeels. In 2000, 35% of the fishmeal and 57% of the fish oil produced was used in aquaculture diets, with the remainder used for livestock, including pigs, poultry and ruminants. Aquaculture production has been expanding globally at over 10% per year since 1984 and the industry is expected to double within the next decade. At the current growth rate, it has been estimated that by 2010, 56% of the fishmeal and 85–98% of the fish oil produced will be utilized by the aquaculture sector. A proportion of this projected increase in the availability of these products for aquaculture is accounted for through the relative decline in the use of fishmeal in poultry diets and fish oils in hardened edible fats.

6.2 World fishmeal and oil production rates have remained relatively static over the last 10 years, except in 1998 when the El Niño phenomenon significantly reduced production in Peru and Chile. On average, global production of fishmeal was 6.6 million tons (product weight) and fish oil was 1.2 million tons in 1999. Fishmeal usage in the aquaculture sector is dominated by the Far East, particularly China (55%) and fish oil usage is largest in the Americas, particularly Chile and Canada (44%). Fish oil usage is relatively low in the Far East (14%), despite their dominance of the fishmeal markets because fish species farmed in this region typically consume low-oil diets. These diets contain approximately 1– 3% fish oil (dependent on species) compared with oil-rich salmon diets that can contain up to 30% fish oil. The main source of the fishmeal and oils for diets produced for the UK aquaculture industry is from the South American fisheries, although a proportion of the meal and oil is still supplied by the ‘traditional’ Norwegian and Icelandic fisheries. The transfer to fisheries in the Southern Hemisphere in recent years reflects the greater fishery production and product quality compared with stocks typically found in the Northern Hemisphere. The majority of the fish feed (95%) used in Scotland is manufactured in the UK and the remainder is imported from Denmark, Norway and the Faeroe Islands. The dominant UK producers are BioMar Ltd., EWOS Ltd. and Trouw Aquaculture and the annual production of fishmeal in 1999 was 51,000 tons compared with the total European production of 348,000 tons.

6.3 Concern has been raised that as the aquaculture industry grows, extra pressure will be placed on wild stocks for the production of fishmeal and oil. The predominant geographical region of growth in the aquaculture sector is the Far

East. Aquaculture production is greatest in China where the industry is dominated by carp species, although the production of tilapia and milkfish has increased significantly in the last decade. Culture species in the Far East are typically herbivores/omnivores and it is possible that the predicted increases observed in the aquaculture sector would not have any significant impacts on wild fish stocks. However, the expansion and intensification of aquaculture in China, particularly in the coastal provinces, which comprise 60% of production, has led to an increase in culture systems based on formulated feeds. Even though the culture species are herbivorous, the formulated diets include fish oil to improve (a) the efficiency of the immune system; and (b) the tolerance to intensive culture systems. Because of this, even though the proportions of fish oil use by weight are low in the diet, the total tonnages used in the Far East are such that this region has considerable influence on fish oil use, with usage forecast to increase markedly over the next decade.

6.4 In Norway, the aquaculture industry is also expanding rapidly with Atlantic cod production being the main new growth area; the industry is actively supported by the Norwegian government. Atlantic cod require less fish oil in their diet (12–15% fish oil) compared with salmon (~ 30% fish oil). However, a relatively low FCR will potentially require a diet that is initially high in fishmeal because of the incomplete understanding of the nutritional requirements of cod during the initial years of cultivation.

6.5 Interest in marine oils has also been increasing in the pharmaceutical, health and technical industries. These sectors currently purchase 4–6% of the annual production at prices that are significantly higher than the prices paid by the fish feed manufacturers for the premium oils.

6.6 As fisheries for large, high-value carnivorous species have become increasingly fully- or over-exploited, the proportion of smaller, less valuable pelagic species, such as sardines, pilchard and capelin, are increasing in the catch. This is likely to be exacerbated by an increase in human demand for some of these fish species, particularly in Asian countries in the next few years as the economy recovers from the financial crisis in the late 1990s. The ‘fishing down the food chain’ principle is initially thought to improve catches before leading to a phase of stagnating or declining catches. It is proposed that this change in exploitation patterns is unsustainable.

6.7 Fisheries control over the major resources for fishmeal and oil production has been introduced. International Organization of Standardization (ISO) 14001 certification and FAO Code of Conduct for Responsible Fisheries have been endorsed by members of Scottish Quality Salmon. The main species, including anchovy, sardine, capelin and sandeels, are subject to management through total allowable catch (TAC), area catch limits, minimum mesh sizes, fleet capacity controls, fleet capacity controls, closed areas and seasonal bans. In the UK, a TAC of 1 million tons was set in 1998 for the North Sea sandeel stock and a 20 km2 area of the Moray Firth was closed to industrial fisheries in 2000 because of concern over the breeding success of locally nesting seabirds that rely upon the sandeels for food. The management of fisheries in general, however, is widely considered to be ineffective because of the poor condition of many important fish stocks. The level of enforcement of fisheries controls in the certain areas of fishmeal and oil production is also debatable, although satellite tracking has been introduced in Peru and Chile to enforce closed areas for anchovy and sardine. The long term effect of the removal of large quantities of feed organisms from the marine ecosystem is an issue that has yet to be quantified. In the North Sea, declines in certain species with economic value, such as cod, and changes in the distribution, population sizes and reproductive success of various seal and sea-bird colonies have been attributed to the over-fishing of sandeel and other small pelagic fish stocks. In addition, the industrial fishery for anchoveta in Peru was implicated in the loss of significant numbers of seabirds through a reduction of food availability and an inhibition of population recovery after crashes induced by El Niño events.

6.8 The fishmeal industry has suggested that discards, which account for approximately a quarter of the annual global landings (27 million tons), should be utilized by the industry. Norway, Canada and Iceland have all introduced a ban on the at-sea discarding of certain commercial species and a proportion of the by-catch is utilized by the fish feed manufacture industry. This ban has been coupled with an extensive monitoring and surveillance system whereby areas can be closed when bycatch rates exceed a certain level. The use of selective fishing gears has also become compulsory in a number of Norwegian fisheries. In Europe, EU legislation prohibits the landing of any fish that is caught outside the regulatory size range or quota allowance. The Commission favors measures such as greater selectivity of fishing gear and alterations in fishing practices rather than a ban on discards. It is clear, therefore, that although there is a trend towards greater utilization in certain fisheries, in others there is more pressure to reduce the capture of potential discards. On balance, the probability of an increase in the availability of fishmeal and fish oils through the future utilization of discards is low.

6.9 There can be no argument that the availability of fishmeal and oil has the potential to limit the sustainable growth of those forms of aquaculture (e.g. salmon production) that depend on this resource. Furthermore, as pressure on fish stocks for production of these products grows, the vulnerability of an aquaculture industry dependent on these stocks is high. It is recognized that climate oscillations such as El Niño can have a major effect on fishery production: a drastic reduction in fishmeal supply would increase prices of feed such that industries where profits are low, e.g. salmon culture in Europe, could collapse. However, recovery of stocks following the most recent El Ninõ collapse (1998) was rapid in the South American fishmeal fishery indicating that these sources may be robust and sustainable at the present capture levels.

6.10 FCRs are continuously improving as feeds become increasingly tailored to the dietary requirements of the cultured species. Feed wastage continues to be reduced through the use of advanced pellet monitoring systems (e.g. underwater cameras, Doppler, StorvicTM systems) and feedback loops because of economic and, partially, environmental pressures. This is particularly the case in the highly regulated northern salmon industries where studies have found that under commercial conditions Atlantic salmon can reach 5.5kg with a feed conversion ratio of 0.85 using a fishmeal and oil based diet in 1999. It is envisaged that further advances in husbandry practices and the optimization of protein: energy rations will enable FCRs to approach 1:1 i.e. one kg fish product (whole fish, wet weight) per kg feed (compound feed, typically around 10% water). Despite these potential improvements, it still requires between 2 and 5 kg of wild fish to produce 1 kg of fishmeal-fed cultured fish.

6.11 This apparently wasteful use of the fish resource is to some extent mitigated by the fact that not all of the fish used for fishmeal production are fit or appropriate for human consumption. In addition, the conversion of low commercial value small pelagic fish into high value carnivorous species is probably more efficient in culture than in the wild where there is likely to be a much lower transmission of energy between trophic levels. It is also possible that competition with cheap, farmed fish may reduce fishing effort thus protecting endangered stocks, although this is offset by the fact that it may be possible to sell the wild product at an increased price to a sophisticated market.

6.12 Substitutes for fishmeal protein and marine fish oils are continuously being sought and progress is being made. An EU research project is currently studying ‘Perspectives of Plant Protein usage in Aquaculture’ (PEPPA) and research in Norway has been investigating the use of soya meal in feed for salmonids. Protein substitutes are already used in fish feed in the UK and Norway with up to 25% of the protein in the feed derived from plant origin.

6.13 The uptake of fish oil substitutes has been slower. For the first time, with the exception of 1998, the price of fish oils in 2002 is approximately the same as for plant oils. Concerns over the dioxin and polychlorinated biphenyl (PCB) levels in the northern hemisphere fish oils has increased the pressure on fish feed manufacturers to produce oils with reduced levels of dioxins. This has created a growing interest in the use of low-dioxin vegetable oils. In Scotland, Scottish Quality Salmon (SQS) has recently revised it’s Quality Manual (Product Certification Scheme for Scottish Quality Farmed Salmon) to allow up to 25% of the oils added to the fish feed to be derived from a plant-based origin. This revision comes with the proviso that the diets should maintain a certain level (still to be decided) of essential fatty acids (eicosapentaenoic acid, EPA, and docosahexaenoic acid, DHA – both n-3 (or omega 3) highly unsaturated fatty acids, HUFA) in the final product. The basic problem in using vegetable substitutes was thought to be their lack of essential amino acids (such as lysine and methionine) and essential fatty acids, EPA and DHA. Concerns were also expressed over the inefficient conversion of carbohydrates in these substitutes to energy by carnivorous fish. The species used in the production of fish oils, such as herring, sardines and anchovies store large amounts of oil in their flesh that is rich in n-3 HUFA that are only found in fish. These HUFA, along with the essential n-6 HUFA arachadonic acid, are vital for the development of organs with dense neural activity and are crucial to inflammatory and cardiovascular processes.

6.14 Research has already proved that partial replacement of fish oils with rapeseed and linseed oils can successfully be used in the culture of Atlantic salmon without significantly influencing growth performance. Current research, including an EU funded project, ‘Researching Alternatives to Fish Oil in Aquaculture’ (RAFOA), is studying the effect of substitution of fish oils with plant oils on growth performance, fish health and product quality during the entire life cycle of salmon, rainbow trout, sea bream and sea bass. The Directorate of Fisheries Institute of Food and Nutrition in Norway has also conducted similar research. In addition, a second project, ‘Fish Oil Substitution In Salmonids’ (FOSIS), is currently investigating whether fish oil can be replaced by vegetable oils in the diet without reducing the nutritional value or the growth performance of the fish, whilst minimizing fat deposition in the flesh. A further two EU research projects are studying the effects of plant oils on fish digestion and metabolism, ‘GLUTINTEGRITY’ and ‘FPPARS’. Feed companies have also progressed significantly in this type of research, although, because of commercial confidentiality, access to their results is limited. In addition to vegetable oils, a EU research project ‘PUFAFEED’ is investigating the use of cultivated marine microorganisms as an alternative to fish oil in feed for aquatic animals.

6.15 Intensive research is studying processing methods and the genetic modification (GM) of soya oil to produce DHA and EPA, which may enable the addition of this oil to fish feeds in the future. Problems associated with modifying plants to produce sufficient quantities of essential fatty acids for use on a commercial scale has, to date, slowed progress in this area. Concern over public response to the use of GM oils has prompted SQS to specify in their Quality Manual that the fish feed used by their members, must contain ‘non-GM’ plant derived material if the fish oils have been substituted by vegetable oils. The difficulty in identifying whether oils have been genetically modified has also been highlighted as an area of concern.

6.16 Fish feed substituted with plant meal and oils, particularly rapeseed oil has already been used commercially in Norway. The main issue at present facing the plant meal and oil substitution option in Scotland, however, is consumer opinion and the affect that this may have on the continued acceptance of Scottish salmon as a ‘high quality’ product. To produce a product as ‘near to the wild product as possible’, research is also focusing on the ‘dilution’ of vegetable oils in the flesh when the fish are fed diets containing 100% marine fish oils for 6 months prior to harvest. This will potentially counteract any potential loss in flesh quality caused by the use of diets containing vegetable oils and preliminary results are promising, with EPA and DHA increasing in the flesh within a few weeks of the diet switching from plant to fish oils. In addition, research is examining the potential for salmonids to produce their own DHA and EPA. These essential fatty acids are naturally produced by fresh water fish, including salmonids, and production is inducible and repressed in the presence of dietary fish oil containing EPA and DHA. Studies on rainbow trout concluded that the synthesis of DHA by the trout was only a fraction of that obtained from the diet and thus fishmeal would still be required in the diet to maintain a constant level of DHA in the fish. It has been suggested, though, that biosynthesis of DHA and EPA by salmonids fed vegetable-based diets could be enhanced by selective breeding.

6.17 In 2000, a review published in the journal Nature raised the issue that the production of carnivorous fish species would not compensate for the decline in capture fisheries and could indeed contribute to their collapse. However, the review under-reported the influences of other global industries that relied on fishmeal production (e.g. livestock) and largely ignored the advances being made by the aquaculture industry in utilizing diets containing plant proteins and oils in order to reduce their dependence on wild fisheries.

Summary

6.18 The issues concerning the use of industrial fishmeal and fish oils in artificial pelleted diets in the Scottish salmon farming industry are wide-ranging and complex. Although aquaculture production is predicted to rise significantly over the next decades, catches from industrial fisheries are set to remain static in volume. Forecasts differ, but there are concerns over how the Scottish salmon growing industry may perform if fishmeal and/or fish oil supplies become limited. Firstly, the aquaculture industry in Scotland is relatively a very small component in the global aquaculture field and could be badly affected by global aquaculture product trends. Approximate estimates suggest that the proportion of the global fishmeal use attributable to the Scottish salmon industry is less than 0.8%. Secondly, the Scottish salmon industry is probably running at very low profit margins and is unlikely to sustain fish feed price rises as easily as sectors with higher margins of profit. Fish feed companies have been well aware of these two points for many years, and research on fishmeal and oil alternatives is well advanced. However, because of the near-market nature of that research and development, there is little published literature on which to base a thorough assessment of the current status of alternative feed types. Therefore, current and forecasted future market forces have already created a situation where fish feed suppliers are actively developing alternatives to wild fishery sources of fishmeal and fish oil.

Research Gaps

6.19 The following concerns and areas for future research relating to the sustainability of feed supplies have been identified:

- Accurate fisheries data collection and mathematical modeling of the pelagic fisheries are required in the main industrial fishing areas to ensure the sustainability of these fisheries. The influence of climate oscillations (e.g. El Niño) and climate change on recruitment and spawning stock compared with the impact of industrial fisheries are also very difficult to quantify and little research has been published in this area. The sustainability of the Blue Whiting fishery in the North Atlantic fishery also requires urgent research as fisheries controls are still under debate.
- Peer-reviewed literature is required relating to the effects of near market use of plant meal and oil substitutes on fat and protein composition, flesh quality and taste in salmonids.
- Peer-reviewed studies are required on refining the vegetable oil and protein requirements of the cultured fish species relating to life stage and seasonal variations in digestibility experienced with certain vegetable oils.
- Knowledge regarding the blending of oils, reducing the dependency of manufacturers on a few plant oils and tailoring the taste of the final product to the customer needs.
- Information regarding nutritional studies and the implications of substitution of fishmeal and oils with vegetable alternatives on ‘new’ species for cultivation, particularly cold-water species such as cod, haddock, turbot, halibut, Dover sole and lemon sole.

CHAPTER SEVEN ENVIRONMENTAL LIMITATIONS ON THE SCALE OF THE SCOTTISH MARINE FISH FARMING INDUSTRY

7.1 In this report we have discussed the environmental effects of 5 main aspects of marine aquaculture in Scotland:

* The discharge of waste nutrients and their interaction in the wider marine environment
* Effects of other discharges from aquaculture, e.g. medicines and chemicals
* Disease impacts on wild and farmed stocks
* Escapes from fish farms and potential effects on wild populations
* Sustainability of feed supplies – including research on plant meal substitution

7.2 Within each topic the main areas of concern have been outlined and gaps in knowledge have been highlighted in order that future research might be focused on projects that contribute to areas of most uncertainty. In each section, mention has been made the concept of carrying capacity. In this last section, a brief assessment is made of the relative importance of each of the key impacts and how this relates to the scale of the industry as a whole.

The discharge of waste nutrients

7.3 Contamination of sediment by wastes from finfish culture can be severe if the scale of the farm operation is not correctly matched to the local conditions of current speed and depth. However, fish farms only occupy a relatively small area of the Scottish coast and it is unlikely that effects of organic wastes on the seabed will be the environmental factor limiting increases in production.

7.4 Dissolved nutrients can be dispersed over a wide area but, on the basis of current understanding, it is concluded that nutrients from fish farms currently make only a small contribution to algal production and probably do not directly affect toxicity either by promoting toxic strains or increasing the toxicity of toxic strains. These conclusions are based to a large extent on the results of modeling studies, which need backed up by the collection of appropriate long-term data. Assuming they are confirmed, then it is unlikely that dissolved nutrients will become the factor limiting the scale of the industry, except in specific restricted systems with low flushing rates.

7.5 Shellfish farms produce much more limited local waste than finfish farms and the issue of carrying capacity revolves around establishing that there are sufficient planktonic organisms in the water to grow a given biomass without seriously depleting the resource. For many areas of Scotland this is unlikely to be a major problem even should there be a major expansion of the shellfish farming industry.

MEDICINES AND CHEMICALS

7.6 A variety of chemicals are used on fish farms. The most important in terms of potential impacts are thought to be sea lice treatment medicines and anti-foulants based on metals. Although these products are used under controlled conditions such as to protect the environment using the Ecological Quality Standards concept, there are still many important research gaps.

7.7 Even at present, many sites are to some extent restricted in the biomass that they can farm owing to the discharge limits for sea lice medicines. In the future, much depends on whether current strategies for minimizing sea lice are successful. If they are then it is possible that sea lice medicines may not be an important limiting factor. However, if lice numbers continue to be a problem, and concerns for wild populations continue to grow generating a continued downward pressure on lice burdens, then it is likely that for many areas the use of these medicines will become a factor that limits the scale of the industry.

DISEASE IMPACTS

7.8 The most significant issue in terms of transfer of disease and parasites between farmed and wild populations is clearly sea lice. It is important that the relationships between the various factors that might influence the degree to which farmed lice can affect wild populations are determined. Current thinking indicates that smolts of both sea trout and salmon are more susceptible to infestation in fish farming areas. If protecting wild salmonid populations are agreed to be important then it is likely that lice transfer from farmed salmon will limit the scale of the industry, particularly in areas with important populations of wild fish. However, if, in the future, lice on farmed fish can be brought completely under control by some new chemical, vaccine or technology then the constraint from this aspect might be reduced.

ESCAPES

7.9 Escapes from salmon farms probably represent a serious threat to wild populations of salmonids. This is not the case for farmed rainbow trout, which are sterilized. The situation with other species is not yet well understood.

7.10 The magnitude of escapes varies over time but typically escaped salmon may be greater in number than the estimated adult population of wild fish in farming areas. The current level of escapes is probably unsustainable in terms of the health of wild populations. It is difficult to determine how this relates to the scale of the industry, as it is clearly the scale of escapes rather than the scale of the industry that is important. Were the industry to significantly improve containment and/or reduce the fertility of farmed fish then it is obvious that escapes might then limit the scale of production to a lesser extent.

SUSTAINABILITY OF FEED SUPPLIES

7.11 Fishmeal and oil will become limited in the future as more of the world's supply is used for aquaculture feeds. As this happens, the industry will become increasingly vulnerable to changes in supply caused by changes in the productivity or management of the relevant fisheries. Alternative feedstocks are being actively researched and, especially if fishmeal and oil become more expensive, new products are likely to be brought to market to fill the fishmeal/oil gap. In addition, managers of fisheries globally have a poor record of conserving fish stocks and sustaining harvests, so any unexpected reductions in fishmeal production caused by a decline in the fishery before alternatives have been fully developed could reduce the scale of the industry both in Scotland and worldwide.

SUMMARY

7.12 The supply of nutrients to the marine environment is unlikely to be the factor that limits the scale of fish farm production in the foreseeable future. More likely to limit production are the linked issues of medicine usage and sea lice transfer to wild populations. The rate of escapes of farmed salmon is probably unsustainable and represents a major threat to wild populations. Changes in fishmeal supply may affect the sustainability of the industry in the short-term but substitutes for fish meal/oil are actively being developed to fill the medium-term gap in supply.

ACKNOWLEDGEMENTS

7.13 The authors gratefully acknowledge the assistance of Professor Tom Cross who commented on an early draft of the section on escaped salmon."

"Scottish Association for Marine Science May 2002

Introduction

To address the issue of current and future research on aquaculture impacts worldwide, a questionnaire was devised (see below) and sent by email to workers identified from a variety of sources. The MARAQUA web site (http://www.biol.napier.ac.uk/maraqua) maintained by Napier University was an initial source of contact addresses for European researchers. To widen the target community, members of the ICES Working Group on Mariculture and The Environment were sought for contact addresses.

To identify workers in the field in the United States, the Aquaculture Information Center – DOC/NOAA website (http://www.lib.noaa.gov/docaqua/basicaqua.html) provided addresses and links to the various state Sea Grant programs. The Aquaculture Association of Canada (http://www.aquacultureassociation.ca) provided links to researchers in Canada. Finally, recent worldwide symposia on aquaculture impacts were studied for relevant addresses.

A total of 481 emails were sent containing the questionnaire. There were 52 returned from email servers stating the user was unknown, indicating that the addressee had changed address, or had provided an incorrect email address. Where possible these erroneous addresses were corrected. 30 researchers replied affirmatively, and returned completed questionnaires, 15 replied that they were not doing any work in the area, 9 said they were out of the office and would deal with the reply on their return, and 3 were not sure.

The replies were entered into a database, and extracted into areas of research for compilation into the annex appended. The areas of research were divided into: Discharge of Waste Nutrients; Effects of Medicines/Chemicals; Disease Impacts (including parasitic sea lice); Escapes From Fish Farms and Potential Effects on Wild Stocks; Sustainability of Feed Supplies; Carrying Capacity; Impacts on Seabird/ Sea Mammal Populations; Impacts of Trace Metals; Assessment of Impacts (Modeling/Monitoring); and Others. The annex contains only the title of the project, acronym, commencement date, location of host institute, and a brief description of the project.

The text of the questionnaire:

Environmental Impacts of Aquaculture – Questionnaire

In response to a Scottish Parliament Transport and Environment Committee Review examining the interactions between Aquaculture and the Environment it was announced that a full review should be undertaken by the Scottish Association for Marine Science (SAMS) on the recent and on-going research concerning the Environmental Impacts of Aquaculture. Published by Dr Kenneth Black, SAMS, Dunstaffnage Marine Laboratory, Oban, Argyll, Scotland, U.K. PA37 1QA or e-mail: kdb@dml.ac.uk

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Priority Publications (must have):

Final Environmental Assessment for an Offshore Open Ocean Fish Farm Project Off Unualoha Point, Kona, Hawaii. Prepared for: Land Division, Department of Land and Natural Resources. Prepared by: Kona Blue Water Farms (a division of Black Pearls, Inc.) P.O. Box 525, Holualoa, HI 96725. July 29, 2003.

Appendix VI to the above report: Management Plan, Appended to CDUA Application "Final Management Plan for an open ocean fish farm offshore of Unualoha Point, North Kona, Hawaii. Prepared for: Board of Land and Natural Resources, pursuant to Section 13-5-24R-1 HAR. Prepared by: Kona Blue Water Farms (a division of Black Pearls, Inc.) P.O. Box 525, Holualoa, HI 96725. June 25, 2003. Their web site for other information is http://www.blackpearlsinc.com/3_4.shtml.

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RELEVANT ONGOING PROJECTS WITH THEIR OWN WEB SITES AND PUBLICATIONS:

AQCESS –Aquaculture and coastal economy and social sustainability.

FORM – Fish oil and meal replacement.

Kona Blue Water Farms - http://www.blackpearlsinc.com/3_4.shtml.

MEDVEG- Effects of nutritional release from Mediterranean fish farms on benthic vegetation in coastal ecosystems.

MERAMED – Development of monitoring guidelines and modeling tools for environmental effects from Mediterranean aquaculture.

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Additional Information:

Japan undergoes a public interest review to insure that it does not "impede other public interests" and to detail the particular area open for farming but Japan does not employ a formal nationwide marine zoning structure. Instead, decisions of placement of aquaculture facilities have been made taking into account the "public interest of the sea area" and the cultural and socioeconomic factors of the coastal towns. Without a formal planning process, aquaculture license holders still face challenges from recreational and other users.

Similar to the system developed in Japan, Canada has a system that is based on leases and aquaculture licenses. The Canadian Aquaculture Act, was established to promote orderly development of the aquaculture industry. The Act seeks to secure aquaculture property rights, minimize use conflicts and develop cooperative decision-making. To accomplish these goals Canada's industry is organized by a set leasing and licensing structure. All applications for aquaculture licenses go through the Minister of Fisheries. If granted, a license is for a specific site, set species of aquatic plant or animal and specifics predetermined terms and conditions. Furthermore, licenses may be granted to persons that own, lease or otherwise have rights to the application site. Regulations promulgated by the Canadian Provinces control specific details of aquaculture by establishing the criteria for site development plans, annual reports, records of transfers, disease, food use and leasing procedures. For example, New Brunswick regulations require notification, allow for public comments to the Ministry of Fisheries and provide for consideration of user conflicts before a lease will be granted.

Additionally, countries in the Mediterranean, such as Greece, have developed systems designed to organize aquaculture development, balancing environmental and health concerns with increasing resource demands. A strictly regulated Greek permit system has emerged which requires applicants to obtain clearance from numerous government agencies (environmental protection, navigation, shipping, health protection, protection of antiquities, commercial fisheries, tourism, recreation, nature conservation and wildlife) before a permit and lease will be granted. The national coordinating authority for aquaculture is the Greek Ministry of Agriculture, however there are regional differences due to the division of Greece into sensitive and very sensitive regions (aquaculture is typically not permitted in very sensitive regions). In order to receive final approval the application and the required environmental impact assessment (EIA) must be submitted to the Physical Planning Ministry for the Environmental, Physical Planning and Public Works. The EIA requires the applicant to assess environmental impacts, as well as social benefits and harms to people, their homeland, livelihoods or other activities.

Many elements from other country's programs will have a great benefit to the developing U.S. industry and will work well when coordinated together in a comprehensive marine zoning plan. The identification of and proposed solutions to issues surrounding siting, environmental concerns and social and economic impacts can be built into a marine zoning system for U.S. waters.

Texas regulators (mainly Texas Commission on Environmental Quality and Texas Parks and Wildlife) have discussed for years the use of BMPs for aquaculture, but nothing has been firmly put into place; mainly because of the complications with each individual operation on the Texas coast having its own specific discharge limitation requirements, which are dependent upon the receiving waters, that varies from site to site. Water on the upper Texas coast generally has more suspended particles and influence from rivers and a lower salinity than does clearer, higher salinity water at South Texas coastal operations. So each must have different discharge criteria accordingly. The BMPs would have to be written in such a general format that it is thought that the BMP exercise would be fruitless and redundant, merely adding another layer to the permitting/monitoring process. The producers are in favor of BMPs, but in lieu of the government regulations, and are not in favor of having both.

What Texas regulators have come up with most recently is a general permit for aquaculture. Details are available at the TCEQ web site. http://www.tceq.state.tx.us/permitting/water_quality/wastewater/general/WQ_general_permits.html#txg13issued. TCEQ does not specifically include BMPs as part of the process. Most likely the BMPs would not be applicable enough to individual uses to be of assistance when their projects were finally permitted. General BMPs that are already in place (international and US-based BMPs) should be utilized, rather than the Government regulatory agencies making up new BMPs.

International environmental guidelines applicable to offshore aquaculture development have already been developed and are in place. The best example of this is FAO – Code of Conduct for Responsible Fisheries, Food and Agriculture Organization of the United Nations (FAO). 1995. FAO. Rome, Italy. 41 pp.

GESAMP Planning and Management for Sustainable Coastal Aquaculture Development is another international environmental guideline and the resolutions of the North Atlantic Salmon Conservation Organization- NASCO). Additionally, Codes of Conduct for Aquaculture have already been published by NMFS/NOAA and NMFS/NOAA is working on offshore operational standards. When complete, the NMFS operational standards can be used to regulate offshore aquaculture and provide clear regulatory operational standards and measures that must be met by operators. These operational standards should be sufficient without adding an additional layer of BMPs, which would have to be developed with commercial offshore operators, which are few and far between now. The emphasis on environmental regulations must be to control unacceptable environmental impacts (SEPA 1998). Controlling the scale of the activity does not allow for economic growth and provides a disincentive for technological innovation (GESAMP 2001). If operators are required to develop BMPs and live by them and live by the operational standards set by NOAA as well, it is redundant and takes the operator away from what he needs to be doing, growing product efficiently. In addition to the various Codes of Conduct developed by FAO and NMFS/NOAA, the GESAMP Planning and Management for Sustainable Coastal Aquaculture Development report can be used as a guide (rather than BMPs), as well as the resolutions of the North Atlantic Salmon Conservation Organization (NASCO), especially the Oslo resolution to minimize impacts from aquaculture. All these international agreements set standards with which U.S. procedures should comply. For many provisions, U.S. standards already in place by EPA, FDA, USDA/APHIS, USCG, and USACOE, may be more stringent and precise. Additionally, the NOAA Code of Conduct provides general guidelines for development plans and management strategies, permitting, general criteria for individual sitting, suggestions for zoning, managing risk and uncertainty, guidelines for conserving biodiversity, general guidelines for aquatic animal health, guidelines for monitoring, evaluation and enforcement and makes reference to BMPs. The Code also gives guidance on record keeping, prevention of escapes and endangerment to other species, product quality and safety, management of aquatic health, general guidance on research and development, public education, outreach and information dissemination. The NOAA Code of Conduct states “Best management practices (BMPs) are recognized as valuable tools for industries to set responsible performance and production standards **which can be used in lieu of government regulation**, and serve as a 'seal of quality' for products.”

Monitoring requirements and regulations should be flexible and adaptive so that they can respond to changes in operating procedures or environmental conditions. Frequent consultations between industry and regulatory authorities will minimize the monitoring burden and maximize the effectiveness of regulations. Monitoring results should be promptly reviewed by the appropriate regulatory authority for compliance with lease conditions as well as ecosystem impacts. In the US EEZ, the NOAA Office of Offshore Aquaculture should pass the responsibility to NMFS to coordinate monitoring, data collection and enforcement activities. Permit violations should be subject to civil and criminal penalties. If an operation causes damage to the ecosystem, then the operator should be held responsible for remediation and restoration, or, when such actions are not possible, reasonable costs of such damage.

Regulations differ in different countries but they all seek to ensure the same thing, namely that fish farms produce safe, wholesome fish with the minimum of environmental impact. In most countries and especially the U.S., Canada, and much of Europe, fish farm regulations are extremely strict. Typically, fish farms are regulated to control where they can be located, what species of fish can be farmed, the quality and quantity of any discharge or the impact levels on the sea bottom and water column, fish health, the use of chemotherapeutics, worker and navigational safety, and food safety. In some states in the U.S., fish farmers must utilize feed waste monitoring systems (e.g., underwater cameras, detectors, or upwellers) and they must use best management plans and have contingency plans and protocols for dealing with virtually all contingencies. The Texas Parks and Wildlife now (2008) has a full set of rules and regulations for offshore aquaculture in Texas. See Appendix B for the new TPWD offshore aquaculture rules. Other Texas aquaculture regulations require hurricane contingency plans and protocols for dealing with diseases. Similar plans could be adopted offshore in each respective state, rather than setting up new plans and protocols for offshore. For more information, a detailed publication entitled “Updated Governmental Permitting and Regulatory Requirements Affecting Texas Coastal Aquaculture Operations” can be found for free download at the Texas Sea Grant web site http://texas-sea-grant.tamu.edu/online%20publications/permitting.html.

Marine Net Pen Best Management Practices for Finfish Aquaculture

NOTE: These best management practices were provided to the Ad Hoc Aquaculture Advisory Panel prior to the publication of an EPA final rule, 40 CFR Part 451, Effluent Limitation Guidelines and New Source Performance Standards for the Concentrated Aquatic Animal Production Point Source Category, on August 23, 2004. This rule added new aquaculture effluent limitation guidelines and source performance standards for net pen operations to those sections of the Clean Water Act that pertain to the standards imposed in National Pollution Discharge Elimination System (NPDES) permits. Noted within this document are the new operational practices and management requirements that duplicate certain best management practices suggested here.

These Best Management Practices pertain only to the operation of net pens or cages that are anchored or floating in the Gulf of Mexico Exclusive Economic Zone managed by the Gulf of Mexico Fishery Management Council and the National Marine Fisheries Service for the purposes of cultivating marine finfish. Net pens and cages are submerged, suspended, or floating holding systems (hereinafter referred to as “net pens”).

Net pen operations must acquire: 1) a Section 10 permit from the U.S. Army Corp of Engineers to establish a facility permanently or temporarily attached to the seabed, 2) a National Pollution Discharge Elimination System (NPDES) permit from the U.S. Environmental Protection Agency if the facility produces more than 100,000 pounds of fish annually, and 3) a permit from the

U.S. Coast Guard for conformity with markers and the private aids to navigation. Bivalve molluscs (clams, mussels, scallops or oysters) being produced for sale as edible product can only be cultured within the boundaries of Shellfish Harvesting Areas classified and managed by states bordering the Gulf of Mexico. This limitation is not in effect when shellfish are being polycultured with marine finfish solely for the ecological benefits they provide and the shellfish will not be sold as a food product.

Best Management Practices

These Best Management Practices are to improve the environmentally friendly performance of net pen aquaculture facilities. Practices are provided for site selection, feed management, solids management and disposal, management of escapees, mortality removal and disposal, and facility operation and maintenance. Net pen systems may be used to culture a variety of marine fish species. The diversity of species, stocking density, pen design, numbers of pens, and culture methods used in net pen systems may make the implementation of these Best Management Practices to attain the environmental conservation or preservation goals of the **[Agency]** a very challenging decision making process for the farmer. An effective Practice for one species or facility may be totally inappropriate for another. Furthermore, Practices may be combined in unique ways to achieve certain environmental conservation goals. The **[Agency]** recommends that the net pen operator consult with the **[Agency]** before implementing any of these Best Management Practices.

SITE SELECTION

Site selection requires balancing of multiple factors. Appropriate site selection for net pens is critical for the minimization of potential environmental impacts, optimal fish health and performance, worker safety and the minimization of production costs. With the exception of site selection, net pen farm operators have little ability to control the environmental conditions their fish may experience. Fish physiology, metabolic performance and health are all highly influenced by the environmental conditions in which they are cultured. Small changes in environmental conditions can cause sublethal stress, suppressed growth rates and elevated food conversion ratios. All of these effects result in elevated production costs to the farmer.

Wise site selection has significant potential to reduce the risk of environmental impacts associated with net pens. Site selection to minimize environmental impacts may have to balance conflicting goals. For example high-energy exposed sites tend to reduce the risk of benthic waste deposition. However, due to their exposure, these same sites may increase the risk of storm damage, fish escape, or compromise worker safety. Appropriate sites combined with careful farm management can result in minimal environmental impact.

Best Management Practices

1) Evaluate each potential farm site to insure that environmental conditions on the farm site are appropriate for the species being considered for culture and the equipment proposed for use.

Farm Record: A Farm Site Plan with net pen schematic that maps the location of the net pens, anchoring, and feeding systems should be maintained, updated and made available for review by **[Agency]** personnel during site inspections.

2) Select sites with good water exchange that are not depositional environments.

3) Baseline site surveys must be conducted and submitted to the **[Agency]** prior to pen placement in order to characterize the marine habitat, ecosystem and hydrographic conditions that prevail on the site prior to the establishment and operation of a farm.

At a minimum, water depth, circulation patterns, current speeds, wind-wave fetch, water quality (nitrate, phosphate, and ammonia) and benthos (sediment type and composition, interstitial species identity and number) should be documented or, in the case of fetch, calculated. Predominant seasonal weather patterns should be considered. Baseline studies should also include a characterization of the seasonal variation in the above characteristics and the potential maximum sea state (wave height and frequency) of the site. These surveys should be used to confirm that site conditions are appropriate for the species being cultured and equipment to be deployed.

Farm Record: A Baseline Site Survey should always be available for review by **[Agency]** personnel during site inspections. Pertinent hydrographic data should be included in the Net, Pen Structure and Mooring System Preventative Maintenance Program.

4) Impacts on worker safety, product quality, and animal welfare should also be considered during the prospective site review.

Sites with frequent, extreme weather or sea-state conditions that would limit the grower's access to the farm site and cultured animals should be reconsidered.

5) Care should be taken during site selection to minimize the risk of negative impacts on farm animals from off-farm human activities such as industrial development (oil or gas exploration and drilling), and oil, chemical or sewage spills.

6) The distribution and prevalence of potential pests and predators should be examined when selecting sites. Where practical, farmers should select farm sites away from high pest and predator concentrations.

7) Sites for polyculture of finfish and filter-feeding shellfish (mussels, clams, oysters or scallops) can only occur in Shellfish Harvesting Areas classified and managed by the states bordering the Gulf of Mexico. This is not a required where shellfish are being cultured solely for the ecological benefits they provide or will not be sold as a food product. Contact the Interstate Shellfish Sanitation Conference to identify the responsible state agency for classifying Shellfish Harvesting Areas and implementing the provisions of the National Shellfish Sanitation Program (http://issc.org/).

8) The number of net pens or their configuration may require the allocation of the capital, labor and time required to move net pens and allow the recovery of a site to avoid benthic degradation (referred to as "fallowing"). Farms that intend to implement a fallowing strategy must inform the **[Agency]** of this intent during the permit application process and identify potential fallowing sites in the Farm Site Plan and mooring management and adjustments in the Net, Pen Structure and Mooring System Preventative Maintenance Program.

FEED MANAGEMENT

NOTE: The EPA NPDES Permit requirements include: 1) employ efficient feed management and feeding strategies to limit feed input to the minimum amount reasonably necessary to achieve production goals and sustain targeted rates of aquatic animal growth (§451.21(a)), 2) minimize the accumulation of uneaten food beneath net pens through the use of active feed monitoring and feed management practices that may include one or more of the following: real-time feed consumption monitoring, monitoring of sediment quality beneath pens, monitoring of benthic communities, capture of waste feed or feces, and other practices approved by the permitting authority (§451.21(a)), 3) the calculation of representative feed conversion ratios, and the maintenance of records documenting feed amounts and estimates of numbers and weight of aquatic animals in culture (§451.21(g)(1)), and 4) training of staff in feed procedures and proper equipment use (§451.21(h)(2)).

Waste feed and fish feces constitute the major portion of the wastes generated by a net pen farm. However, because net pens operate in high-energy environments, the waste management (collection and concentration) can be very difficult. Therefore, the most effective way to reduce the potential environmental impact of net pens is to aggressively and proactively manage the selection, distribution and utilization of feed. Effective feed management is based on two components: waste reduction and optimal feed conversion ratio.

Waste reduction focuses on ensuring that feed used by the farm is not lost or discharged prior to intake by the fish. Optimal conversion focuses on ensuring that all feed offered to the fish is actually consumed, optimally digested and utilized.

Fish nutrition and feeding practices are active areas of research, and technology is constantly evolving. An important farm production goal is to improve the efficiency of nutrient utilization by fish, thereby enhancing economic returns and reducing waste production. Because technology is rapidly changing, feed management objectives should be flexible so that newer and better practices and technology can be implemented as they become available.

Best Management Practices:

1) Feed storage, handling, and delivery methods should minimize waste and fine particles of feed.

> Feed storage areas should be secure from contamination, vermin, moisture, and excessive heat. Long-term storage of feed can affect feed quality. As such, feed should be rotated (oldest feed used first) and not stored beyond the manufacturer's recommended use date. Care should be taken during feed handling to minimize pellet damage or crushing and reduce the creation of fine feed particles that cannot be utilized by the fish.

2) Farms should calculate feed conversion ratios by using feed and fish biomass inventory tracking systems.

> Calculation of feed conversion ratios is an essential economic function on all net pen farms. Monitoring long- and short-term changes in feed conversion ratios allows farmers to quickly identify significant changes in feed consumption and waste production rates in individual net pens.
>
> **Farm Record**: Daily Feed Conversion Records and Analysis of the prior 12-month feed conversion trend analysis must be maintained, updated and made available for **[Agency]** personnel review during site inspections.

3) In cooperation with feed manufacturers, farmers should seek to minimize nutrient and solids discharges through optimization of feed formulations.

> Feeds should be formulated for optimum feed conversion ratios and retention of protein (nitrogen) and phosphorus. Feed formulations should consider numerous factors including, pellet stability, digestibility, palatability, sinking rates, energy levels, moisture content, ingredient quality and the nutritional requirements of the species being grown. Feeds should be formulated and manufactured using high-quality ingredients. Feed ingredients should have high dry matter and protein apparent digestibility coefficients. Formulations should be designed to enhance nitrogen and phosphorus retention efficiency, and reduce metabolic waste output. Feeds should contain sufficient dietary energy to spare dietary protein (amino acids) for tissue synthesis. Feeds should be

water stable for sufficient periods such that pellets remain intact until eaten by fish.

Farm Record: Feed Manufacturer Labels, or copies thereof, should be retained for the prior 24-months of operation for review by **[Agency]** personnel during site inspections.

4) Farmers should use efficient feeding practices.

   Feed may be delivered by hand, demand feeders, automatic feeders, or by mechanical feeders. Regardless of the delivery method or system, the amount of feed offered should optimize the balance between maximum growth and maximum feed conversion efficiency. The appropriate quantity and type of feed for a given species is influenced by fish size, water temperature, dissolved oxygen levels, health status, reproductive status, and management goals. Feed particle size should be appropriate for the size of fish being fed. Feeding behavior should be observed to monitor feed utilization and evaluate health status.

5) Feeding equipment should be regularly checked to ensure efficient operation.

   Improperly adjusted or malfunctioning feeding equipment can over or under feed a net pen of fish and lower feed and production efficiency.

6) Whenever practical, farmers should grow fish strains that have demonstrated efficient feed conversion ratios.

7) Farmers should make every effort to reduce fish stress and optimize culture conditions to reduce feed conversion ratios.

8) Farms should conduct employee training in fish husbandry and feeding methods to ensure that workers have adequate training to optimize feed conversion ratios.

9) Wherever practical, monitoring technologies such as video, “lift-ups,” Doppler, or sonar sensors should be used to monitor feed consumption and reduce feed waste.

   If automated feeding systems are used, fish monitoring systems should, if possible, be actively linked to feeding control systems to provide direct control feedback to reduce feed wastage. Even if monitoring systems are employed, active monitoring by farm operators should also occur to ensure that all systems are functioning properly and fish are behaving and feeding normally.

10) Farmers must annually examine the bottom under their net pens.

Close attention should be paid to the presence of any waste feed and how the benthic environment appears to be assimilating the nutrient load. Bottom survey analysis should be immediately used to adjust feed and/or farm management practices.

Farm Record: Bottom Survey Data and Analysis should be retained on file for review by **[Agency]** personnel during site inspections.

SOLID WASTE MANAGEMENT AND DISPOSAL

NOTE: The EPA NPDES Permit will include requirements to: 1) collect and return to shore and properly dispose solid wastes (§451.21(b)), 2) staff training to prevent spills, clean-up spills and spill response (§451.21(h)(1)), and 3) staff training to properly operate and clean equipment (§451.21(h)(2)).

Waste feed and fish feces constitute most of the solid wastes generate by a net pen farm. In many cases, waste feed will be consumed by fauna attracted to the net pen. However, concentration and collection of unconsumed solid wastes is difficult because net pens operate in high-energy, open-waters environments exposed to currents, waves, and storms.

While it is theoretically possible to install secondary net or deflector systems to collect solid wastes, to date experimental trials have demonstrated significant operational and economic problems. For example, the industry trend is towards sites with higher current speeds, and in areas with even moderate currents, pellets that are not consumed by the fish may be swept out of the cage before they are deposited on a collector located on the bottom of the net. Net pen operations in Hawaii and Puerto Rico reported that their operations attract a variety of wild fish that immediately consume pellets exiting the nets.

The most effective and practical way to manage solid wastes associated with feeding fish is aggressive feed management and proper site selection, as described in the Feed Management section of this chapter. Other possible sources of solid waste include biofouling organisms that colonize nets, mortalities, feedbags, packaging materials, scrap rope and netting, worn or broken net pen structural components, and other miscellaneous items.

Best Management Practices:

1) Farmers must conduct a systematic review of their operations and develop a waste management plan. This plan should identify all wastes generated on a site or from a facility.

Waste management plans should clearly identify all wastes generated on a site and classify them with respect to any risks associated with their collection and appropriate disposal. The waste management plan should be designed to minimize the generation of waste while recognizing the practical challenges associated with marine operations. Whenever possible, waste management plans should encourage recycling of waste except in cases where human or animal health may be compromised. In these cases, a clear containment and disposal method should be outlined. These methods and actions should be designed to minimize any human or fish health risks and benthic impacts associated with the waste. At a minimum, waste management plans should address: human waste, feedbags, scrap rope, scrap netting, fish mortalities, packaging materials and any other solid waste.

Farm Record: A Solid Waste Management Plan must be created, maintained, implemented, and made available to **[Agency]** personnel during site inspections.

2) Proactive efforts should be taken to minimize the generation of all types of solid waste.

Farmers should review their operations and consider whether there are alternative practices that help reduce the use of materials that generate solid waste. The use of packaging and materials handling methods that reduce total packaging needs should be strongly considered.

3) Farmers should avoid the discharge of substances associated with in-place pressure washing of nets.

Every effort should be made to use gear and production strategies that minimize or eliminate the need for on-site wash down and rinsing to reduce biofouling. The use of air-drying, mechanical, biological, and other non-chemical procedures to control net fouling are strongly encouraged. In some areas with high flushing rates or great depth, in-place net washing may be acceptable. In areas with high fouling rates, treatment of nets with anti-fouling compounds permitted by EPA may represent a lower environmental risk than frequent net washing.

4) All feed bags, packaging materials, waste rope and netting, or worn structural components should be collected, returned to shore and disposed of properly. Recycling is strongly encouraged.

MANAGEMENT OF ESCAPEES

NOTE: The EPA NPDES permit require: 1) routine net pen inspections, repair and maintenance to prevent escape (§451.21(f)), and 2) recordkeeping net changes, inspections and repairs (§451.21(g)(2)).

The escape of cultured species may pose a variety of potential risks to aquatic ecosystems or unrelated economic activities. Potential risks include pathogen transmission, genetic interaction, and competition for resources. For net pen operations in Gulf of Mexico, these outcomes are not anticipated to occur because: 1) a strong economic incentive exists for producers to prevent escape of cultured animals and to recover animals that do escape; 2) most pathogens are naturally occurring and ubiquitous; and, 3) culture is restricted to species native to the Gulf of Mexico or sterile organisms.

There are three principle causes of escapees from net pen farms: equipment failure, operational errors, and predator attacks. While it is theoretically possible to prevent fish escape by the installation of secondary containment nets, these systems have environmental costs. Double netting systems significantly reduce water flow rates through net pens. This flow reduction may negatively impact dissolved oxygen in and around cages, increase sedimentation rates, and alter water circulation patterns on farm sites. The additional stress on fish may predispose fish to diseases and increase feed conversion ratios, resulting in increased waste production per unit of fish biomass. The use of double netting increases the net surface area subject to biofouling, thereby increasing the need for net cleaning and disposal of fouling waste. The heavier physical loads associated with double netting structural, flotation, and mooring requirements will all increase. These increased equipment requirements, in combination with the additional netting required, would significantly increase the consumption of energy and petroleum products used in the manufacture of net pen farming equipment.

The two most effective ways to reduce potential environmental impacts of escapees are prevention and genetic isolation. Prevention involves proactively reducing the potential causes of escape. Genetic isolation is accomplished by using highly domesticated strains that are unlikely to survive in the wild or unable to interbreed with wild fish or sterile organisms. Escape response actions such as net repair and animal recovery plans, may also help mitigate the impact of escapes if they occur. All net pen farms should continuously strive to reduce escape risk.

Best Management Practices:

1) Marine finfish in culture must be derived from Gulf of Mexico species.

Farm Record: Documentation of the source and genetic heritage of broodstock, fry and fingerlings or proof of fry and fingerling sterility for all fish cultured will be maintained and made available to **[Agency]** personnel during site inspections.

2) Before installing net pens on a site, operators should consider how site characteristics might impact the risk of escapes.
   Site characteristics that may be relevant include frequency of extreme weather, degree of site exposure, type of bottom, and distribution and prevalence of predators, and navigational considerations. When practical, sites should be selected that minimize the impacts of these aspects.
3) Net pen farms should develop and implement a Loss-Control and Escape Recovery Plan.
   Plans should include a site-specific analysis of the potential risks of escapes, their causes, and the specific procedures employed by the farm to reduce the risk. Loss-control plans should be designed to address the three principle causes of escapes (equipment failure, operational errors, and predator attacks) and should include: 1) minimum equipment and operating standards, 2) emergency repair procedures, and 3) escape recovery procedures.
   In the event of a significant escape, farmers should make attempts to recapture escaped fish. Recapture procedures should be based on the escape recovery actions the farmer has developed. Plans should allow for continuous improvement and revisions based on innovations in farming methods and technology.
   Farm Record: A Loss-Control and Escape Recovery Plan should be created, maintained, implemented and made available to **[Agency]** personnel during site inspections.
4) Fish transfers such as stocking, grading, transfer, or harvest should be conducted in appropriate weather conditions and under constant visual supervision. Equipment appropriate to the weather and net pen or cage designs should be used. Where necessary or appropriate, shields or additional net should be used to prevent stray fish escape during transfer.
5) All holding, transportation, and culture systems should be designed, operated and maintained to prevent escape.
6) Nets should only be obtained from a manufacturer or supplier whose equipment design specifications and manufacturing standards meet generally accepted standards prevalent in the aquaculture industry.

Net design and specification should be commensurate with the prevailing conditions of the site. Stress tests should be preformed on all nets with more than three years of use in the marine environment when the net is pulled out and cleaned. All nets in use should be ultraviolet light (UV) protected.

7) Net pens should only be obtained from a manufacturer or supplier whose equipment design specifications and manufacturing standards meet generally accepted standards prevalent in the aquaculture industry.

Net pen design, specification, and installation should be commensurate with the prevailing conditions and capable of withstanding the normal maximum weather and sea conditions.

Farm Record: A written statement from the net pen manufacturer certifying that net pen(s) have been assembled and moored to their specifications must be available to **[Agency]** personnel during site inspections.

8) Net pens should have jump nets installed to prevent fish from jumping out of the primary containment net.

Jump nets should be an integral part of the primary containment net or joined to it in a fashion that prevents fish escape between the primary net and the jump net. Jump nets should be of a height appropriate to the jumping ability and size of fish they are containing.

9) Nets should be secured to the cage collar such that the collar bears the strain and not the handrail of the net pen or cage.

Net weights, when used, should be installed to prevent chafing. A second layer of net should be added one foot above and below wear points. The use of weight rings should be encouraged at appropriate sites.

10) A preventative maintenance program for nets, net pen structures, and mooring systems should be developed.

The program should have the ability to track individual nets, net pen structures, mooring systems and schedule and document regular maintenance and testing. Nets or net pen structural components that fail testing standards should be retired and disposed of properly. The program should document regular maintenance, the nature of the maintenance, date conducted, any supporting documentation for new materials used, and the identity of the individuals or firms that conducted the maintenance.

Farm Record: A Net, Pen Structure and Mooring System Preventative Maintenance Program should be created, maintained, updated, implemented and made available to **[Agency]** personnel during site inspections.

11) Mooring system designs should be compatible with the net pen system they secure.

Mooring systems should be installed in consultation with the net pen manufacturer or supplier. Mooring system design, specification and installation should be commensurate with the prevailing conditions of the site and be capable of withstanding the normal maximum conditions likely to occur at a site. A mooring system schematic must be included and updated as a component of the Farm Site Plan. Design maximums should be recorded in the Net, Pen Structure and Mooring System Preventative Maintenance Program.

12) Site operators should regularly inspect and adjust mooring systems as needed.

Rigging tension should be maintained to installation standards. New components should undergo their first inspection no later than two years after deployment. A diver or remote camera should regularly visually inspect subsurface mooring components. Special attention should be given to connectors and rope/chain interfaces. Chafe points should be identified and subject to more frequent inspection and removal of marine growth. With the exception of anchors, mooring systems should be hauled out of the water for a visual inspection of all components at least every five years. When considering what inspection method to employ net pen operators should consider the relative risks and benefits associated with the inspection method. On sites frequently exposed to severe weather, or where it is difficult conduct above-water inspection; equipment haul out may represent a greater risk than regular underwater inspections.

13) Shackles used in mooring systems should be either safety shackles, wire-tied, or welded to prevent pin dropout.

14) Where appropriate, bird nets should be used to cover net pens in order to reduce the risk of escape due to bird predation. Bird nets should be constructed using appropriate materials and mesh sizes designed to reduce the risk of bird entanglement.

15) Site operators should develop a service vessel Standard Operating Procedure (SOP).

Vessel operations around a net pen site can cause escapes. All vessel operators should receive appropriate training in the operation of the vessel. The SOP should minimize the risk of damaging nets and/or mooring system components with the propeller of the vessel.

Farmers must provide a service vessel SOP to the **[Agency]** to assist personnel in completing their inspections in a manner that will avoid damage to net pens, associated structures and moorings, or service vessels.

MORTALITY REMOVAL AND DISPOSAL

NOTE: The EPA NPDES permit requires the: 1) minimization of discharge associated with the transport or harvesting of aquatic animals including blood, viscera, carcasses or water containing blood (§451.21(c)) and 2) the proper removal and disposal of mortalities to prevent discharge (§451.21(d)).

Proper fish health management is the best means for reducing costly mortalities in net pens. Optimizing fish health will reduce the need to deal with dead fish. Even under optimal conditions some mortality will occur naturally. Net pens, by their very design, contain and collect mortalities. This facilitates mortality monitoring and their timely removal.

Best Management Practices:

1) Farmers should proactively manage their fish stocks to optimize animal health.
2) Weather permitting; mortalities should be collected regularly and frequently.

   Farmers should use collection and removal methods that do not stress remaining animals, compromise net integrity, or jeopardize worker safety. Mortalities should only be stored and transported in closed containers with tight fitting lids.

FACILITY OPERATIONS AND MAINTENANCE

NOTE: EPA NPDES permits require: 1) recordkeeping that includes feed conversion ratios, feed amounts, number and weight of animals in culture, net changes, net inspections and net repairs (§451.21(g)(1)(2)), 2) the proper storage of drugs, pesticides and feeds in a manner to prevent spills that may discharge (§451.21(e)(1), 3) implementation of procedures for properly containing, cleaning and disposing of spilled material

(§451.21(e)(2)), and 4) staff training in the proper equipment operation and cleaning of production systems (§451.21(h)(2)).

Net pen farms are expensive to install and operate. Operators are subject to elevated public scrutiny because they are located and actively utilize public waters. Net pens farms operate in these public waters under the provisions of permits from the U.S. Environmental Protection Agency, U.S. Army Corp of Engineers and U.S. Coast Guard that can be revoked for noncompliance. Net pen operators who do not operate their facilities in compliance with permit conditions and these Best Management Practices risk the revocation of permission to culture marine fish in the Gulf of Mexico and directly jeopardize their investments.

Best Management Practices:

1) Net pen operations that annually produce less than 100,000 pounds of live product are exempt from acquiring the U.S. Environmental Protection Agency's National Pollution Discharge Elimination System (NPDES) permit.

To appropriately manage net pen operations that are not required to have NPDES permit, the [Agency] may require periodic Water Quality Monitoring in addition to the Bottom Survey and Data Analysis requirement.

Farm Record: Water quality monitoring (nitrate-N) will be periodically completed by the farm operator at locations that will characterize background concentrations and in an array that will adequately detect: 1) farm contribution to the water column and 2) the nitrate-N attenuation point(s) relative to the farm.

Prior to farm installation the farm operator must submit a Water Quality Monitoring Plan to the **[Agency]** for appraisal. Upon approval by the **[Agency]**, the Water Quality Monitoring Plan must be maintained, updated, implemented and made available to Division personnel upon request.

2) When considering modifications to existing farming practices, procedures or structures, growers should include a review of the type and extent of probable environmental impacts that may occur as a result of the new methods and amend the proposed methods to mitigate potential impacts.

3) Therapeutic drugs and chemicals approved by the U.S. Food and Drug Administration and the U.S. Environmental Protection Agency must be used in accordance with manufacturer's label directions or as prescribed by a licensed veterinarian.

4) When conducting activities such as stocking/seeding, harvesting, feeding, grading, thinning, transfer, cleaning, gear maintenance or fallowing, all standard operating procedures should include diligent efforts to minimize probable environmental impacts.

5) Comprehensive stocking and production strategies that optimize production while minimizing environmental impacts should be used. Production planning should include a systematic review of any probable environmental impacts that would be associated with a particular production plan or method.

6) When installing net pens and their associated mooring systems, careful consideration should be given to their potential impacts on water circulation patterns. Gear deployment should seek to optimize circulation patterns and maximize water exchange through the pens, thereby improving fish health and reducing benthic impacts.

7) Harvest procedures and equipment should be designed and operated in a fashion that reduces any associated discharges. Harvest and postharvest vessel and equipment clean-up procedures should minimize any wastes discharged overboard.

8) Net pen operators should consider the practicality of polyculture using shellfish and/or marine plants to reduce the contribution of nutrients and particulate matter to waters outside the farm lease.

> Where practical, shellfish, marine plant and finfish farms should be colocated in order to maximize production synergies and reduce potential water quality impacts.

9) Farm support vessels should only be fueled at licensed fueling stations.

> All fuel or oil spills should be immediately reported to the fueling station operator. All on-board spills and leaks should be immediately reported to the captain of the vessel. Appropriate clean up and repair actions should be initiated as soon as practicably possible. All fuel or oil spills should be reported as required to the appropriate state and federal authorities.

10) Farm support vessels of the appropriate size should have approved Marine Sanitation Devices (MSD) on board. All human wastes should be disposed of according to applicable state and federal regulations.

11) If antifouling paints are used on farm support vessels, nets or structures, only boat-bottom paints approved for use by state or federal regulations should be used.

12) Develop a record-keeping system.

Good record keeping is the hallmark of a well-operated aquaculture facility. Farm Records identified as components of these Best Management Practices must be updated, maintained and made available to **[Agency]** personnel during site inspections. Farm records that require the collection and analysis of environmental data (physical, chemical or biological) must be documented in a Quality Assurance Project Plan. Farm operators must submit such plans to the **[Agency]** prior to farm construction.

Farmers may keep and analyze additional records related to feeding, chemical use, water quality, serious weather conditions, fish culture operations and inventory to facilitate improvements in the efficiency of farm input use. Such records should be reviewed periodically to determine if they are useful and to provide insight into opportunities for improvement of farm operation.

Using EPA's BMPs, it would seem that if NOAA would establish operational standards for offshore aquaculture, this would be all that would be necessary for protecting the environment. Offshore technologies are changing rapidly and BMPs developed, identified and implemented would also have to be changed constantly as technologies change. It would take a constant effort to stay abreast of the technology changes. Specific BMPs for each project would be best left in the individual producer's hands.

Colin Nash (personal communication June, 2006 and retired in 2008) informs me that " NOAA is developing an **AQUACULTURE MATRIX (OPERATIONAL STANDARDS FOR MARINE AQUACULTURE).** NOAA has the responsibility under the National Offshore Aquaculture Act of 2005 to set operational standards for the practices of aquaculture in federal waters of the United States both to protect and, where possible, enhance the quality of their surrounding ecosystems. These operational standards, in the form of Environmental Quality Standards and Protocols are for the purpose of making marine aquaculture in federal waters compliant with the Clean Water Act and the National Pollution Discharge Elimination System permits, and to be consistent with the national use of these waters and protection of their aquatic wildlife. It is also recognized that these Standards and Protocols need not necessarily be universal, and that they may be adapted to recognize (perhaps) 10 marine biogeographic Provinces around the nation's coasts, each with their physical, chemical, and biological characteristics." According to Nash, "in 2003, NOAA recognized that the diversity of marine aquaculture cut across a number of its line services and consequently elevated the sector to a Matrix for management and administration purposes. But the long-established policy objectives for its responsible development remained the same. Because of the agency's responsibility for good stewardship of the oceans and their resources, the objectives focused primarily on environmental quality with emphasis on:

- Ways to minimize any adverse impacts on the environment and wild stocks,
- Using science-based criteria for enabling marine aquaculture operations, including determination of permissible discharges and optimal treatment of effluents, requirements for siting new operations, assessment of both deleterious and beneficial ecological impacts, and all necessary information for establishing Environmental Quality Standards and Protocols to facilitate the permitting process.
- Communicating this information for planning, and the regulatory and permitting processes at all levels of government."

According to Nash, under the **NOAA AQUACULTURE MATRIX - OPERATIONAL STANDARDS FOR MARINE AQUACULTURE,**

NOAA will be setting environmental standards and protocols.

"For many reasons, identifying Environmental Quality Standards (EQS) and Protocols to minimize the environmental impact from the practices of marine aquaculture in federal offshore waters is a relatively straightforward task for NOAA because there is already a large repository of information available. For example, under the many statutes containing regulatory sections that can be applied directly or indirectly to the marine aquaculture sector, for which the most important are the Clean Water Act and the National Environmental Protection Act, both federal agencies and coastal State agencies have already set a number of specific standards and regulations. Secondly, there are other industrial marine sectors which have the same risks, and for which some relevant EQS already exist. These are, for example, processing marine fish, operating recreational marinas, and ocean dumping. And finally, at an international level, there are EQS for marine aquaculture already established or are being established by many countries encouraging responsible sector development. These include, inter alia, almost all of the coastal member-nations of Europe, following a Directive from the European Union, together with Australia (and some of its States), Canada (and its coastal Provinces), Chile, and Norway.

In addition, the process of establishing international EQS and Protocols through risk assessment studies has been initiated. For example, the FAO Group of Experts on the Scientific Aspects of Marine Pollution (GESAMP) has formed a Working Group on Environmental Impacts of Coastal Aquaculture, and produced a background and discussion paper (Hambrey and Southall 2002); the International Council for Exploration of the Seas (ICES) Mariculture Committee has formed a number of working groups, and produced a series of relevant reports since 2001 (ICES 2002a,b; 20032,b; 2004); and more recently a group of international experts assembled to prepare Guidelines for Ecological Risk Assessments for Marine Fish Aquaculture (Anon 2005) for the FAO Committee on Fisheries (COFI) Sub-committee on Aquaculture in anticipation of its next meeting in India in 2006.

Although those EQS, which have been established globally, are not necessarily the same exactly, due to the ambient variables of each country's respective marine ecosystem(s), it is clear that the process of establishing EQS and Protocols for marine aquaculture has identified some important common denominators. Specifically these are:

The prioritization of the environmental risks, The location of impact, Some key indicators of effect, The use of both Numeric and Narrative EQS, and The similarity of monitoring programs.

(i) The prioritization of the risks Experts participated in a workshop in response to the international delegates to the bi-annual meeting of the FAO Sub-committee on Aquaculture at Trondheim, Norway in 2004. The result of their meeting was the production of guidelines for the risk assessment of marine fish aquaculture (NOAA 2006). The purpose was to provide a common framework for subsequent case studies and revisions in standards by member nation, as necessary.

The guidelines noted that among the perceived risks of marine fish aquaculture, which can be grouped into eight main categories, the top priorities for EQS are the effects of:

Increased organic loading on the benthos,
Biological interactions following escapes, and
Transmission of disease.

Of lower priority are the effects of: Nutrient enrichment of the water column, Residual heavy metals in the substrate, Residual therapeutants in the substrate and the water column, Physical interactions with other marine wildlife, and Physical damage to marine habitats.

Two additional categories are included by some countries and groups, but these are judged to be fisheries priorities rather than low-level marine aquaculture priorities. These are the effects of:

Using wild juveniles for grow-out, Harvesting industrial fisheries for aquafeeds.

(ii) The location of impact

Marine fish aquaculture, like all other human interventions in the marine environment, has an impact. The greater impact is clearly in and around the area where the activity is taking place, therefore most regulatory authorities adopt an Allowable Zone of Effect (AZE). The AZE is defined as "the area of sea-bed and/or volume of receiving waters in which an EQS may be exceeded or some damage to the environment may occur." This device was created, among other reasons, to recognize that many pollutants were rapidly diluted, and that their effects should be measured at a reasonable distance away from the point source.

The AZE, however, will differ firstly according to the type or class of aquaculture activity; for example, the intensive containment and rearing of marine fish compared with the extensive ranching production of marine mollusks. Secondly, it will differ according to the rearing and management practices that might produce a perceived pollutant and the release event. For example, the AZE for continuous events, such as the accumulation of organic waste on the substrate or release of nutrients into the water column, will be different from that for intermittent events, such as the release of water containing a therapeutant after an immersion treatment or the replacement of chemically treated nets.

An AZE may be spatial, as defined by a fixed area of the seabed or a fixed volume of the water column beneath or around the aquaculture facility, or it may be temporal, as defined by a measurement at a fixed point so many hours after an event.

(iii) Some key indicators of effect

(iv) The use of both Numeric and Narrative EQS

(v) The similarity of monitoring programs"

According to Nash, NOAA is proposing a **"Classification of Marine Aquaculture Systems and Practices."**

"NOAA proposes a 3-category classification to describe all types of aquaculture systems and practices in the marine environment. The purpose of the classification is to enable <u>only</u> the most appropriate EQS and Protocols to be selected, and <u>only</u> the most relevant parameters to be monitored.

The NOAA classification system is as follows:

<u>Class A</u>. Any intensive or semi-intensive system producing a marketable crop confined in a structure anchored directly or indirectly to the sea bed, and providing all husbandry requirements. Examples would be raising and feeding fish (such as cobia or tuna), crustaceans (such as lobsters or prawns), or mollusks (such as abalone) in any form of engineered enclosure, such as a cage or sea-pen.

Class B. Any extensive system producing a marketable crop confined in or attached to any structure anchored directly or indirectly to the seabed, and providing only management requirements. Examples would be raising mollusks (such as scallops, oysters and mussels) or edible seaweeds within or attached to any form of engineered structure, such as lantern nets or ropes.

Class C. Any extensive system producing a marketable crop without any form of engineered structure, and providing only management requirements. Examples would be raising mollusks (such as giant clams, clams, or ark shells) or live rock in managed areas of the sea bed."

The above system described by Nash would seem superior to BMPs. It would seem adding BMPs to these proposed NOAA Operational Standards for Marine Aquaculture would only further complicate the process for regulators and for offshore aquaculture projects. Recommend not pursuing BMPs and allowing NOAA to develop the Operational Standards for Marine Aquaculture.

NOAA's RECOMMENDED ENVIRONMENTAL QUALITY STANDARDS (draft from Colin Nash, June 2006). Nash is now retired.

"NOAA proposes the following environmental quality standards for the protection of marine ecosystems in the vicinity of aquaculture sites. They have been selected carefully for a number of reasons.

Firstly, the standards are the most qualitative. Marine farms in coastal waters, mostly for fish species, have been in existence all over the world for some 40 years. Their impacts on their immediate environment have been measured and monitored continuously for respective regulatory authorities, and many sites have been the focus of innumerable ongoing research programs. Consequently experience now shows that some parameters are much more indicative of meaningful changes in the conditions of the environment than others, and these are proposed.

Secondly, the standards are quantitative. Again, because of the accumulation of data regarding environmental change over time, most of which has been faithfully documented in scientific and technical literature, numerical levels of these parameters at which risks to the environment are becoming no longer acceptable are now identifiable, and it is these levels that are proposed.

Finally, the procedures to measure the standards are relatively straightforward and inexpensive to carry out. Consequently it is intended that the parameters proposed are monitored frequently during the routine operations at any site, and do not impose any unnecessary or restrictive financial burden.

Four standards are recognized as key indicators of change and potential environmental impact. These are:

- Dissolved inorganic nutrients, nitrogen and phosphorus, in the water column,
- Total volatile solids (TVS) in the sediment,
- The redox potential (Eh) of the sediment,
- The presence of soluble hydrogen sulfide (free sulfide) in the sediment.

Four additional standards are useful indicators of some changes occurring in the environment, but are not imperative, as they do not provide information that cannot be deduced from the four priority standards. These are:

- Dissolved oxygen in the water column,
- The acidity or alkalinity (pH) of the water column,
- The presence of Chlorophyll – a
- Suspended solids"

The recommended NOAA standards (from Nash) will include the following: "

- Standards for marine farms irrespective of production capacity, with an allowable zone of effect (AZE) extending 100 m from the perimeter of each production unit or complex of units, the accepted limits of chemical concentration, and the rationale for the standards.
- The recommended NOAA standards for total volatile solids (TVS) in the sediment, the redox potential (eH) of the sediment, soluble hydrogen sulfide, dissolved oxygen, Chlorophyll-a, pH, suspended solids and the rationale for each of these standards. "

These operational standards from NOAA, when completed, should be adequate without requiring additional BMPs. Experience from Texas indicates that producers desire BMPs and would like to be self-regulated, using only BMPs, in leu of government regulations, but producers do not want government regulations and BMPs because they can be redundant.

Cicin-Sain et. al. 2005. (Recommendations for an Operational Framework for Offshore Aquaculture in U.S. Federal Waters), states "Aquaculture practices in marine waters can generate environmental impacts as a function of: (1) the applied technique: (2) site location; (3) size of the production: and (4) capacity of the receiving body of water (Ackefors and Sodergren, 1985), as well as (5) the selection of species and genetic strains. Aquaculture may affect water quality, the benthic layer, the native gene pool, the spread of disease, and the ecosystem as a whole. As particular considerations and issues are site and species-specific, anticipated and actual impacts will have to be assessed on a case-bycase basis. Furthermore, assessments of environmental impact need to be made at several stages in the process of planning, permitting, and executing aquaculture development. The nature and intensity of all the offshore aquaculture impacts cannot be predicted at present due to the limited experience thus far within the industry."

A new report (**GAO-08-594)** released by the U.S. Government Accountability Office on Offshore Marine Aquaculture identifies key issues in the development of an effective regulatory framework for U.S. offshore aquaculture, which would involve raising fish and shellfish in the open ocean. The full title of the report is **OFFSHORE MARINE AQUACULTURE Multiple Administrative and Environmental Issues Need to Be Addressed in Establishing a U.S. Regulatory Framework**

The full report can be accessed at: http://www.gao.gov/new.items/d08594.pdf

A report summary is at:
http://www.gao.gov/docsearch/abstract.php?rptno=GAO-08-594

A document with report highlights is at
http://www.gao.gov/highlights/d08594high.pdf

And lastly, the Woods Hole Oceanographic Institution, with support from the Pew Charitable Trusts, has convened a small, diverse panel of experts with scientific, regulatory, business and policy-making backgrounds to evaluate key issues related to regulating aquaculture operations in marine waters. To address aquaculture's risks and maximize its benefits, the Marine Aquaculture Task Force will develop a suite of protective, science-based standards to assure that aquaculture development poses minimal threats to the ocean environment. For additional information on this project go to the following web link:

http://www.whoi.edu/sbl/liteSite.do?litesiteid=2790&articleId=4439.

Appendix B. Texas Parks and Wildlife (TPWD) Offshore Aquaculture Rules and Regs. For Texas (2008)

Texas Administrative Code
TITLE 31 PART 2
CHAPTER 57
SUBCHAPTER C

RULE §57.251-57.259

RULE §57.251 Definitions
The following words and terms, when used in this subchapter, shall have the following meanings, unless the context clearly indicates otherwise.

(1) Aquaculture--The business of producing and selling cultured species raised in private facilities.

(2) Aquatic plant--All plants whose seeds germinate in either the water phase or the substrate of a body of water and which must spend part of the life cycle in water (Reid, G.K., and R.O. Wood 1976, Ecology of Inland Waters and Estuaries).

(3) Disease condition-

(A) The presence of contagious pathogens or injurious parasites known or clinically suspected of constituting a threat to the health of native species of aquatic organisms; or

(B) A mortality rate of five percent or more occurring within a period of seven days in a single enclosure.

(4) Enclosure--A structure in public water that is capable of preventing the escape of the stock confined within it and the entry of aquatic animal life from surrounding waters.

(5) Fishing--Taking or attempting to take aquatic animal life by any means.

(6) Native species--All fish, shellfish, or aquatic plants documented by the department to live, spawn, or reproduce in Texas offshore waters and whose first documented occurrence in Texas offshore waters was not the result of intentional or unintentional importation by man.

(7) Offshore aquaculture facility--All enclosures and associated infrastructure used to produce, hold, propagate, transport, or sell stock under authority of an offshore aquaculture permit.

(8) Offshore aquaculture zone--All waters of the Gulf of Mexico seaward from the shoreline for a distance of three marine leagues, but does not include bays, passes, rivers or other bodies of water.

(9) Shellfish--Aquatic species of crustaceans and mollusks, including oysters, clams, shrimp, prawns, and crabs of all varieties.

(10) Stock--Native species of fish, shellfish, or aquatic plants intended for use in, being transported to, or contained within an offshore aquaculture facility under the terms of an offshore aquaculture permit.

(11) Waste--As defined in Water Code, §26.001.

RULE §57.252 General Provisions

a) A permit issued under this subchapter shall be issued to a named individual only and not in the name of a corporation, company, or other entity.

(b) A permit issued under this subchapter shall not be sold or transferred except with the approval of the department.

(c) A one-time introduction permit, for releases other than those made into an offshore aquaculture facility, is valid for 60 days from the date of issuance or until the permitted introduction has been completed, whichever comes first.

(d) For offshore aquaculture facilities:

(1) An offshore aquaculture permit authorizes permitted activities in a designated area within the offshore aquaculture zone.

(2) The offshore aquaculture permit shall be issued only for the cultivation of native species. Upon request the permittee shall provide the form and type of evidence requested by the department that the individuals are:

(A) obtained from the Gulf of Mexico; or

(B) descended solely from individuals obtained from the Gulf of Mexico.

(3) An offshore aquaculture permit shall be valid from the date of issuance until the date of expiration, but for no longer than 5 years after the issuance date.

(4) The department may inspect:

(A) any enclosure or infrastructure used to engage in offshore aquaculture; or

(B) vessel used to transport stock and equipment to and from an offshore aquaculture facility.

(5) The department may order the removal of all stock from an enclosure upon:

(A) a determination that a disease condition exists; or

(B) an enforcement action by a federal or state agency resulting in the suspension or revocation of a clearance, permit, or authorization that is required under §57.253 of this title (relating to Permit Application).

(6) The department may sample stock to determine genetic lineage.

(e) A holder of an offshore aquaculture permit must:

(1) notify the department at least three calendar days prior to the placing of any fish, shellfish, or aquatic plant into public water;

(2) notify the department at least three calendar days prior to removing any fish, shellfish, or aquatic plant from an offshore aquaculture facility;

(3) notify the department immediately upon discovering that a disease condition exists within an offshore aquaculture facility;

(4) notify the department immediately upon determining that an offshore aquaculture facility has been damaged and the threat of the unintentional release of stock exists; and

(5) remove all enclosures and associated infrastructure from public waters within 10 calendar days of permit expiration or revocation.

(f) A permit is not required for any person, while fishing, to place goldfish (Carassius auratus), common carp (Cyprinus carpio), native shrimp, crabs, crawfish and nongame fish into public waters or to immediately release any fish that does not comply with size and bag limits for that species.

(g) An employee of the department acting at the direction of the executive director is exempt from the permit requirements specified by these sections.

RULE §57.253 Permit Application

a) An applicant for a permit under this subchapter shall complete and submit an application to the department on a form supplied by the department, accompanied by the fee prescribed by §53.15 of this title (relating to Miscellaneous Fisheries and Wildlife Licenses and Permits).

(b) Except for applications for offshore aquaculture permits, an application must be received by the department at least 30 days before the proposed introduction.

(c) An application for an offshore aquaculture facility:

(1) must be received by the department at least 90 days prior to the proposed deployment of any enclosure or infrastructure;

(2) must include:

(A) The name, address, and telephone number of the owner(s) of the facility and all stock;

(B) proof that the applicant has obtained:

(i) a valid license issued by the Texas Department of Agriculture to operate an aquaculture facility (Agriculture Code Chapter 134);

(ii) all applicable state and/or federal permits or authorizations relating to water quality standards;

(iii) all applicable state and federal permits, authorizations, or clearances related to navigational hazards; and

(iv) approval from the General Land Office to anchor the facility;

(C) a clear and concise facility design, including scale plans and schematics of all infrastructure that, as determined by the department, is sufficient to:

(i) prevent the escape of stock from the facility; and

(ii) protect wildlife resources adjacent to the facility from:

(I) disease transmission from stock;

(II) the discharge of pollutants produced from feed or waste materials into public waters, including discharges resulting directly or indirectly from extreme weather conditions or physical collision;

(III) the escape of stock from the facility as a result of extreme weather conditions or physical collision; and

(IV) death or injury from ensnarement, entanglement, collision, or other physical interactions with enclosures or facility infrastructure;

(D) a clear and concise operations plan, which shall include best management practices that minimize potentially harmful discharges into public waters from the facility;

(E) a prospective timeline of proposed activities, by species, from the time of introduction to the time of harvest or removal for each enclosure;

(F) a plan for removing all stock from the facility within 72 hours of notice from the department under §57.252 of this title (relating to General Provisions); and

(G) a statement that all stock meets the requirements of §57.252 of this title.

(d) An offshore aquaculture permit will not be issued unless the department has conducted an inspection of all enclosures and infrastructure and found such to be consistent with the information provided in the application.

RULE §57.254 Denial

A permit application, permit renewal, or permit amendment under this subchapter will be denied if:

(1) concerning an application for one time introduction:

(A) the application, renewal or amendment does not meet the requirements of §§52.101 - 52.401 of this title (concerning Stocking Policy); or

(B) the proposed introduction is not consistent with management objectives of the department; or

(2) concerning an application for an offshore aquaculture facility, the application does not contain or inadequately addresses the requirements of §57.253(c) of this title (relating to Permit Application).

RULE §57.255 Renewal

(a) The department may renew a current offshore aquaculture permit, provided:

(1) the applicant has complied with all requirements of this subchapter and permit provisions during the one-year period immediately preceding renewal;

(2) the facility is in compliance with all operational and facility standards as reflected in the current permit (including amendments);

(3) the applicant has completed and submitted an application for permit renewal; and

(4) the applicant has paid the fee prescribed by §53.15 of this title (relating to Miscellaneous Fisheries and Wildlife Licenses and Permits).

(b) The department will not renew an expired permit.

RULE §57.256 Amendment

(a) An offshore aquaculture permit may be amended, provided the applicant:

(1) has complied with all requirements of this subchapter and permit provisions during the one-year period immediately preceding the date of the application for amendment;

(2) has complied with all applicable requirements of §57.253 of this title (relating to Permit Application);

(3) has completed and submitted an application for permit amendment; and

(4) the amendment is not extensive enough to warrant an additional facility inspection. An amendment extensive enough to warrant an additional facility inspection shall be treated as an application for a new permit and the provisions of §57.253 of this title shall apply.

(b) Prior to approval of a permit amendment, no person shall:

(1) introduce new species of stock to a facility;

(2) discontinue any species of stock in a facility;

(3) change the source of stock;

(4) modify methods, procedures, facility design, or facility infrastructure affecting:

(A) the physical components of the facility;

(B) the prevention of escape of stock from the facility; or

(C) the discharge of pollutants from the facility; or

(5) change the physical structure or components of an enclosure.

(c) An application for a permit amendment must be submitted within 10 days of any change in ownership of the facility or stock.

(d) The department will not amend an expired permit.

RULE §57.257 Reporting and Recordkeeping

a) An offshore aquaculture permitee shall maintain and keep current an accurate daily record of all stock introduced or removed from each enclosure within a facility, including mortalities.

(b) An offshore aquaculture permitee shall complete and submit an annual report to the department on a form supplied by the department by no later than January 15 of every year.

(c) While performing any permitted activity within or in transit to or from an offshore aquaculture facility, a person must physically possess a legible copy of the offshore aquaculture permit under which the activity is being performed.

(d) The records required by this section shall be made available to the department upon the request of a department employee acting within the scope of official duties.

RULE §57.258 Prohibited Acts

Except as provided in this subchapter, it is an offense if:

(1) a person holding a permit under this section fails to notify the department at least three calendar days prior to the placing of any fish, shellfish, or aquatic plant into public water;

(2) a person holding a permit under this section fails to notify the department at least three calendar days prior to removing any fish, shellfish, or aquatic plant from an offshore aquaculture facility;

(3) a person holding a permit under this section fails to notify the department immediately upon discovering that a disease condition exists within an offshore aquaculture facility;

(4) a person holding a permit under this section fails to notify the department immediately upon determining that an offshore aquaculture facility has been damaged and the threat of the unintentional release of stock exists;

(5) any person to whom the department has issued an offshore aquaculture permit fails to remove all enclosures and associated infrastructure from public waters within 10 calendar days of permit expiration or revocation.

RULE §57.259 Violations and Penalties

a) A person who violates a provision of this subchapter or a provision of a permit issued under this subchapter commits an offense punishable by the penalty prescribed by the Parks and Wildlife Code, §66.012.

(b) A permit issued under this section is not a defense to prosecution for any conduct not specifically authorized by the permit.

Appendix C. The following information is from the Gulf of Mexico Fisheries Management Council meeting in June, 2008.

Suitable Aquaculture Areas

Gulf of Mexico EEZ:	209,226 nm^2	
Suitable for aquaculture:	28,719 nm^2	(13.7%)
Aquaculture zones 1-13:	10,392 nm^2	(5.0%)

Area of 10 12-cage* facilities:	0.07 nm^2	(0.00003%)
Area of 50 12-cage* facilities:	0.35 nm^2	(0.00016%)
Area of 100 12-cage* facilities:	0.69 nm^2	(0.00033%)

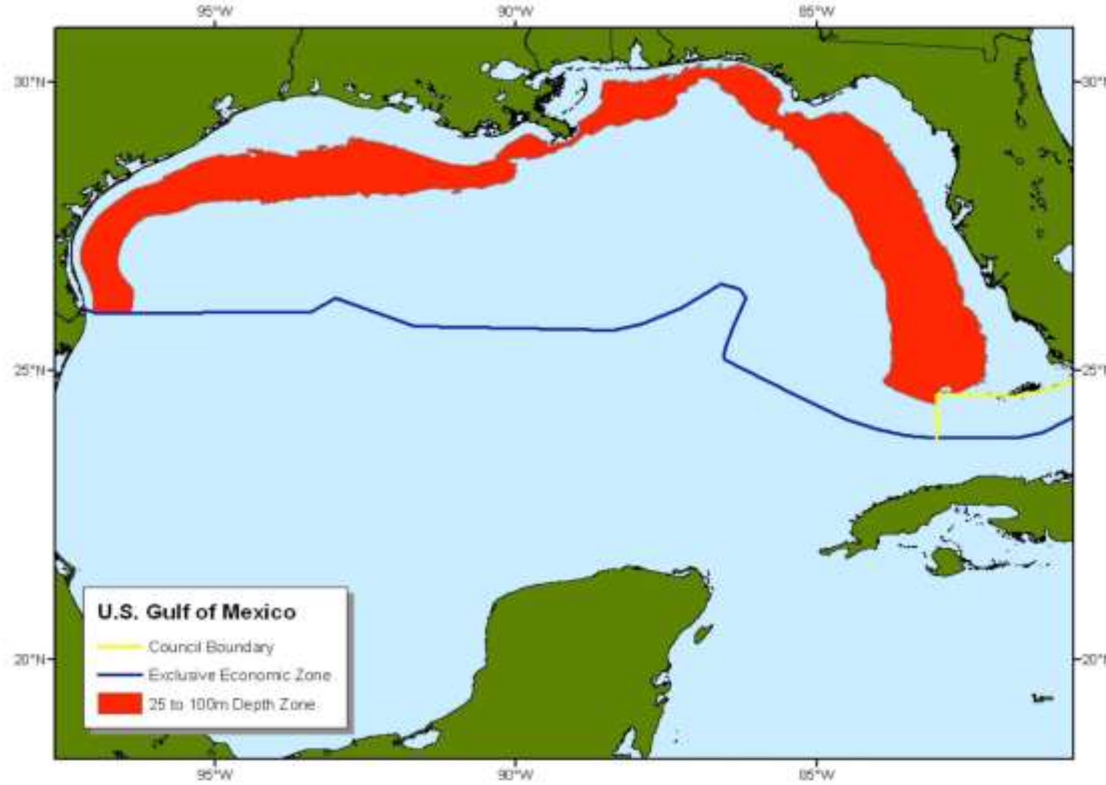
4 runways** at Houston Hobby Airport:	0.10 nm^2
Minute Maid Park (Houston Astros; 29 acres):	0.34 nm^2

* Based on 100 foot diameter cages and facility that is 300 feet in width and 850 feet in length
** 7,602 ft X 150 ft (2), 5148 X 100 ft, and 6,000 ft X 150 ft

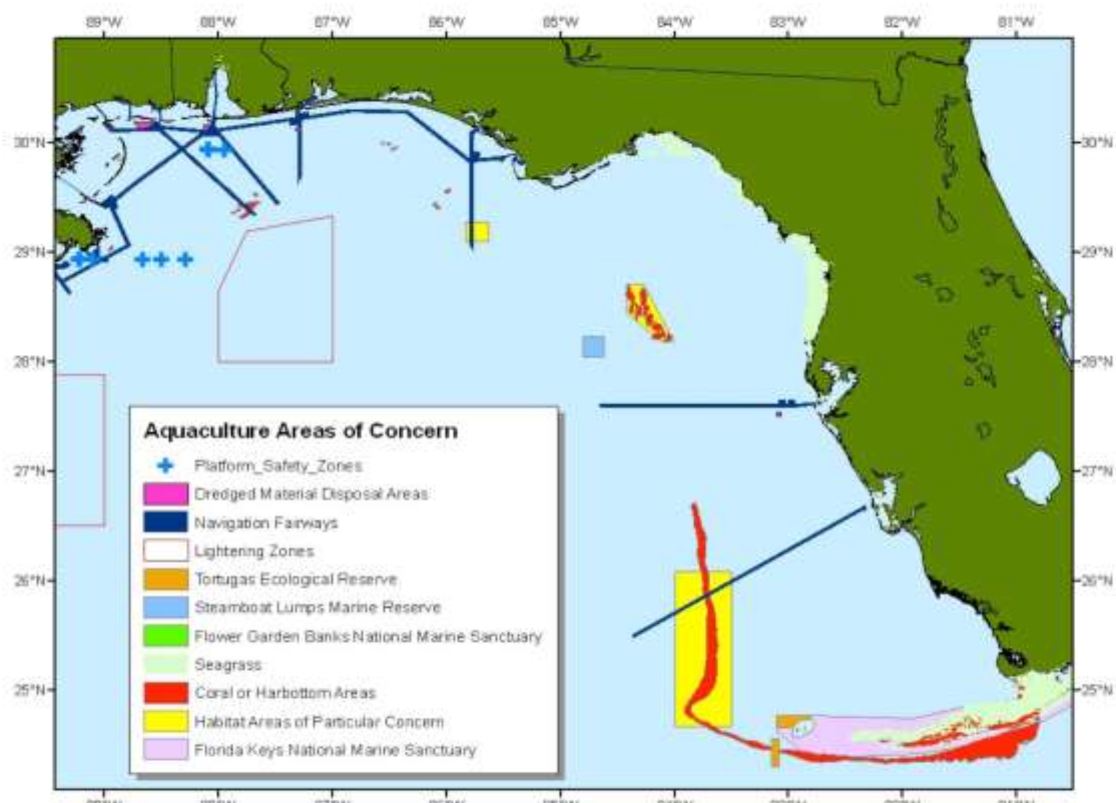
Areas Defined as Not Suitable for Offshore Aquaculture

- Navigation fairways
- Permitted artificial reefs/areas
- Marine reserves
- MPAs
- Marine sanctuaries
- HAPCs
- Coral reefs
- Seagrasses
- Depths < 25 m and > 100 m
- Current speeds < 0.1 m/s
- High use shrimp areas
- Platform safety zones
- LA hypoxic zone
- Lightering zones

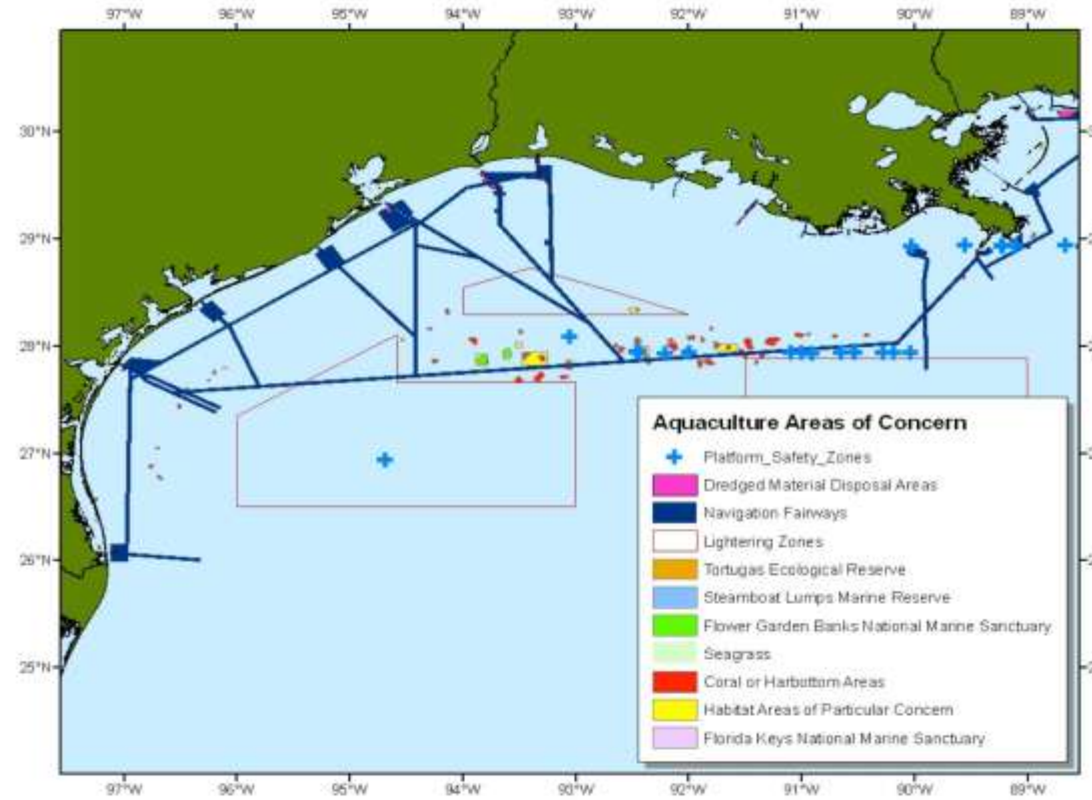
- 5 km ecological buffer zones were placed around seagrasses, coral reefs, MPAs, HAPCs, and marine sanctuaries
- 3 km safety buffer zones were placed around lightering zones, shipping fairways, and dredged material disposal areas
- 1 km buffer zones were placed around artificial reefs and artificial reef zones to mitigate potential user conflicts.

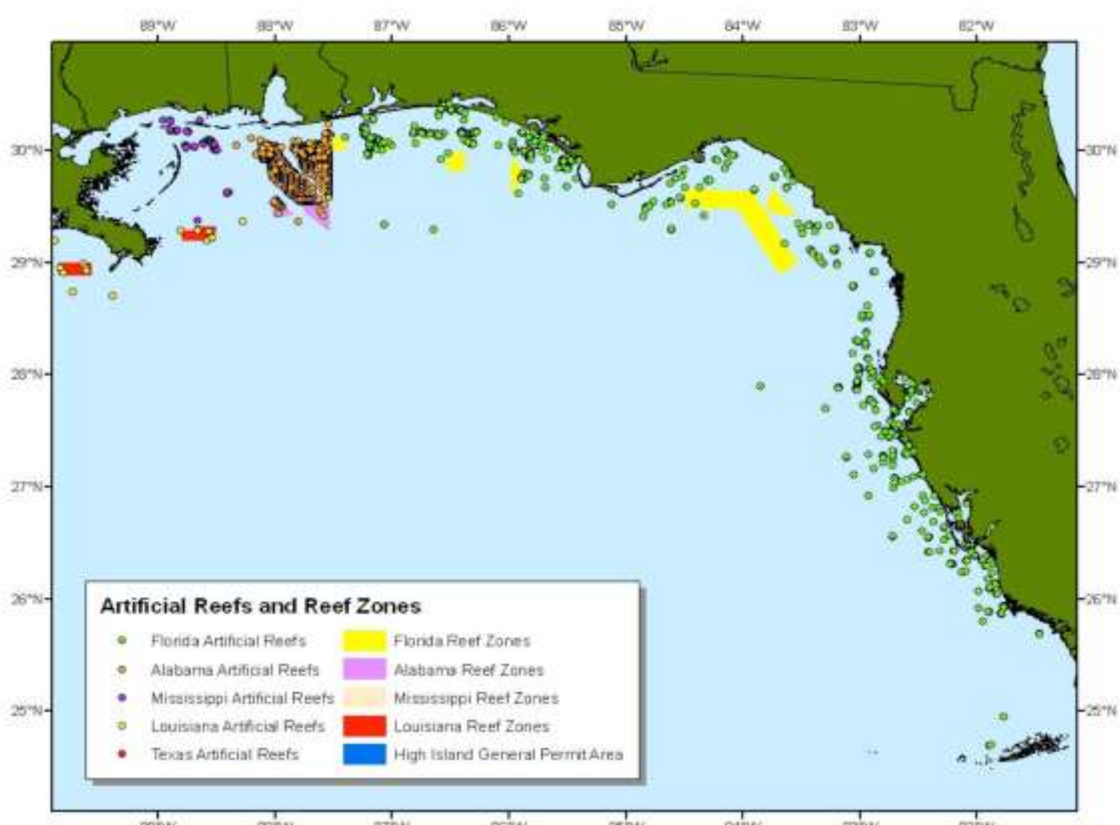


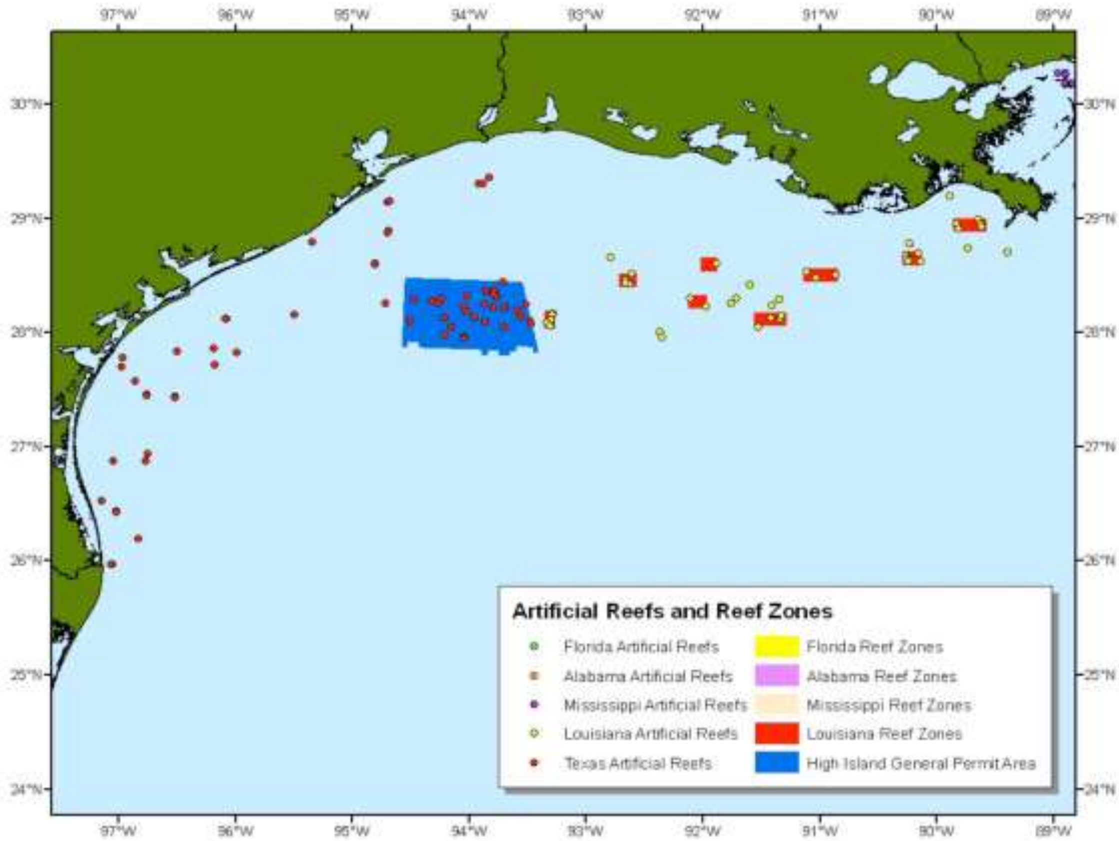
U.S. Gulf of Mexico
Council Boundary
Exclusive Economic Zone
25 to 100m Depth Zone
95°W
90°W
85°W
30°N
25°N
20°N



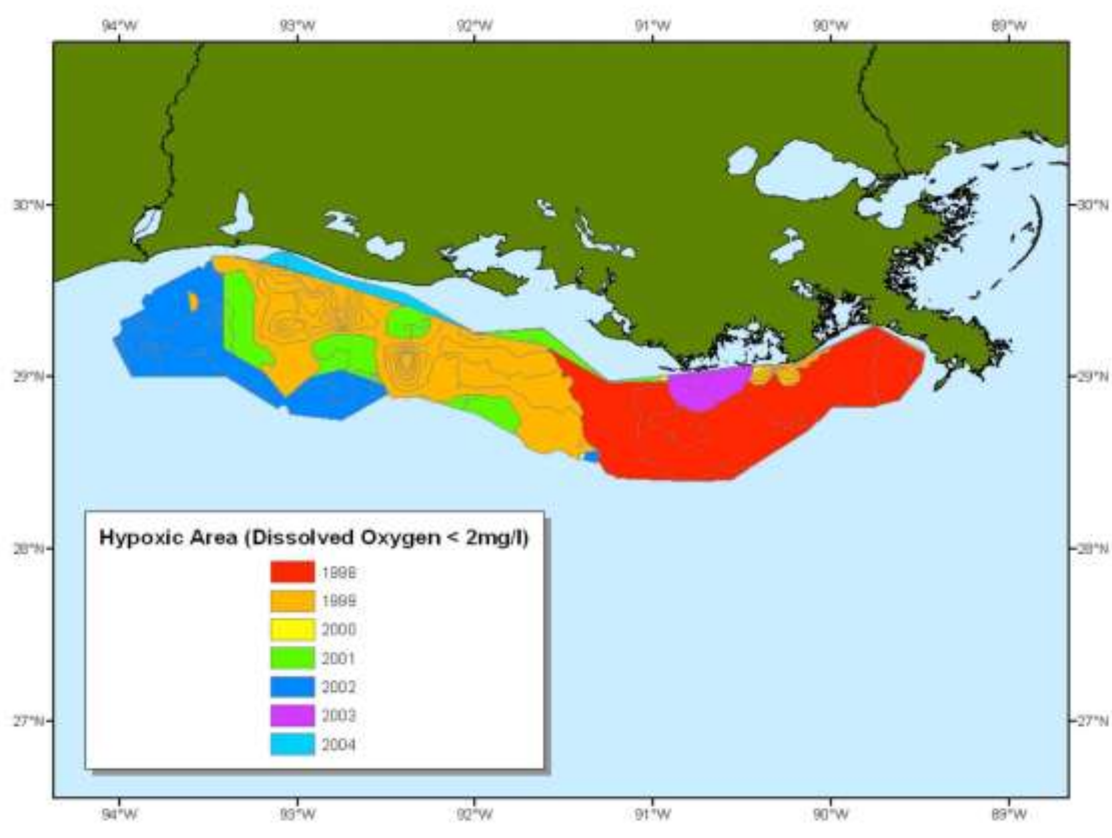
Aquaculture Areas of Concern
Platform_Safety_Zones
Dredged Material Disposal Areas
Navigation Fairways
Lightering Zones
Tortugas Ecological Reserve
Steamboat Lumps Marine Reserve
Flower Garden Banks National Marine Sanctuary
Seagrass
Coral or Hardbottom Areas
Habitat Areas of Particular Concern
Florida Keys National Marine Sanctuary
89°W
88°W
87°W
86°W
85°W
84°W
83°W
82°W
81°W
30°N
29°N
28°N
27°N
26°N
25°N


Aquaculture Areas of Concern
Platform_Safety_Zones
Dredged Material Disposal Areas
Navigation Fairways
Lightering Zones
Tortugas Ecological Reserve
Steamboat Lumps Marine Reserve
Flower Garden Banks National Marine Sanctuary
Seagrass
Coral or Hardbottom Areas
Habitat Areas of Particular Concern
Florida Keys National Marine Sanctuary

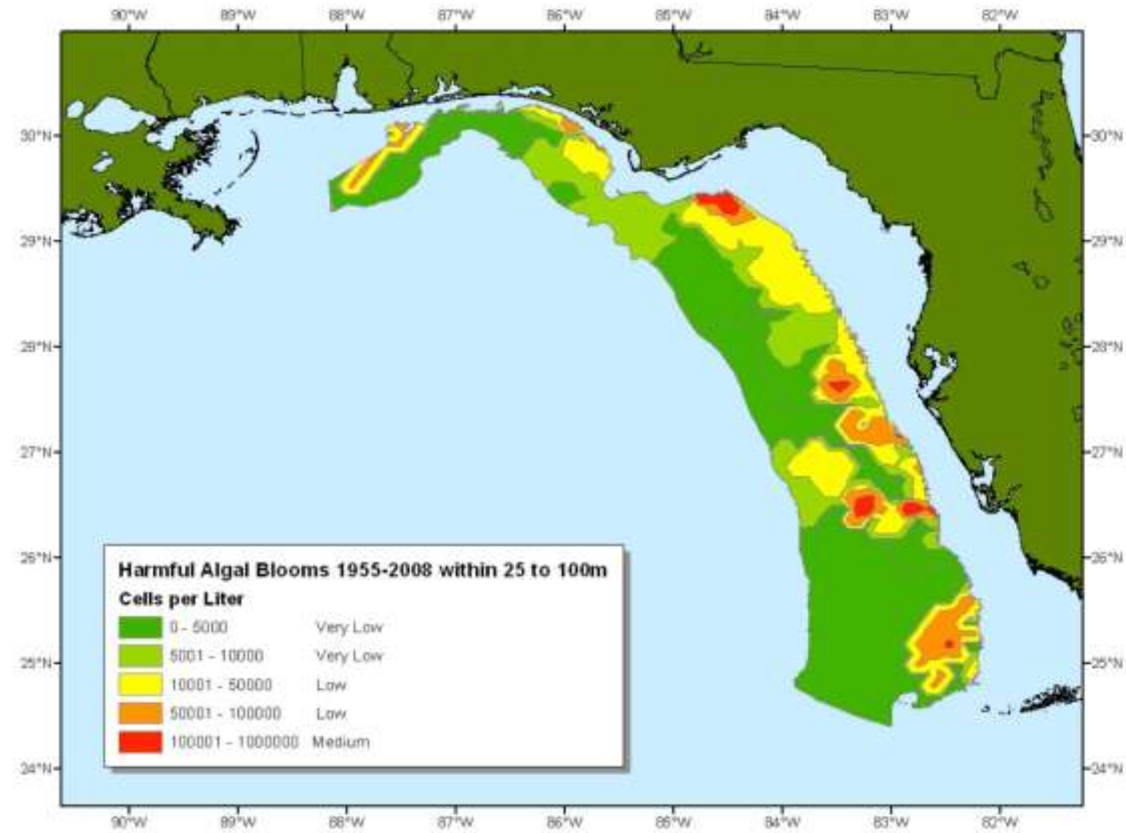

Artificial Reefs and Reef Zones
Florida Artificial Reefs
Alabama Artificial Reefs
Mississippi Artificial Reefs
Louisiana Artificial Reefs
Texas Artificial Reefs
Florida Reef Zones
Alabama Reef Zones
Mississippi Reef Zones
Louisiana Reef Zones
High Island General Permit Area

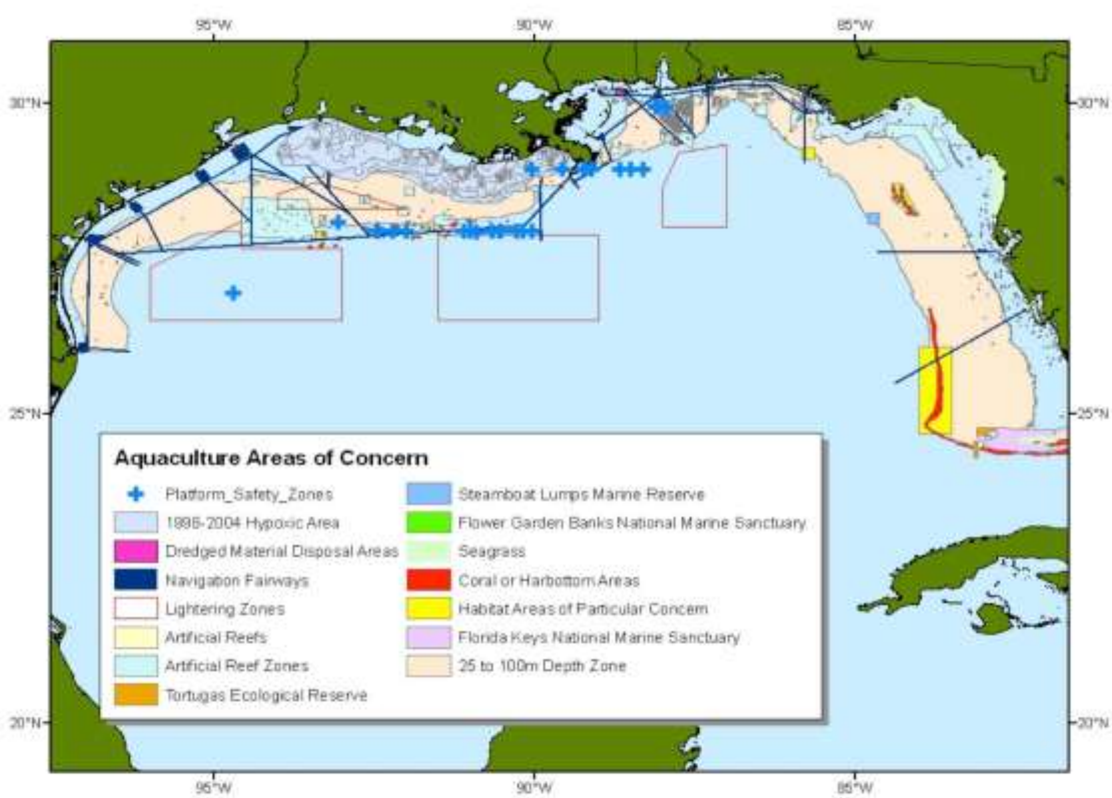


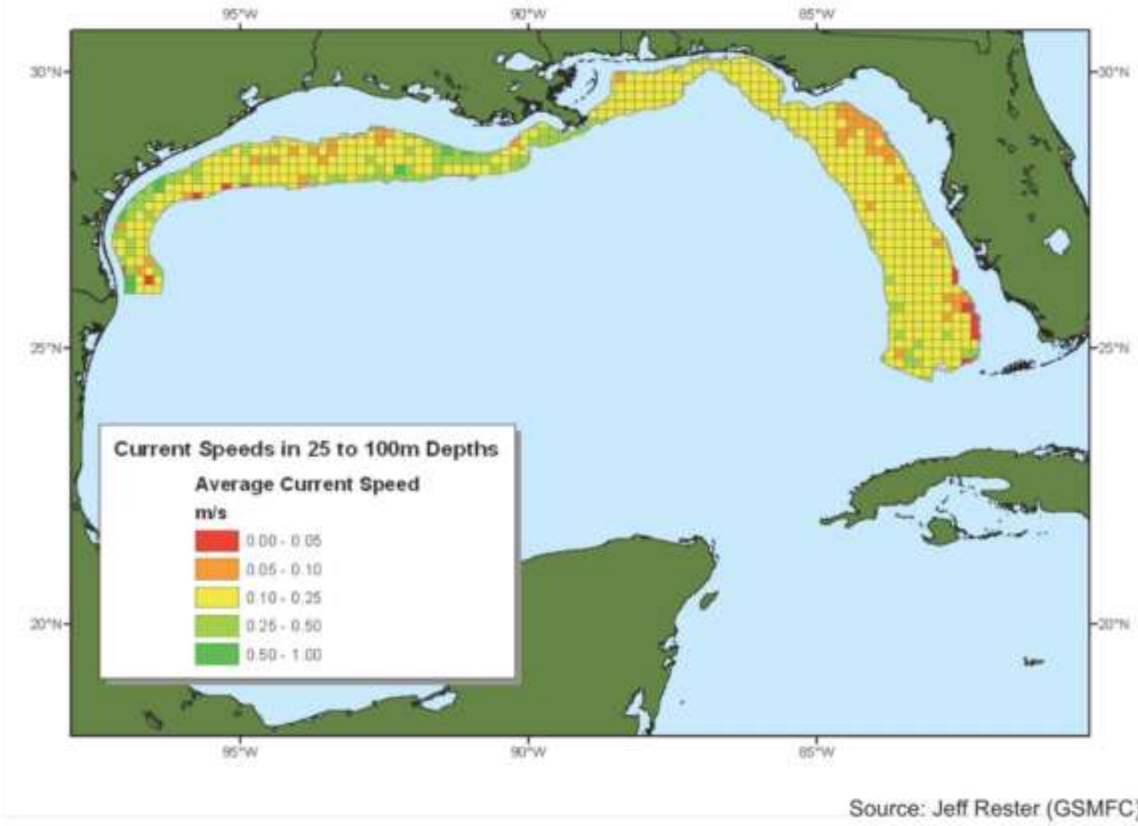
97°W
96°W
95°W
94°W
93°W
92°W
91°W
90°W
89°W
30°N
29°N
28°N
27°N
26°N
25°N
24°N
Artificial Reefs and Reef Zones
Florida Artificial Reefs
Alabama Artificial Reefs
Mississippi Artificial Reefs
Louisiana Artificial Reefs
Texas Artificial Reefs
Florida Reef Zones
Alabama Reef Zones
Mississippi Reef Zones
Louisiana Reef Zones
High Island General Permit Area



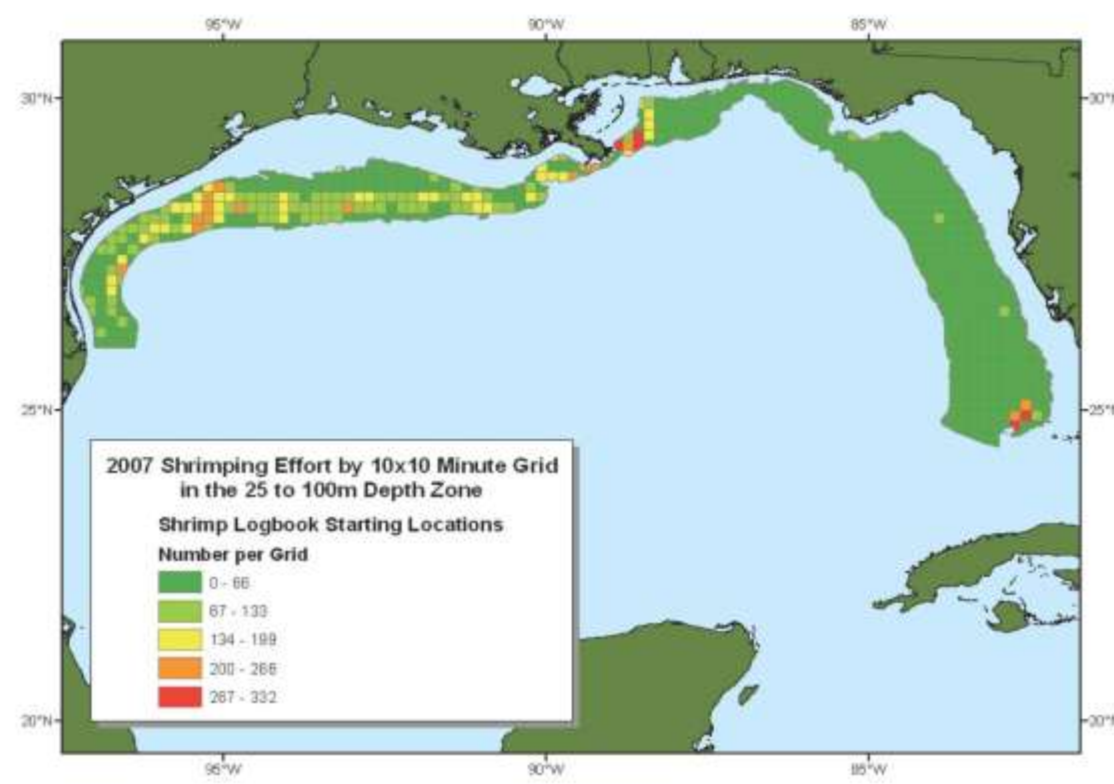
94°W
93°W
92°W
91°W
90°W
89°W
30°N
29°N
28°N
27°N
Hypoxic Area (Dissolved Oxygen < 2mg/l)
1998
1999
2000
2001
2002
2003
2004

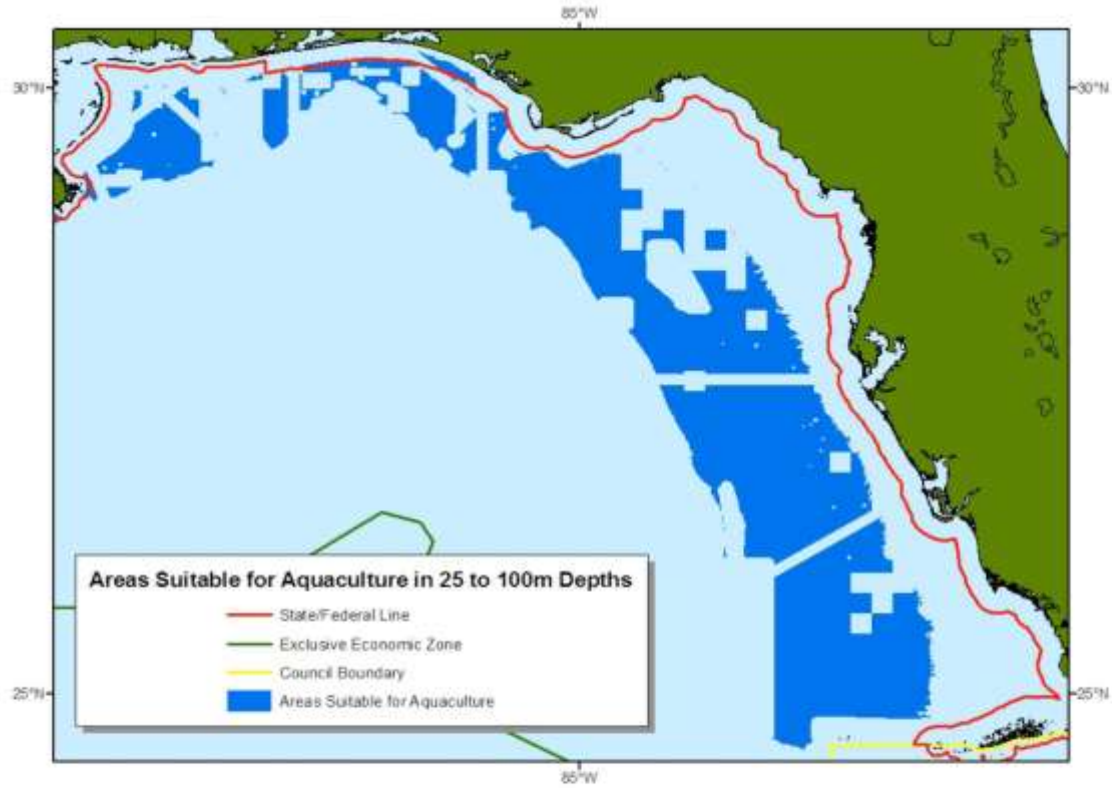

Harmful Algal Blooms 1955-2008 within 25 to 100m
Cells per Liter
0 - 5000 Very Low
5001 - 10000 Very Low
10001 - 50000 Low
50001 - 100000 Low
100001 - 1000000 Medium


Aquaculture Areas of Concern
Platform_Safety_Zones
1985-2004 Hypoxic Area
Dredged Material Disposal Areas
Navigation Fairways
Lightering Zones
Artificial Reefs
Artificial Reef Zones
Tortugas Ecological Reserve
Steamboat Lumps Marine Reserve
Flower Garden Banks National Marine Sanctuary
Seagrass
Coral or Hardbottom Areas
Habitat Areas of Particular Concern
Florida Keys National Marine Sanctuary
25 to 100m Depth Zone

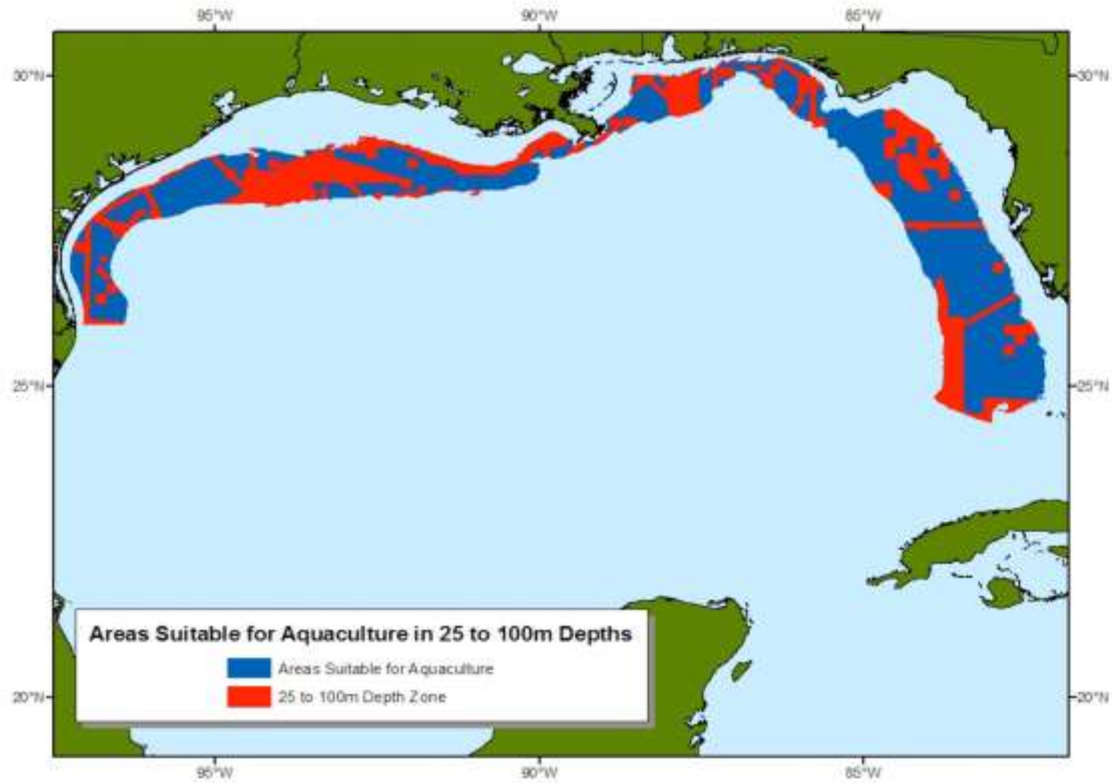


Source: Jeff Rester (GSMFC)




85°W
30°N
25°N
Areas Suitable for Aquaculture in 25 to 100m Depths
State/Federal Line
Exclusive Economic Zone
Council Boundary
Areas Suitable for Aquaculture


95°W
90°W
30°N
25°N
Areas Suitable for Aquaculture in 25 to 100m Depths
State/Federal Line
Exclusive Economic Zone
Council Boundary
Areas Suitable for Aquaculture



95°W
90°W
85°W
30°N
25°N
20°N
Areas Suitable for Aquaculture in 25 to 100m Depths
Areas Suitable for Aquaculture
25 to 100m Depth Zone

Zone 1
Zone 2
Zone 3
Zone 4
Zone 5
Zone 6
Zone 7
Zone 8
Zone 9
Zone 10
Zone 11
Zone 12
Zone 13

Gulf of Mexico Fisheries Management Council's aquaculture amendment includes Aquaculture zones 1-13 (10,392 nm^2). Pink (above) represents all areas considered suitable for aquaculture in the Gulf of Mexico EEZ (28,719 nm^2).

At their meeting in Houston on June 5, 2008 the Gulf of Mexico Fisheries Management Council passed the last series of modifications to the Offshore Aquaculture Amendment without significant objection and elevated the process from a Generic Amendment for all Fishery Management Plans to a full stand alone Fishery Management Plan. The Fisheries Management Plan will allow NOAA Fisheries SE Regional Administrator to permit aquaculture operations for any native species of fish in the Gulf. Dr. Roy Crabtree, Director of the Southeast Regional Office of NMFS, stated at the meeting that the Environmental Impact Study will be completed and posted for a 60 day comment period. The latest version of the Public Hearing Draft of the Offshore Aquaculture Amendment can be downloaded from the Gulf of Mexico Fisheries Management Council's web site at http://www.gulfcouncil.org/.

There is a great potential for offshore aquaculture in the Gulf of Mexico. According to NOAA – NMFS Statistics No. 2003, the total fish and shellfish production for the Gulf of Mexico averages about 194 million pounds annually, excluding Menhaden and shrimp. According to a spokesperson at Sea Fish Mariculture in Houston, 457 cages (32 meter diameter) carrying 20 kg/cubic meter of fish could produce the entire annual commercial finfish catch of the Gulf, requiring a sea bottom area of only 800 hectares or about 2,000 acres. Of course you would not want to put the fish in a concentrated area, but would spread them out over the Gulf. There are no permitted offshore aquaculture projects in Texas. The regulatory framework is still a major source of uncertainty for potential offshore producers. The Texas Parks and Wildlife has established its rules for offshore aquaculture in state waters and has published them on the State Registar and the Gulf of Mexico Fisheries Management Council has approved an offshore aquaculture amendment to allow commercial offshore aquaculture in Gulf of Mexico Federal waters (EEZ, from state boundary out to 200 miles). The process of establishing the regulations is very slow, and has met with opposition from environmental groups. Under the Magnuson-Stevens Fishery Conservation And Management Reauthorization Act of 2006, the “Gulf Council” has only been able to allow research projects to conduct offshore aquaculture under an exemption to the Act. Until now, legally, no commercial operation could be allowed in the Gulf under this Act, without an amendment passed to the Act allowing it. This process was finalized by the Gulf Council and the full fisheries amendment adopted as a stand-alone fisheries management plan. The Gulf Council approved the offshore aquaculture fisheries management plan and amendment in Jan. 2009 and passed the recommendation to implement the fisheries management plan to the US Dept. of Commerce, NOAA/NMFS. The status of the management plan as of May 8, 2009, according to Joe Hendrix (Sea Fish Maricutlure, and board member of the Gulf of Mexico Fisheries Management Council), “NOAA Fisheries is still making the transition under the new administration, as soon as all new Administrators are in place approval of new Fishery Management Plans such as the Aquaculture Amendment for the Gulf of Mexico will go forward to receive final approval and be implemented. The new biologist in charge of reviewing all applications for aquaculture projects in Federal waters of the Gulf of Mexico is in place at the Southeast Regional Office of NOAA Fisheries and reviewing all current aquaculture facilities on the Gulf Coast.” The new SE Regional Aquaculture Coordinator is Fishery Management Specialist, Dr. Jessica L. Beck. She is now in the SER NOAA/NMFS office in St. Petersburg, Florida. Jessica made the following statement on May 11, 2009, “

The Fishery Management Plan for Regulating Offshore Marine Aquaculture in the Gulf of Mexico (FMP) was transmitted to NOAA Fisheries Service Headquarters and the Secretary of Commerce for review in Spring 2009. The Secretary had the authority to approve, disapprove, or partially approve the FMP. There were opportunities for the public to comment on the implementing regulations as well as on the Environmental Impact Statement during the review process. If the plan is implemented, permit applications for aquaculture projects in federal waters of the Gulf of Mexico would be reviewed in the Southeast Regional Office. For questions on aquaculture in the southeast region, contact the Regional Aquaculture

Coordinator at Jess.Beck@noaa.gov. "

The potential for offshore aquaculture in the Gulf of Mexico offers the US a way to help offset part of its huge seafood trade deficit, and produce some of its own fish. No organization or Government group expects offshore aquaculture in the Gulf to supply all the US seafood demand, but if allowed, commercial offshore aquaculture in the Gulf could supply some of that demand and help keep US money at home, while safeguards are in place to see that it is done on a sustainable basis, without damage to the environment. The Texas aquaculture industry has great potential in the future helping the U.S. to offset part of its seafood trade deficit with catfish production and with the potential of offshore aquaculture production of a variety of fish and shellfish. Wild fisheries cannot meet the rising demand for domestic seafood.

Acknowledgments for "The Texas Aquaculture Industry – 2012"

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