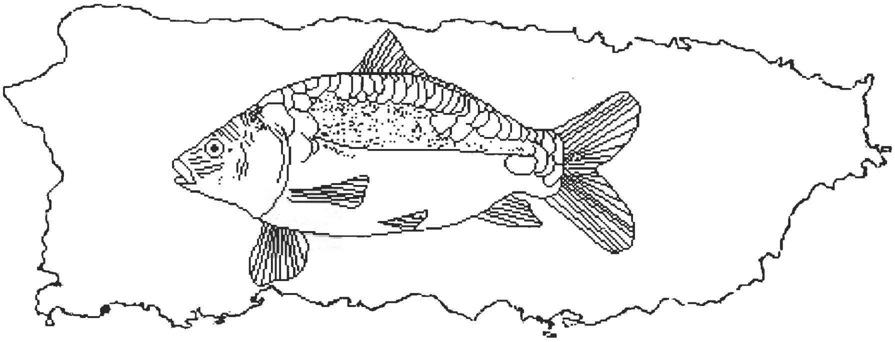
ENVIRONMENTAL, POLITICAL, AND SOCIOECONOMIC ASPECTS OF OFFSHORE CAGE CULTURE



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ABSTRACT

This report was prepared for the Colegio Tecnológico de San Juan in Puerto Rico. Overfishing has threatened the livelihoods of fishermen and disrupted the ecosystem. The feasibility of an aquaculture project was assessed for a fishing village in San Juan, and it was determined that such a project would be difficult to implement and would not be beneficial for the fishermen. We then directed our efforts toward analyzing the viability of offshore cage culture as a means for offsetting the Island's dependency on imported seafood. This report investigates the environmental, political, and socioeconomic aspects of cage culture. Previous and ongoing projects, as well as expert opinions, were studied to provide recommendations for the implementation of offshore cage culture in Puerto Rico.

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Dr. Dallas Alston, of the Marine Sciences Department of the University of Puerto Rico, was kind enough to open his personal libraries for research and give us a tour of the University's aquaculture facilities. We are extremely grateful for his overwhelming

generosity and sincere interest in our investigation. Jesús Rodriguez, the director of a local San Juan fishing village, provided essential information regarding the plight of the Puerto Rican fishing industry. Dr. Angel Olivares allowed us to tour the intensive aquaculture facilities of the University of Puerto Rico in Rio Piedras and discussed the feasibility of such a project for the village of San Juan. His detailed explanations and key insight were of tremendous importance. Edgardo Ojeda Serrano and the people of the Sea Grant College Program of the University of Puerto Rico in Mayagüez were also very helpful. We sincerely appreciate the time Ojeda Serrano spent discussing the development of aquaculture in Puerto Rico.

The Office of Agricultural Statistics within the Department of Agriculture of Puerto Rico aided us by providing statistics regarding the fishing industry of the island. Daniel Matos-Caraballo from the Laboratorio de Investigaciones Pesqueras also provided critical information about the registered fish catches in Puerto Rico. The aforementioned researchers and professors were critical to the progress of our project, and our gratitude will never compensate for their generosity.

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¡Mil gracias por su tiempo, interés y sincera generosidad!

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EXECUTIVE SUMMARY

Although Puerto Rico is an island, its fishing industry is surprisingly in grave danger. Overfishing has caused a decline of the fish stocks, and approximately 95 percent of the seafood consumed on the island is imported. The grim situation has caused the fishing industry to dwindle. The fishermen of Puerto Rico are in dire need of both economic and political support.

An economically viable, yet environmentally sound solution to the demise of the fishing industry is required. Hence, we assessed the feasibility of implementing an aquaculture project in the fishing village of San Juan, hoping that this would set an example for other fishing associations and possibly improve the overall situation.

Aquaculture consists of the culture of fish under controlled conditions. Aquaculture systems can be land or water-based. Depending on the level of technology applied, they range from extensive to intensive systems. Extensive systems culture fish using simple technology and rely mainly on the natural resources available. Although the purchase and maintenance is inexpensive, production in extensive systems is limited by the carrying capacity, or the density of fish the pond is capable of maintaining. Intensive systems use high-technology equipment such as re-circulating tanks, flowing raceways, and indoor facilities to culture fish under carefully controlled conditions. The carrying capacity of the system is greater, allowing for higher fish densities and near-optimum growth conditions. Thus, yields of intensive systems are generally higher than in extensive pond cultures. Nevertheless, the cost of the equipment and maintenance of an intensive system is much higher than that of an extensive system. In Puerto Rico, tilapia

and freshwater shrimp, or prawns, are frequently cultured together in extensive and intensive systems.

Aquaculture operations may also be established in the open ocean. Specially designed cages, with volumes reaching 4,000 cubic meters, provide a virtually natural habitat for the cultured fish and take advantage of ocean currents. These improved conditions allow for the production of substantial amounts of fish. For example, approximately 35 tons of Pacific threadfin, *Polydactylus sexfilis,* were produced from one 3,000 cubic-meter cage after six months of culture in Hawaii. Mutton snapper is being considered for offshore cage culture near Puerto Rico.

After learning that the village of San Juan has approximately five acres of land available, we researched the possibility of establishing an extensive pond system and training the fishermen to become aquaculturists. A series of interviews with pertinent experts, however, helped us to determine that such an operation would not be feasible on the limited land available. In addition, the location of the fishing village is not suitable for an aquaculture operation as designated by proposed regulations by the Department of Natural and Environmental Resources of Puerto Rico.

Next, we considered adapting an intensive system, such as an indoor facility with re-circulating tanks, but a considerable investment in technology would be required to establish a profitable operation on the limited land available. Furthermore, the yields of such a project would not compensate for the costs of equipment and maintenance. We, therefore, determined that an intensive aquaculture operation would not be economically viable. Moreover, a pilot-scale demonstration farm would not be beneficial for the fishermen. Finally, although the fishing village was hopeful that aquaculture could provide assistance, they viewed this practice as a supplement to their fishing activities and not as an alternative. Hence, the transition from fishing to aquaculture would be unlikely.

We, then, considered an offshore aquaculture project as an option for the fishing industry. Although it may not directly aid the fishermen of San Juan, the implementation of such a technology may revive the Puerto Rican fishing industry. Consequently, we investigated the environmental, political, and socioeconomic considerations of offshore cage culture. Information from previous and ongoing projects, as well as expert opinions from around the world, were studied to provide a series of recommendations for the implementation of this technology in Puerto Rico.

We conducted an economic analysis and concluded that offshore cage culture has the potential to become a financially viable industry in Puerto Rico. A system consisting of one cage stocked with mutton snapper is not expected to generate a profit; however, multiple cages allow for the sharing of operating expenses and profitable operation. Future development of a local hatchery and feed production facility would further increase profitability. Cage manufacturers are currently considering relocating manufacturing plants to China, where labor costs are lower, in order to reduce production costs. Regulations are also being adapted to consider the needs and environmental impacts of offshore cage culture. Although many areas still require further research, offshore cage culture may revolutionize the fishing and aquaculture industries in Puerto Rico.

PROJECT INTRODUCTION

This project focuses on the social, economic, and technical aspects of aquaculture in Puerto Rico. Overfishing has caused a depletion of coastal resources and has directly affected the livelihoods of the Island's fishermen. As surprising as it seems, Puerto Rico imports 95 percent of its seafood products. An environmentally sound, yet economically viable solution to this problem is required. By studying the concerns of a local San Juan fishing village, we learned that their problems are symptomatic of the Puerto Rican fishing industry. Thus, any possible solutions to the problems of the fishing village would have broad implications and could revolutionize the entire industry.

This project consists of two parts, each containing a literature review and methodology. The first part considers the feasibility of various types of aquaculture that could benefit the San Juan fishing village. After we determined that aquaculture would not be feasible in this fishing village, the focus of our project shifted to an examination of another option, offshore cage culture. The second part of our report fully explores these aspects and discusses the analysis of our data. The final section describes our conclusions and recommendations to the Colegio Tecnológico de San Juan. The untraditional structure of this report allowed us to completely describe the development of our project and to discuss the problems we encountered and decisions we made as they occurred.

Part One of this project consists of four chapters and discusses the development of our research. Chapter One describes the aspects of the geography and climate in Puerto Rico that are favorable for aquaculture. We determined that many factors such as water quality and temperature would have to be considered for a successful aquaculture project.

Factors such as these will have an effect on the species of fish selected, the type and location of the system, and various other aspects of aquaculture implementation.

Chapter Two discusses the fishing industry of Puerto Rico and the problems that have been faced in recent years, including overfishing and the dwindling of the industry. Fish stocks have been depleted all over the world while the demand for seafood has remained high. Therefore, it is imperative that we find a method of producing seafood in an environmentally and economically sustainable manner.

In Chapter Three, the focus is on the fishing village of San Juan. The fishermen of this village have also faced problems with overfishing. The options presented to the village and the reactions of the fishermen are discussed in this chapter. Furthermore, the idea of training fishermen to transition to aquaculture is also explored.

Chapter Four discusses the different types of land-based aquaculture systems. Each system, extensive or intensive, has different land and resource requirements. Factors such as costs, species selection, facility maintenance, and management are discussed. Furthermore, the feasibility of each system in the San Juan fishing village is analyzed in this chapter.

Part Two of this project focuses on a new technology called offshore cage culture or mariculture. This section discusses the environmental, political, and socioeconomic aspects of this type of aquaculture. Chapter Five describes the characteristics of offshore cage culture including a historical background, general description, and a discussion of the benefits. Chapters Six, Seven, and Eight address the environmental, political, and socioeconomic aspects, respectively, of offshore cage culture implementation and maintenance. Chapter Nine is an analysis of offshore cage culture including the feasibility and payback analysis of commercial implementation. Chapter Ten provides a series of recommendations for the development and implementation of offshore cage culture in Puerto Rico.

Data was obtained by conducting a series of semi-structured interviews with various experts, and fishermen from a local San Juan fishing village. Additional data was acquired from government documents, phone interviews, electronic mail, and facsimiles. The experts provided information regarding the most feasible and beneficial approach to aquaculture and its possible implementation. The government documents provided statistics regarding aquaculture and seafood consumption. Communications via phone, electronic mail, and facsimile added essential information. Also, through our discussions with representatives at the fishing village, we became aware of the fishermen's problems and needs. Using these resources, we changed the focus of our research several times in order to fully explore the possibilities that exist for aquaculture in Puerto Rico.

We believe this project will be of interest and value to the Colegio Tecnológico de San Juan, the San Juan fishing village, aquaculture experts in the United States and Puerto Rico, and to persons concerned with the economy of Puerto Rico. This project has economic, environmental, and social importance. Aquaculture can supplement fishing without diminishing natural fish stocks in the coastal waters. It may also provide new employment opportunities. Furthermore, if cage culture is adopted in Puerto Rico, it could grant greater self-reliance by allowing Puerto Rico to replace imports with locally farmed aquatic products and also increase exports of these products. Our proposed system, however, will require vocational training and education in order to be successful in Puerto Rico. The Colegio Tecnológico de San Juan will be able to provide this training. This study may also give the Colegio Tecnológico de San Juan important data from which they can perform future projects relating to offshore cage culture.

An Interactive Qualifying Project (IQP) encompasses the application of technology to address modern-day social concerns. This project enables students from Worcester Polytechnic Institute to understand the social impacts of their knowledge and grasp the potential of their work. Our project reveals the importance of the societal impacts of technology by analyzing aquaculture technology as a means to improve the dwindling fishing industry of Puerto Rico.

This report was prepared by members of Worcester Polytechnic Institute Puerto Rico Project Center. The relationship of the Center to the Colegio Tecnológico de San Juan and the relevance of the topic are presented in Appendix A.

PART I

CHAPTER 1: GEOGRAPHICAL INFORMATION OF PUERTO RICO

Puerto Rico is an island commonwealth of the United States of America, located in the Caribbean Sea and having an area slightly less than three times the size of Rhode Island. The island is mostly mountainous, with a coastal plain belt in the north and sandy beaches on the coastline (US CIA, 2000).

The climate of Puerto Rico can be classified as tropical marine, indicating that the climate remains warm and sunny for much of the year. Although temperature fluctuations occur when moving inland due to the island's mountainous interior, these variations are not significant. The United States Weather Bureau has never recorded temperatures below 21°C or above 36°C in the city of San Juan (Rivera, 2001). Furthermore, the average water temperatures along the shores of San Juan remain fairly consistent between the temperatures of 25 °C and 28 °C (Refer to Table 1.1).

Table 1.1 Average water temperatures (°C) in San Juan, Puerto Rico.

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
25	26	26	26	27	27	27	28	28	28	27	27

Source: http://www.nodc.noaa.gov/dsdt/wtg12.html

Puerto Rico has endured several hurricanes in recent years. On September 21, 1998, Hurricane Georges entered Puerto Rico near Humacao and traveled from east to west through the interior of the island exiting just south of Mayagüez in Cabo Rojo. Next, on October 20, 1999, Tropical Storm José entered the northeast region of Puerto Rico before turning north through the Atlantic. Also, on November 16, 1999, Hurricane Lenny entered the southern coast of Puerto Rico and eventually turned east into the

Atlantic. As seen in Figure 1.1, the probability of a hurricane in Puerto Rico is extremely high at nearly 50 percent.

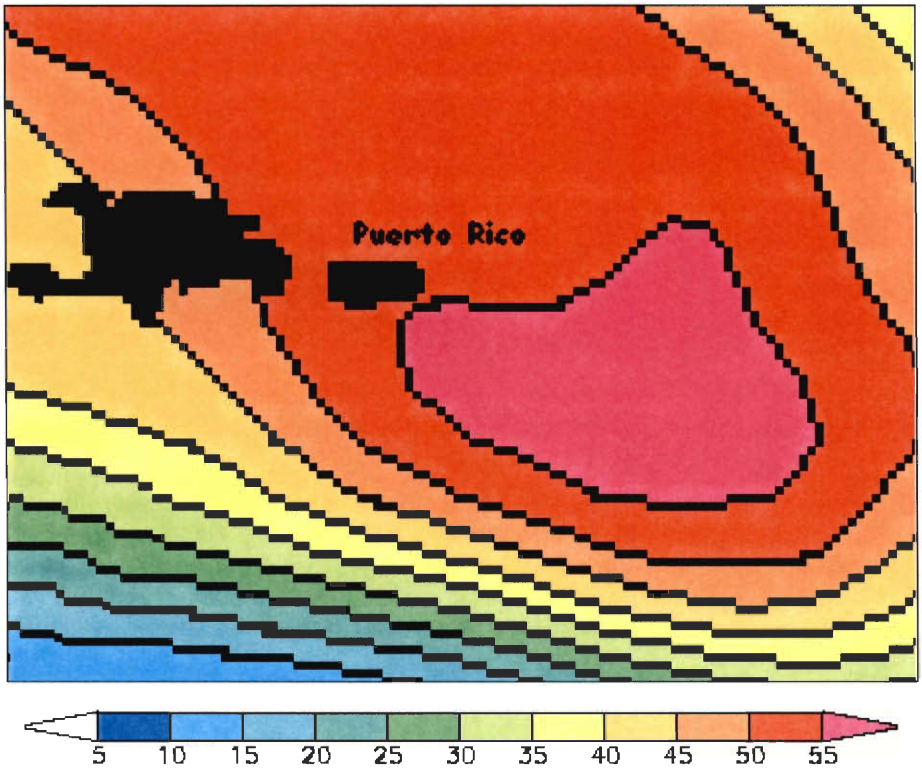

Figure 1.1 Hurricane probability for the Caribbean region.
Adapted from http://www.aoml.noaa.gov

However, as shown in Figure 1.2, the average occurrence of hurricanes between the years of 1944 and 1997 has been less on the southwestern coasts of Puerto Rico. The mean occurrence of hurricanes per year in the southwest was 0.5 and on the northeastern coasts, the mean occurrence was 0.6.

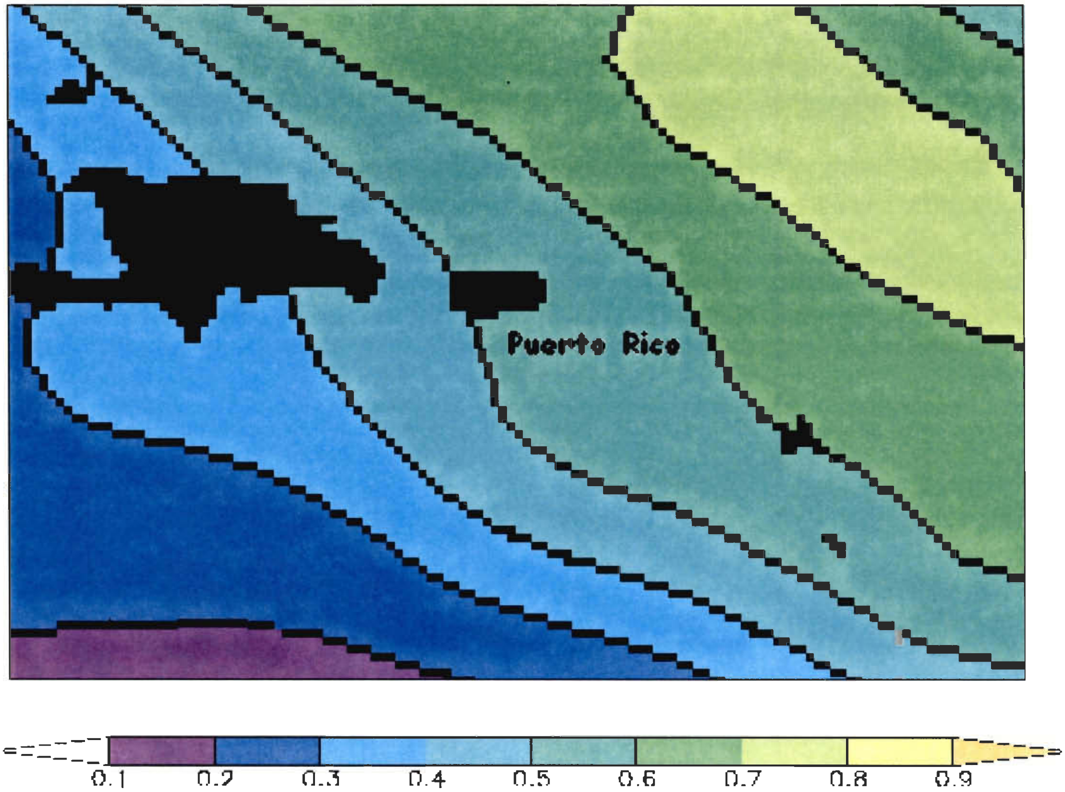

Figure 1.2 Mean occurrences of hurricanes in the region from 1944-1997.
Adapted from http://www.aoml.noaa.gov

Puerto Rico has a limited coastline extension of 501 kilometers, a restricted shelf dimension, permanent temperature gradient, and waters that are lacking in plant nutrients. This confining scenario produces unfavorable fishing conditions. However, the coral reefs and saltwater ponds are a nucleus of biodiversity and are responsible for coastal organic production (USGS, 2001).

CHAPTER 2: PUERTO RICAN FISHING INDUSTRY

The Caribbean Marine Research Center (CMRC), which has the responsibility of overseeing undersea research throughout the entire Caribbean region, reported (2001) that the tropical ecosystems of the Caribbean have been adversely impacted by both natural and human factors such as the reduction of dissolved oxygen in coastal waters from sewage discharge and deforestation. Furthermore, overfishing has caused a depletion of some species, such as the manatee, in these tropical ecosystems. The CMRC also reported that due to the depletion of several species, the fishing industry has been curtailed in many areas. However, few efforts have been made to assist the restoration of the endangered ecosystem. Daniel Matos-Caraballo (1999), researcher at the Laboratorio de Investigaciones Pesqueras in Mayagüez, Puerto Rico, stated that for the last fifteen years, overfishing has caused a major impact on the fishing industry of Puerto Rico. Fishermen sweep reefs of their valuable species and then move on, eliminating entire populations of species within the areas they leave behind (World Resources Institute, 2000).

Coral reefs, which represent the most valuable coastal resource of the islands in the Caribbean, play important roles in the ecosystem. These roles include providing homes for most of the island's fish, protecting the shoreline from erosion, and creating sandy beaches. Reefs are highly productive with a rate of 2,900-4,200 grams of organic carbon per square meter per year. Coral reefs are subjected to many disturbances by nature and humans. First, hurricanes frequently weaken the reefs by storm activity. Next, collection of corals by people and anchoring of ships have inflicted severe damage on the reefs. Also, the techniques used by fishermen have caused the most serious problems for the Puerto Rican ecosystem. These problems could lead to an extensive loss of coral reefs and their dependent species (USGS, 2001).

In 1994, environmental journalists Sharon and Kenneth Friedman pointed out the now obvious view that, contrary to the beliefs of many fishermen, the supply of fishes in the oceans is not unlimited. They reported a series of events that has occurred. The increase in the population of the world has put pressure on the supply of fish. Furthermore, as the number of fish caught exceeds the capacity of a species to breed, the population decreases and eventually causes a decline in the fishermen's catch. Many fishermen depend on the fishing industry for food for their families and personal income. Therefore, if an area becomes depleted, the fishermen lose their source of income and food. In India, for example, fishermen used mechanized ships to increase their catch by 15 percent, but, after several years, severely overfished the area and decreased their total catch by 50 percent. Simultaneously, the mechanized boats not only contributed to the problem of overfishing, but their bottom-sweeping techniques damaged the ecosystem and interrupted sea life involved in the aquatic food chain. Some governments have recognized these problems and set limits on commercial catches of fish in order to allow stocks to recover. However, certain stocks remain in short supply, and market prices continue to increase.

The Environmental Defense Fund (1997) also reported that overfishing and pollution have caused depletion in many fish stocks and damage to the ocean ecosystems. The reasons for this destruction are poor fisheries management, coastal development, and bycatch, which is the inadvertent capture of one species while fishing for another. Although the oceans have been a plentiful source of food throughout human history, thirteen of the world's seventeen major fishing areas have seriously damaged fish stocks or are in severe decline.

CHAPTER 3: THE FISHING VILLAGE OF SAN JUAN

San Juan has several fishing villages located throughout the municipality. During the late 1970's, the city developed plans to unite these various villages by constructing a centralized facility adjacent to the Parque Central. As a result of an assortment of bureaucratic delays, the facilities were not built until 1998. Of the four fishing villages that the municipality intended to unite, only two currently occupy the city's facilities. The remaining two villages refused to relocate and remain in their original locations. Many factors influenced their decision against moving to the Parque Central; the most significant was their refusal to change their political structures. The villages did not agree with the idea of being subordinate to a leader that had not risen through their own ranks, and they believed this would occur if the villages agreed to unite and share facilities (Jesús Rodriguez, Appendix C).

3.1 General Description

A tour of the facilities of the fishing village of San Juan and an interview with Mr. Jesús Rodriguez (Refer to Appendix C), director of the village, provided information regarding the situation of the fishermen. The municipality owns facilities consisting of a building and docks located on the waterfront. The unit houses forty-eight lockers that are each assigned to a fisherman. These lockers are used by the fishermen to house their personal belongings including items such as fishing lines, nets, lures, and bait. Many fishermen may also use these rooms as sleeping facilities after long fishing trips.

The neighboring room houses the processing plant that contains equipment necessary to fillet the incoming fish. The plant also has scales where the fisherman can weigh their total catch or individual fish. Large freezers contain shaved ice for the storage, transportation, and sale of the product, and a large door provides easy access to the plant from the docks.

A small store that sells fish to the public is also located within the building. Fresh fish are on display and sold directly to the public. According to Jesús Rodriguez, the City of San Juan provides the village with a sales associate; however, this help is unreliable. A set of docks and boat ramp are located behind the building. Rodriguez believes the docks were very poorly designed and as a result, the fishermen have a difficult time transporting their catch to the processing plant. The docks are situated in water that ranges from six to ten feet deep. This limits the size of the boats that can be docked. However, the only large boat that the village owned capable of deep-sea fishing was stolen in recent years. The boat ramp provides easy access to the docks and is frequently used to remove or place fishing vessels into the water.

The fishing village is situated on five cuerdas (4.85 acres) of city owned land. The facilities occupy 3.1 cuerdas (3.01 acres), leaving 2.9 cuerdas (2.82 acres) of undeveloped land. The municipality intends to use this land to attract tourists to the waterfront area. The blueprints include a restaurant, bait and tackle shop, and new docks. However, these blueprints were drafted in 1977 and no government action has been taken since their drafting.

3.2 Current Situation of the Fishermen of San Juan

The fishermen of San Juan face the immediate problem of a dwindling fish supply in coastal waters. A previous project completed for the Colegio Tecnológico de San Juan stated that this decreasing supply of fish is the result of many factors, which include pollution, the effects of Hurricane Georges in 1998, and overfishing. The average catch per fishing excursion in 1999 was between 45 and 68 kilograms (Karl & Pappo, 1999). According to Jesús Rodriguez, the average catch has dropped approximately 25 percent to be between 36 and 45 kilograms.

Since there are currently no regulations on the size of fish caught, the fishermen's catches are increasingly comprised of small fish of 15 to 20 centimeters in length. Consumers on the island prefer fish larger than 15 to 20 centimeters. Thus, the majority of these small fish are unnecessarily wasted. Since these young fish do not have the opportunity to mature and reproduce, the fishermen are further depleting the aquatic resources on which they depend so heavily and are furthermore exacerbating the overfished coastal waters.

Mr. Rodriguez also mentioned the fact that there are twenty-six fishermen in his village with ages ranging from 54 to 78 years old. He strongly believes that the younger generation has a lack of interest in pursuing fishing as a profession. Mr. Rodriguez attributes this to several factors, which include the low income of the profession, the long hours of work necessary, and the perceived lack of glamour the industry has among newer generations of Puerto Ricans.

Mr. Rodriguez emphasized the fact that many political changes have affected the fishing village. Due to political shifts, political agencies that were created with the intention of strengthening the fishing industry have dissolved, leaving the fishermen without aid. He believes that these changes will continue and are very detrimental to the industry. For example, CODREMAR, was created in the late 1970's to support the fishing industry but does not exist today.

Jesús Rodriguez indicated that at times, the fishing village purchases fish from other suppliers to meet the demand of the consumer. Since they have not been able to catch as many fish as in previous years and the demand for seafood in Puerto Rico has increased, the fishing village has not been able to maintain a plentiful supply of fish. Therefore, the only way to sustain their market has been to seek a source outside of fishing.

3.3 Discussion of Aquaculture as an Alternative

Mr. Rodriguez was very interested in the possibility of aquaculture as an alternative to fishing. He realizes that his fishing village faces serious problems and would be interested in any option that could assist their current situation. Another fisherman, Pedro Lopez Catala, felt strongly that regardless of what alternatives were proposed to remedy the fishermen's situation, he would always continue to fish. Fishing has been his means of subsistence for the majority of his life and this would never change. Therefore, any aquaculture activity would only be a supplement to his current fishing activities. Mr. Rodriguez believed that most of the fishermen in his village would hold these same views and be hesisitant to convert from fishing to aquaculture.

The fishing village expressed particular interest in the farming of freshwater shrimp. Mr. Rodriguez believed that the production of the vilage could be strengthened substantially through these practices. Shrimp is extremely popular in Puerto Rico, and the store already has an existing seafood customer base. In addition, the Mr. Rodriguez mentioned another village on the island that had farmed shrimp successfully.

In summary, the fishing village of San Juan faces a host of social, economic, and environmental problems that include a declining interest in the fishing industry, poor wages, and overfishing. Since the fishing industry has adversely affected the Puerto Rican environment, aquaculture can be a viable alternative that can aid in the prevention of overfishing of coastal waters and promote the regeneration of fish stocks and damaged aquatic ecosystems.

CHAPTER 4: TRADITIONAL TYPES OF AQUACULTURE

Aquaculture can be divided into land-based or water-based systems (FAO, 2000). The former is comprised mainly of ponds, rice fields, and other facilities built on land. Carp and tilapia are commonly grown in freshwater ponds, tanks, or cement pools. Shrimp and finfish, tolerant to more saline waters, are cultured in brackish water ponds. Water-based systems include enclosures, pens, cages, and rafts situated in inland waters, sheltered coastal areas, or the open-ocean. Pens are placed on the bottom of a water body, whereas cages can be suspended. Practices of aquaculture range from low-technology extensive methods to highly intensive systems (Clark & McGuire, 2000).

4.1 Extensive Systems

Extensive aquaculture frequently makes use of the naturally existing bodies of water such as coastal embayments or natural ponds. The growth of the fish is completely dependent on the natural productivity of the water sources and the supply of live food organisms. This approach requires minimal investment and operating costs; however, yields per unit area are generally low (Clark & McGuire, 2000). Nevertheless, several investments are required for implementation. Land-based aquaculture sometimes requires a pond lining if the soil is too porous and a network of supply lines, pumps, and drains for waste removal. Furthermore, an emergency generator will be necessary in the event of a power loss, and a building for storage of supplies and equipment will also be needed. Since equipment maintenance is a vitally important component of any aquaculture facility, a less complex system would be generally easier and less expensive to maintain. Site selection is very important to avoid natural damage from storms and fouling problems. Land-based pond systems should be close to the water source and at low elevation. Factors such as power availability, reliability, and cost will have a continuing effect on operating costs (Holt, 1992).

One of the most important pond-management practices is the carrying capacity, or stocking of the appropriate species and quantity of fish, because there is a limited amount of space and natural food in a pond. Soil conditions and water quality of the pond play a major role in determining the carrying capacity. Systems that employ aerators and water pumps increase the carrying capacity of the pond by elevating the amount of dissolved oxygen in the water (Shang, 1986). Colt (1986) stated that enhanced productivity in aquaculture is based primarily on an improved understanding of the physical, chemical, and biological processes that occur in the ponds.

Species selection determines the carrying capacity of a pond and overall profitability of an aquaculture operation. We originally chose tilapia, a member of the cichlid family, which are freshwater fish endemic to Africa, as our species for extensive pond culture in Puerto Rico. The three major genera, *Oreochromis, Sarotherodon*, and *Tilapia*, are considered important for aquaculture (Popma & Messer, 1999).

Tilapia, of which there are fourteen different species, have been cultured in many places around the world, including East Africa, China, India, Israel, Costa Rica, Mexico, Puerto Rico, and the United States. Tilapia has many positive aspects such as hardiness, easy spawning, quick growth, and high quality of meat. Tilapia is also very tolerant of brackish or salty water and some species can even survive and breed in seawater (Bardach, 1972; Popma & Messer, 1999). Although they tend to be small, tilapia is an excellent food fish. Similar to flounder in its mild taste, fewer bones make tilapia a superior commercial fish.

In addition, tilapia can be cultured with shrimp. In Puerto Rico, it is a common practice to culture freshwater shrimp, *Macrobrachium rosenbergii,* with tilapia. As stated by García-Perez, Alston, and Cortes-Maldonado (2000), in tropical regions, freshwater prawn and Nile tilapia polycultures use feed more efficiently than monocultures. Mallasen & Wagner (1999) indicated that there are no morphological differences between prawns grown in natural and artificial brackish waters, therefore, allowing the introduction of these animals to freshwater ponds with tilapia. Even though yields depend on limiting densities, culture periods, and harvesting strategies, Garcia-Perez *et al.* (2000) believe polyculture of these species optimizes production of each one. Tidwell, Coyle, Weibel, and Evans (1999) concluded that increasing stocking density of prawns enhances total production but decreases marketable production by reducing average weights. García-Perez *et al.* (2000) suggested that in areas having a relatively high market value for each culture, this approach should be considered. Nevertheless, according to Glude in Hargreaves & Alston (1991), at least 70 to 75 acres of ponds are required for a freshwater prawn farm to be profitable in Puerto Rico.

4.1.2 Feasibility Analysis of an Extensive Aquaculture System

An interview with Dr. Dallas Alston (Refer to Appendix B), former Director of Marine Sciences at the University of Puerto Rico, Mayagüez and a tour of the facilities of the Centro de Investigación y Desarrollo de la Acuicultura Comercial en Puerto Rico (CIDACPR) at Lajas, provided information critical for assessing the feasibility of an extensive pond system for the village of San Juan. The ponds at that research facility used for the culture of prawns and red and silver tilapia are a quarter of an acre in size. According to Dr. Alston, pond culture in Puerto Rico is feasible but not economically viable if implemented on a small-scale. He stated that a commercial prawn and tilapia pond system would consist of approximately 60 acres. We discussed possible alternatives to extensive pond aquaculture with Dr. Alston. The aquaculture expert proposed the idea of a more technologically advanced intensive aquaculture operation created as a pilot farm but operated by the fishing village. Dr. Alston referred us to Dr. Angel Olivares, a professor and researcher at the University of Puerto Rico in Rio Piedras who operates an intensive system. Dr. Alston also mentioned his involvement in a proposal for an offshore cage culture system for mutton snapper. This interview with Dr. Alston was very valuable, for it emphasized the limitations of traditional land-based aquaculture systems in addition to the different mentalities of fishermen and fish farmers.

We visited the fishing village in order to further assess their situation and the possibility of developing an aquaculture operation at that particular location. The director of the fishing village of San Juan, Jesús Rodriguez (Refer to Appendix C), indicated that the fishing village has only 2.9 cuerdas (2.8159 acres) of land available for this project. This property is located in the metropolitan area of San Juan and surrounded by buildings and roads. The proximity to the bay is also a factor of concern because of the possibility of contamination of the freshwater required for tilapia and prawn growth.

An interview with Edgardo Ojeda Serrano (Refer to Appendix D), assistant marine researcher at the Sea Grant College Program at the University of Puerto Rico, Mayagüez, confirmed that an extensive aquaculture operation would not be feasible due to the land limitations and the socioeconomic situation of the fishing village of San Juan. Ojeda Serrano discussed a proposed set of regulations by the Department of Natural and Environmental Resources (DNER) restricting the placement of aquaculture operations near bodies of water that could possibly become contaminated. Article 16 of the proposed regulations for the fishing activities in Puerto Rico (DNER, 2000) states that aquaculture operations cannot be located within 500 feet of a submerged cable or sewage pipe. Operations must be situated within a reasonable distance of habitats of special significance as designated by the Secretary of the Department. Finally, aquaculture operations cannot be established near docking areas or 0.25 miles from federal navigation channels, unless approved previously by the United States Coast Guard or the United States Army Corps of Engineers. The fishing village of San Juan has docks and is located in close proximity to busy roads and the bay of San Juan. Ojeda Serrano was concerned about the possibility of heavy metal accumulation in the cultured fish due to the proximity of the land to an urban area of San Juan. Although these regulations do not clearly state that an aquaculture operation cannot be established in an area such as the fishing village of San Juan, Ojeda Serrano believes that it would be extremely complicated to obtain the proper permits. Therefore, in addition to the lack of land that exists, location of the land would not be suitable for a successful aquaculture project.

Ojeda Serrano also emphasized that due to the difficulty of the manual labor involved, the fishermen would not be able to dedicate the time required to maintain such an aquaculture operation. He believes the situation of the fishermen will not improve until the fishing industry dies completely and people begin to realize the need to complement and revive the industry. He further stated that he did not believe an extensive aquaculture project would be beneficial for the fishermen.

The compilation of these expert opinions and relevant literature allowed us to conclude that an extensive pond culture system would not be economically feasible or environmentally sound if placed in the current location of the land available to the fishing village of San Juan. We therefore opted to consider the feasibility of an intensive system, a more land-efficient approach to aquaculture.

4.2 Intensive Systems

Intensive fish farming involves complete control of the nutrients and, therefore, the growth of the fish is entirely dependent on the outside sources. Intensive aquaculture utilizes systems such as tanks and raceways where parameters can be carefully monitored (Clark & McGuire, 2000). Operating costs and investment are substantial, but high yields per unit area are produced. Fish are cultured from egg to adult stages and stocked at higher densities in well-designed facilities. Chemicals are used to prevent disease and high-protein feeds are provided on a regular basis.

4.2.2 Feasibility Analysis of an Intensive Aquaculture System

During the interview with Dr. Alston, he mentioned the possibility of creating a pilot farm implementing technology from Dr. Olivares. In order to assess the feasibility of creating an intensive aquaculture system in the fishing village of San Juan, we spoke with Dr. Olivares (Refer to Appendix F). The professor emphasized the costs involved in creating the facilities for an intensive operation and warned that the maintenance costs, especially electricity, water, and labor in Puerto Rico, would be considerable. Dr. Olivares stated that the San Juan fishing village could invest in a small pilot farm that could lead to a large one. Nevertheless, he indicated that such an operation would cost approximately $700,000. In addition, the professor believes that this operation would not be economically viable and would serve only as a demonstration. Land limitations decrease possible production, which would in turn require investing in high-technology alternatives to offset yields. Therefore, the cost of producing a filet of tilapia would not be as competitive as in Taiwan or Jamaica, where labor costs are less expensive.

In addition, Dr. Alston stated that a marine shrimp farm requires about 200 acres of ponds even with current industry practices; 75 to 100 acres are necessary when using the latest high-density culture systems. The location of the land in disposition of the fishing village of San Juan may not be in accordance with new zoning regulations proposed by the Department of Natural and Environmental Resources. Edgardo Ojeda Serrano discussed this issue warning us that even the proposal of an indoor intensive aquaculture facility may be met by opposition. He believes that this land will eventually be used for tourism.

Aside from land limitations, intensive aquaculture would require considerable funding to purchase the necessary equipment, as stated by Dr. Olivares. The fishermen would have to be trained accordingly. Costs for training, equipment, labor, and maintenance would exceed the limited production due to the size of the operation. Therefore, we believe an intensive system would not be economically feasible for the San Juan fishing village.

PART II

CHAPTER 5: OFFSHORE CAGE CULTURE

Considerable effort is directed at maintaining a stable physico-chemical environment in intensive systems. Li and Mathias (1994) believe this is not a problem in fish cages, since chemical parameters are relatively stable in open waters, and water exchange throughout the cage netting maintains a similar environment inside and outside of the cage. James P. McVey (1996), Program Director for Aquaculture for the National Sea Grant College Program, stated that there was a marked progression from extensive to intensive aquaculture, including offshore cage culture systems. The new frontier in aquaculture is the development and implementation of economically feasible and environmentally conceivable cage culture systems (McVey, 1997).

Joseph McElwee (1997) of Dunlop Marine and Bonner Engineering in Ireland and James McVey (1997) defined open ocean aquaculture as the rearing of fish in open hostile environmental conditions, in deep waters, exposed to open ocean on one or more sides. McVey stated at the Second International Open Ocean Aquaculture Conference, that Norway, Sweden, Ireland, Russia, Italy, France, Israel, and the United States, among others are currently developing this technology.

McElwee (1997) cited as advantages of cage culture the improved growing conditions in deeper waters because strong currents increase water exchange. Marine fauna and flora are not adversely affected or impeded by the presence of the cages. Once assembled and moored correctly, the maintenance of these cages is relatively inexpensive. More space for more fish enables larger profit potential.

McElwee (1997) indicated that offshore cage systems have been quite successful in Ireland. Cages are also advantageous because they can be stocked at densities far greater than ponds or even some intensive systems (Landau, 1992). Lawson (1995) added that cage farms can be expanded by simply adding more cages as the operation grows. Even though some cages can hold volumes of up to 3,000 cubic meters, cages are still mobile and thus can be moved to other sites to take advantage of better-quality water, seek more abundant food organisms, or escape storms.

Li and Mathias have stated (1994) that the keys to good cage environments are proper site location with adequate water exchange and frequent washing of the nets to prevent clogging. Lawson (1995) indicated that since cages are in public bodies of water, farmers have no control over water quality conditions and pollution. Once installed, the cages are at the mercy of the weather and may be damaged by high waves, tides, and storms. The author also mentioned that cages sometimes pose navigational hazards, deny access to certain areas by commercial and sport fishermen, may be aesthetically unacceptable, and are highly vulnerable to poaching and vandalism.

Lawson (1995) warned that cage facilities do in fact have an impact on the aquatic environment in that large quantities of uneaten feed and feces are released and can adversely affect water quality in the general area. This might lead to primary production and consequently eutrophication, or excessive growth of the natural occurring flora. Lawson expressed concern about the impact of cages on native species and the possible disruption of disease and parasite cycles.

According to Braginton-Smith & Messier (1998), offshore cage culture facilities have many operational and technical requirements. An important fact to remember is that during inclement weather, access to the facilities is limited, if not impossible. Therefore, the first requirement is that the aquaculture system must have the ability for independent operation without human involvement for possible extended periods of inclement weather. Along the same lines, the structure of the facility should be able to maintain its integrity during periods of severe weather. Also, the facility must contain a platform for personnel to perform daily operations and maintenance tasks. The facility or the transportation vessel must include sheltered storage space for feed, tools, spare parts, lines, nets, and other pieces of equipment. A suitable environment for any necessary electrical and electronic equipment should also be available.

The facility should also contain security monitoring and alarming. One of the major concerns of the owner of the cage culture facility is security of such offshore facilities. Potential concerns include accidental collisions by commercial shipping and offshore fishing vessels, interference by marine mammals, human invasion, and detection of structural degradation.

5.1 Cage Technology

Cage technology has been in the development stages since the early 1980's. According to Bugrov (1996) and Gunnarsson (1993) the first generation of submersible cages were diving cages built by Japanese fishermen in 1983. Diving cages are defined as cages that remain slightly below the ocean surface and are submerged deeper in the water during inclement weather. Although diving cages have the unique ability to descend, they have one major flaw: namely that when they are submerged, feeding is impossible and the fish starve. Since the inception of the diving cage, there have been numerous changes to cage design. In the early stages of cage development, many did not function well, much like the early diving cage. Yet, each design has been a stepping-stone towards the high-technology cages of today.

Since 1982, SADCO-SHELF Ltd., of St. Petersburg, Russia, has made several different designs of submersible cages (Bugrov, 1996). The first was similar to an experimental cage and was easy to deploy. Therefore, the cage had the ability to be fastened to a single central anchor. The vertical flexibility of the structure decreased the load produced by the waves. However, the oscillating motions of the cage disturbed the fish population inside. These motions also hindered the servicing and installation due to the absence of a working platform.

Bugrov (1996) described the second design as consisting of two main parts, a pontoon, or barge on the surface of the water, and an underwater cage attached to it. This design seemed promising because all of the technical services could be performed on the pontoon and there were no mechanical devices at the bottom of the sea. However, in 1986, a test in a wave tank showed that the design was unreliable and would not do well in the ocean.

The third design, SADCO-100, was made in 1986 and had the main objective of being able to tolerate most severe weather conditions. According to Bugrov (1996), the cage consisted of a three-dimensional hexagonal prism with a pontoon and an underwater feeder. Overall, the cage was quite successful and was able to withstand storms. The only drawback was its small volume of only 100 cubic meters.

Bugrov (1996) mentioned that the fourth design, KITEZH-500 had six cages similar to the SADCO-100 that were joined together to form a honeycomb shape. The cages were very well engineered, but the output of fish was not high enough to justify the large production costs.

In 1996, Bugrov stated that in 1990, the SADCO-500 was designed with a crystalloid shape, a feeding system, and a cage capacity of 500 cubic meters. The main disadvantage of this design was the costs that resulted from the large amount of steel used in the cage design.

The SADCO-2500 was a design similar to the SADCO-500, except it had central column and a cage capacity of 2,500 cubic meters (SADCO, 2001). This cage design was stable in waves, currents, and wind changes. Again, the main disadvantage, however, was the large cost for the cage.

Bugrov (1996) described the final design in 1994, SADCO-1200/2000, as having a rigid top framework and a flexible suspension system for the bottom (Refer to Figure 5.1).

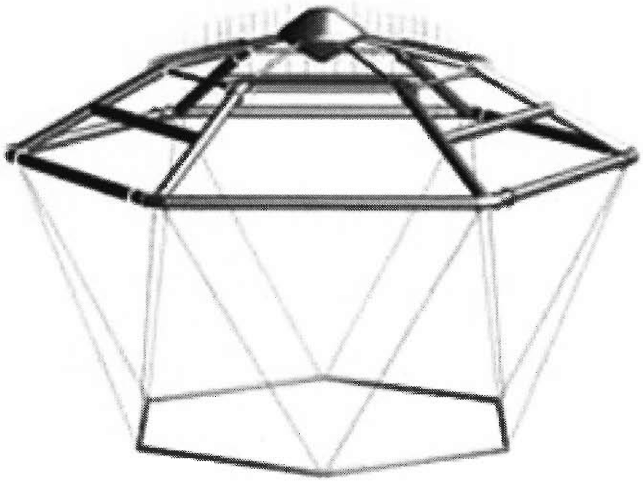

Figure 5.1 SADCO-1200/2000 rigid framework and flexible suspension system.

Adapted from: http://www.sadco-shelf.sp.ru/

The bottom system allowed for minimal oscillations and, therefore, fewer disturbances to the fish. One advantage to this design is that cage capacity can be adjusted from 1,200 to 2,000 cubic meters. Table 5.1 lists the major characteristics of each capacity of the cage.

Table 5.1 Technical data SADCO-1200/2000.

Volume of net chamber	1200 m^3	2000 m^3
Output of production (max)	50 tons	80 tons
Volume of feed bunker	1500 l	2000 l
Height	12 m	16 m
Width	17 m	19 m
Weight	11 tons	12 tons
Main material	Steel	

Adapted from: http://www.sadco-shelf.sp.ru/

The SADCO 4000 model is one of the newest versions of the SADCO cage family (SADCO, 2001). This cage was developed for the culture of species in wind-exposed sea sites. This model, as with the other SADCO models, is protected by its underwater location. The SADCO 4000 allows for successful fish farming in areas with waves up to 15 meters. Its mooring system is characterized by high strength and low costs, and the underwater feeding system allows for regular fish feeding even during storms. Figure 5.2 depicts two views of the shape of the cage, and Table 5.2 lists its principal characteristics.

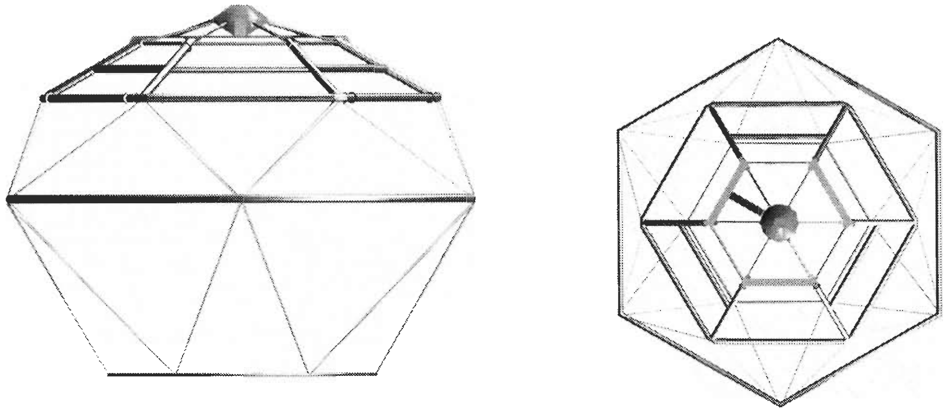

Figure 5.2 SADCO 4000 cage system.
Adapted from: http://www.sadco-shelf.sp.ru/

Table 5.2 Technical data SADCO 4000.

Volume of net chamber	4000 m^3
Output of production (max)	120 tons
Volume of feed bunker	4000 l
Height	20 m
Width	21 m
Weight	15 tons
Main material	Steel

Adapted from: http://www.sadco-shelf.sp.ru/

The SADCO family of cage systems provides fish farming conditions that are very close to the natural environment. According to SADCO (2001), their cage systems reduce diseases, increase fish appetite, and improve general physiological tone. These factors result in high-quality marketable fresh fish.

Ocean Spar Technologies, LLC, a company based in Washington State, manufactures the SeaStation^{TM} sea cage system. As stated by Ocean Spar Technologies, LLC (2001), this rugged system combines two simple and proven marine technologies: the floating spar and circular rim. The company states that the unique design of the SeaStation^{TM} sea cage is based on avoiding the forces from waves rather than opposing them. The SeaStation^{TM} cage can withstand continuous waves of over 7 meters, can be submerged and raised in 15 minutes, and can be easily towed to a new location. Loverich & Gace (1997) from Ocean Spar Technologies, LLC indicated that this cage system is classified as a Class Three self-tensioned and self-supporting cage able to hold its shape in the absence of gravity or anchor line tensions. This structure is then able to resist net deformations and safely contain the fish by minimizing motions. Figure 5.3 shows the relative dimensions of the SeaStation^{TM} 3000 cage.

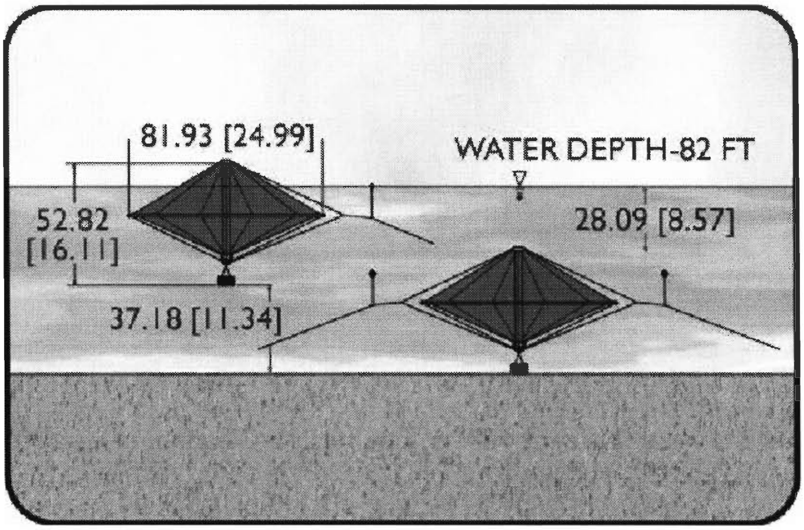

Figure 5.3 Ocean SeaStation^{TM} 3000.

Adapted from: http://www.oceanspar.com

Ocean Spar Technologies, LLC (2001) indicates that the frame of the SeaStation^{TM} sea cage is formed by a central floating steel spar 15 meters in length surrounded by a steel rim 25 meters in diameter (Refer to Figure 5.4). Taut netting is attached to the spoke lines. The net has zippered entries for easy diver access. Several netting materials are available depending on the customer's specifications. Ocean Spar also mentions that currents minimally affect the volume and shape of the cage, maintaining 90 percent of its volume in currents of one meter per second. This ensures a more productive growing environment for the fish. The taut netting panels reduce predator interaction with the fish and can allow for better water flow, promoting healthier fish.

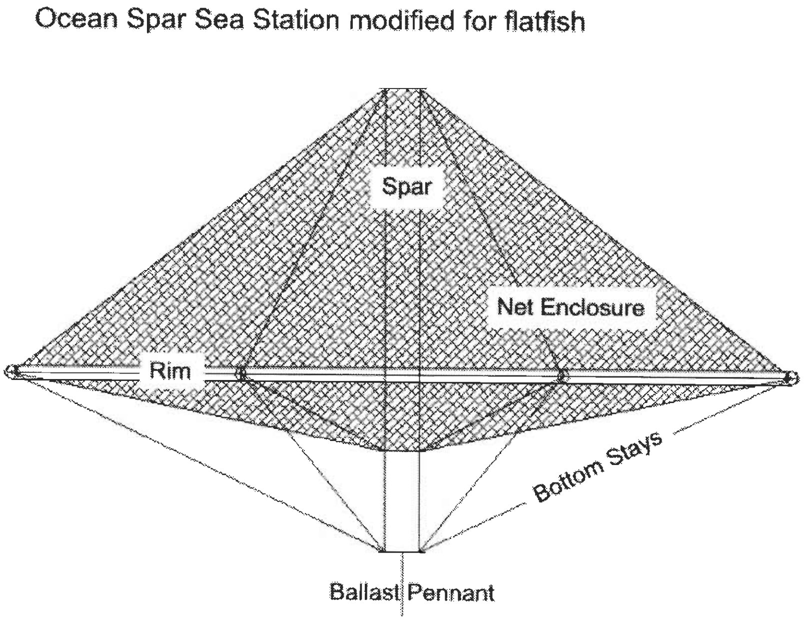

Figure 5.4 Ocean Spar SeaStation™ 3000 modified for flatfish
Adapted from: http://www.oceanspar.com

The OceanSpar Technologies, LLC (2001) website indicates that in severe weather, Sea Station™ can be submerged below the wave action. By varying the buoyancy of the spar, the system can be easily lowered and raised. Maintenance, feeding, and other operational tasks are accomplished from a stable work platform, known as the crow's nest. Towing the cage is facilitated by the rigidity and shape of the Sea Station™ cage. In addition, unfavorable growing conditions such as plankton blooms and low dissolved oxygen can be evaded.

Ocean Spar Technologies, LLC (2001) indicates that harvesting is accomplished by utilizing SeaStation's™ harvest ring that inverts the bottom net panels crowding the fish into a smaller area. Finally, the conical shape of the bottom of the cage assists in the collection of dead fish.

McVey and Treece, an aquaculture specialist, (1998) announced at the Third International Open Ocean Aquaculture Conference in Corpus Christi, Texas that commercial tests of the Ocean Spar SeaStation^{TM} system were carried out on three working farms. Loverich (1998) stated that these 3,000 cubic meter cages worked very well with productions for each cage of at least 255 tons of milkfish per year.

A single 3,000 cubic meter SeaStation^{TM} cage occupies 0.12 acre of sea surface. Loverich (1998) mentioned that the basic SeaStation^{TM} design may need to be adapted for a particular species, as is the case for anchoring systems for the summer flounder. The author also stated that past experiences operating from small open boats proved that SeaStation^{TM} can be utilized by smaller commercial ventures. Loverich concluded his presentation at the Third International Open Ocean Aquaculture Conference by stating that experimental evidence suggested that the SeaStation^{TM} is the best heavy weather sea cage available.

According to Greg Sangster from Ocean Spar Technologies, LLC, the SeaStation^{TM} 3000 cage system costs $90,000 (Refer to Appendix G). With the necessary technical support and labor to install the cage, the price increases to $110,000. Mr. Sangster indicates that other costs associated with the cage include $4,500 for shipping, and four five-ton anchors that cost between $700 and $800. The anchors are almost always purchased in the vicinity of the site location, as it is impractical to ship them. Ocean Spar Technologies, LLC does not sell the anchors, and they must be purchased from another vendor. It is also the responsibility of the customer to provide the necessary boats and equipment to transport, unload, and moor the cage.

Mr. Sangster also indicated that Ocean Spar Technologies, LLC is hoping that manufacturing cages in China may result in lower prices. He stated that stocking densities of the SeaStation^{TM} 3000 range from 10 to 30 kilograms per cubic meter depending on the species cultured. Mutton snapper can be stocked at a density of 15 to 20 kilograms per cubic meter. Mr. Sangster indicates that although the Ocean Spar cages seem expensive, they have a lifespan of ten years, including the netting. When this initial investment is distributed over time, the price is not nearly as substantial.

5.2 Species Selection for Offshore Cage Culture in Puerto Rico

Benetti, Clark, and Feeley (1998) described mutton snapper, *Lutjanus analis*, and red snapper, *Lutjanus campechanus*, as technologically feasible species for cage culture in the Gulf of Mexico with excellent potential. Snapper is a member of the Lutjanidae family and the Lutjanus genera (Nelson, 1994; Paxton & Eschmeyer 1995). The typical appearance of a snapper is a triangular shaped head and a moderately compact body (Bohlke & Chaplin, 1968). In general, snappers have large canine teeth. Nelson (1994) states that they can grow to a meter long. According to the Food and Agriculture Organization (1978), the coloring of snapper varies greatly among species, including yellow, red, gray, violet, and olive. There are typically blotches, lines, or some type of pattern on the body of the fish.

Snappers tend to inhabit the bottom of tropical and subtropical areas and have been found in waters ranging from shallow to 550 meters deep (Nelson, 1994; Paxton & Eschmeyer 1995). They can survive in brackish waters as well as open sea (Bohlke & Chaplin, 1968; FAO, 1978).

Describing snappers, Bohlke and Chaplin (1968) indicated that all snappers are predatory fish and often nocturnal. Snappers consume a variety of foods including crabs, small fish, demeral organisms such as crustaceans and fishes, and occasionally also cuttlefish and worms.

Paxton & Eschmeyer (1995) and Nelson (1994) have indicated that snapper is an important food fish, with different species varying from good to excellent flesh. Unfortunately, the authors also stated that snapper have been found to become poisonous, causing ciguatera, the tropical fish-poisoning disease.

A northern (*Lutjanis campechanus*) and southern (*Lutjanus purpureus*) variety of snapper exists. According to the FAO (1978), the northern and southern types are simply different variations of the same species. The northern red snapper can be found along the Atlantic Coast of the United States up to Massachusetts and in the Gulf of Mexico (FAO, 1878; Shipp, 1986). Southern red snapper is distributed from the southern coasts of Cuba and the Yucatan Peninsula throughout the Caribbean Sea to northeastern Brazil. These fish are most abundant on the continental shelf of Honduras and the Guyanas.

The coloring of the body of the red snapper is a deep rose red that becomes paler on the throat and then bluish streaks along the rows of scales above (Refer to Figure 5.5). Its fins are brick red, with the dorsal being orange with a black edge (FAO, 1978). The intensity of the color varies with the locality. As the fish grows older or is preserved, the coloring becomes lighter. The Food and Agriculture Organization (FAO) (1978) stated that red snapper found in Puerto Rico tend to have an overall paler color and a prominent black lateral blotch.

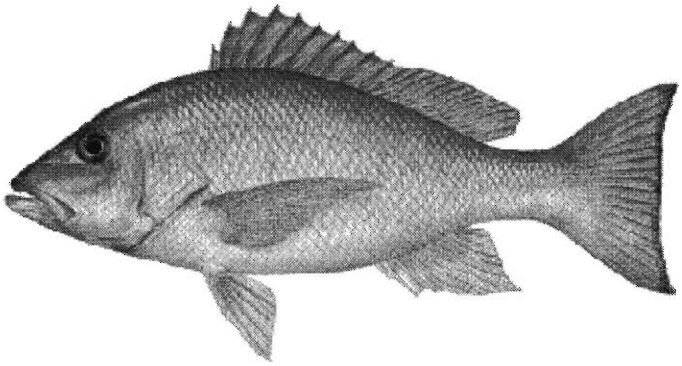

Figure 5.5 Red snapper, *Lutjanus campechanus*
Adapted from Red Snapper Conservation Association, http://rsca.org

Red snapper are commonly found to be approximately two feet long and rarely reach a meter in length.

Another species of snapper is mutton snapper (Refer to Figure 5.6), also known as Caribbean snapper (*Lutjanus analis*).

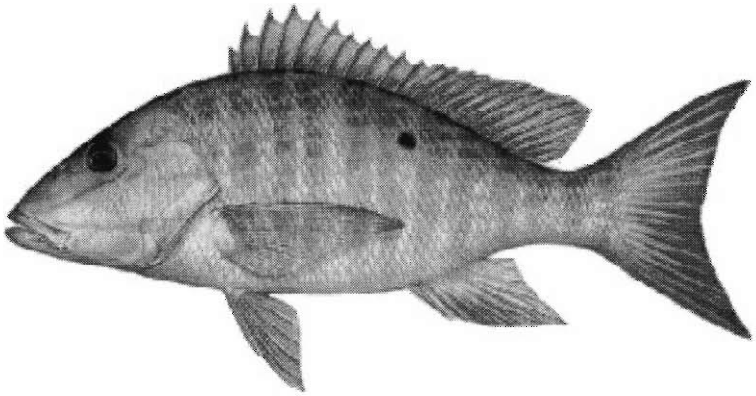

Figure 5.6 Mutton snapper, *Lutjanus analis*
Taken from Snapperfarms Inc. at http://www.snapperfarm.com

The Food and Agriculture Organization (1978) mentioned that this fish could grow to nearly 80 centimeters and a weight of 11 kilograms. It has pointed anal-fin lobes, black blotches between the anterior end of the soft dorsal fin, and fourteen segmented dorsal fin rays. Throughout its life, the mutton snapper has both plain and barred color phases. Usually the barred color phase is when it is at rest and then becomes nearly uniformly colored during swimming. Adults are olive about the lateral line and white with reddish overtones below. However, all of the mutton snappers' fins are red. There are blue lines and spots below, before, and behind the eye. The subdorsal spot is small and entirely above the lateral line (Paxton & Eschmeyer 1995; Nelson, 1994; FAO 1978).

Mutton snapper is typically found in tidal creeks surrounded by mangroves, in canals, and in shallow, protected bays with grasses covering the bottom. Its geographical range extends northward occasionally to Massachusetts and southward to southeastern Brazil. Mutton snapper is most abundant off the coasts of the Antilles, the Bahamas, and southern Florida. Nevertheless, mutton snapper has also been introduced in waters surrounding Bermuda (FAO, 1978).

Mutton snapper feeds on fishes and crustaceans, and, to a large extent, preys on small grunts. According to the Food and Agriculture Organization (1978), similar to the red snapper, the mutton snapper is considered a fine food fish, having flesh of exceptionally good quality.

Benetti *et al.* (1998) indicated that mutton snapper exhibits fast growth and high survival rates, is highly resistant to diseases, and has a high market value. Davis, Arnold, and Holt (1998) from the Marine Science Institute of the University of Texas in Austin, determined that based on predicted growth equations, mutton snapper will only reach a weight of approximately 200 to 300 grams in two years in the wild, but improved growth rates, however, were observed under culture conditions. Despite improvements in growth under controlled conditions, Davis *et al.* (1998) believe that a two to three year production period would be required to produce a fish weighing 500 to 1,000 grams.

Benetti *et al.* (1998) state that Watanabe and Benetti & Feeley have spawned and reared larvae in captivity. After four months in a hatchery, juveniles are suitable for stocking in offshore cages for growth. Watanabe in Benetti *et al.* (1998) reported that juveniles grew from a mean weight of 10.5 to 140 grams after 71 days in re-circulating seawater tanks stocked at densities of 41 fish per cubic meter. Thus, after 71 days, juvenile snappers can be transported from the hatchery to the cage system for stocking. Unfortunately, information on maximum stocking density, or the trade-off between stocking density and growth and health, is not available for many tropical species (Hambrey, 2000). Future research will be critical in providing this information for optimum stocking.

5.3 Previous and Ongoing Cage Culture Projects

Tamaru, Carlstrom-Trick, and Helsley (1997) stated that Hawaii, despite its mid-ocean location, imports more than 75 percent of its seafood. Since this rate is so high, Hawaii has been attempting to promote its aquaculture industry since the early 1980's. However, there have been many obstacles preventing its development. According to Tamaru *et al.* (1997), one of the main obstacles was the unavailability of a supply of post larval stock. Another problem was obtaining the permits required. These permits would take years to obtain and cost tens of thousands of dollars. Hawaii is not the only state that has this type of problem with permits for aquaculture. Tamaru *et al.* (1997) believe this occurs in numerous places, and if other aspects of food production were as severely regulated, the world would not have an overpopulation problem because starvation would have become rampant years ago. Another difficulty faced by Hawaii is the cost of importing all of the materials needed to implement and maintain an offshore aquaculture project. Hawaiian researchers also recognized that huge efforts are needed in order to develop aquaculture to an economically viable level.

During a semi-structured phone interview, James McVey (Refer to Appendix E) described the recent completion of Phase I of the Hawaii Offshore Aquaculture Research Project (HOARP) as a groundbreaking event in the offshore cage culture industry. He explained the involvement of National Sea Grant in this endeavor and stated that the project in Hawaii was very successful.

The Hawaii Offshore Aquaculture Research Project (HOARP) investigated the technical feasibility of offshore production of Pacific threadfin (*Polydactylus sexfilis*) or *moi* in a commercial-sized submersible Ocean Spar SeaStation™ 3000 cage in open coastal waters in south Oahu, 1.6 kilometers from the shore (Ostrowski, 2000). Dr. Anthony C. Ostrowski, program manager for Oceanic Institute, reported that the permit process began during the month of October 1998, and the cultured fish were harvested in by mid-October 1999. Results indicated that Pacific threadfin could be successfully stocked, fed, managed, and harvested under completely submerged conditions, 7 meters below the surface. As described by Ostrowski in the final report of Phase I of the project (HOARP, 2000), a total of 17,381 kilograms of fish weighing between 0.28 and 0.37 kilograms were harvested from the cage at a 82 percent survival rate, adjusted for initial stocking mortality. The report identified the transportation of the fingerlings to the cage as one of the critical areas for subsequent improvement. In addition, data obtained indicated that the use of discrete feedings improves feed conversion ratios. Also, several feeding and harvesting innovations were developed under this project. Ostrowski stated that most maintenance and daily tasks are still very labor-intensive and require skilled divers. Among the conclusions, the author indicated that market research is required to minimize the economic impact on local markets and improve prices for exports.

While Phase I of the Hawaii Offshore Aquaculture Research Project demonstrated the technical feasibility, it remains to be proven whether such operations are economically viable under commercial conditions. Ostrowski (2000) emphasized the need to further assess the effects of the cage culture activities on water quality as well as more detailed evaluations of the cage as a fish-attracting device. Nevertheless, this project was the first recorded successful attempt in the United States to raise a species of marine finfish to market size under completely submerged conditions in an offshore cage. The study in Hawaii has laid the groundwork for environmental permits, technical feasibility, and commercial viability for similar offshore cage systems.

In addition to the recent project in Hawaii, Helsley (1997) mentioned a thriving southern bluefin tuna operation in Boston Bay, South Australia, where more than 2,000 tons were raised in cages stocked with juveniles from the wild. Another example is the successful culture of salmon in offshore regions of Ireland where up to 300 tons of fish were produced in a single cage. Mihelakakis in Helsley (1997) examined the economics and cost breakdown of the production of fish in the Mediterranean region, citing several successful ventures. These and several other promising endeavors have promoted the growth of the open ocean aquaculture industry and attracted entrepreneurs to this potentially lucrative field.

CHAPTER 6: ENVIRONMENTAL ASPECTS OF OFFSHORE CAGE CULTURE

Introducing cages stocked with fish reared in hatcheries may have serious effects on the environment. Offshore cage culture operations must consider the effects these activities may have on the surrounding aquatic life. Problems range from the potential danger of water pollution to the dilution of the genetic pool when caged fish escape. Nevertheless, there have been studies that indicate that cages may attract and enrich aquatic diversity.

6.1 Detrimental Effects of Cage Culture on the Marine Environment

Chen, Beveridge, and Telfer (2000) indicated that since cages are essentially ecologically open systems, wastes produced are inevitably released into the surrounding environment. Benetti, Clark, and Feely (1998) stated that there have been problems related to environmental degradation associated with cage culture in coastal areas of countries including The Philippines, Norway, and Scotland. Nevertheless, these authors also mentioned that the environmental impacts at deep-water locations are usually insignificant. Benetti *et al.* (1998) indicated that contamination of sediments by metals, such as copper from copper-based paints used as antifouling agents and zinc, an important component of fish feeds also used in galvanized cage structures, would be negligible in an offshore environment due to the greater depth, strong water currents, and distance from shore.

According to Chen *et al.* (2000) studies of the environmental impacts of cage aquaculture have shown an increase in the levels of suspended solids, ammonia, organic nitrogen, and carbon. Also, a decrease in dissolved oxygen concentrations was observed near the cages. Bautista & Andrade (1997) studied the quality of the sediments directly beneath cages installed in an offshore fish farm near the Madeira Archipelago. Results indicated a considerable waste load beneath the cages, but with no major impacts on the sediments. According to Bautista & Andrade, the waste mainly consisted of feces, rather than uneaten feed pellets, and the organic carbon content was not significantly higher than the values found for adjacent clean sediment areas.

Benetti *et al.* (1998) indicated that proper management should avoid the use of chemical pollutants while improving growth and feed conversion rates. This requires minimizing wastes due to excessive excretion, uneaten feeds, and feces. Benetti *et al.* indicated that inevitably a limited amount of nutrients and solids will be released from the cages, but excessive growth or eutrophication is not a threat in areas surrounding the offshore cage systems since the carrying capacity of the offshore environment is usually able to assimilate limited amounts of organic and inorganic pollutants. Nevertheless, the authors warn that the natural productivity of the surrounding waters may be expected to increase, and, therefore, periodic environmental assessments of offshore cage culture sites are required. Chen *et al.* (2000) and Helsley (1997) called for more empirical data to refine existing models in order to predict the fate of nutrients and their influence on the marine environment. New modeling efforts could be used to establish appropriate carrying capacities for offshore areas. These models may be then interpreted to establish guidelines for acceptable environmental impact criteria (Helsley, 1997).

6.2 Positive Effects of Cage Culture

According to Joseph McElwee (1998), the managing director of Turband Iarthar Chonamara Teo. in Galway, Ireland, the offshore cage culture industry suffered severely in the early days of its development due to misinterpretation and incorrect information in the media. This hindered the development of the industry and caused many environmentalists to become anti-fish farming. Some of the perceived problems with cage culture include competition for water space, potential conflict with other forms of wildlife, water pollution, inhumane keeping of large numbers of animals, and the dilution of the genetic pool due to escaped fish. Michael De Alessi (1998), of the Center for Private Conservation in Washington, D.C., indicated that offshore cage culture does not create pollution, but rather provides protection against it. The industry not only monitors the waters, but also creates a collection of oceanographic data.

De Alessi (1998) discussed that coral reefs have been severely overfished and are in very poor condition. However, frequently there are as many fish outside an aquaculture cage as inside, which has put aquaculturists in the artificial reef business. Reports of the project in Hawaii support this opinion (Ostrowski, 2000; Ako, Appendix J). De Alessi further stated that in order to secure tenure for offshore aquaculture, much of the challenge will be to discuss the problems that exist for aquaculture, to emphasize the benefits of conservation, and to seek allies within the industry.

CHAPTER 7: POLITICAL ASPECTS OF OFFSHORE CAGE CULTURE

The issues of tenure of the site and liability have considerable political implications. Permits are necessary in order for aquaculture to be implemented. Appropriate government agencies delineate the regulations that offshore cage culture operations must abide. Nonetheless, the lack of appropriate laws specific for cage culture hinder the development of the industry. In addition, property rights to designated sites for cages will determine the quality and success of such an operation. Consequently, the study of the legislations affecting similar offshore aquaculture projects is of crucial importance.

7.1 Exclusive Use of Waters for Offshore Cage Culture

Daniel A. Curran (1997), senior researcher for Woods Hole Oceanographic Institution in Woods Hole, Massachusetts, indicated that the site-specific nature of offshore cage culture operations requires some form of property right to designated areas of ocean space, similar to those rights granted to offshore oil, gas, and mineral resources developers. Without such a guarantee, Curran believes that other users, such as commercial and recreational fishermen, will invariably intrude upon mariculture. This author indicated that no policies providing security of tenure exist for mariculture operations.

Helsley (1997) indicated that two types of ownership exist: exclusive ownership, in which rights of access by others can be excluded; and multiple use ownership, in which other users, such as sport fishermen, continue to have access to the site. Ideas ranging from leases from the controlling state to direct ownership of the farm site have been proposed. Victoria Rechntenwald (1997) emphasized the obligation to ensure that all structures placed in oceans respect the interest of local populations when being exploited by non-locals and the need to preserve the ocean's resources for populations distant in time and space.

According to Hayden (1997), obtaining permits has been and will continue to be a difficult process because state and federal agencies have not yet developed regulations that specifically address offshore cage culture. At this time, there is little guidance on how to proceed, and regulatory agencies are hesitant to take action on requests for offshore cage culture due to the lack of a legal framework (Curran 1997; Hayden 1997; McVey, Appendix E). De Alessi (1997) agreed that the issue of marine tenure is essential to the offshore cage culture industry. He further stated that the legal and social organizations that define marine tenure will delineate the rules of the industry, and these rules will affect and possibly determine the manner in which every other challenge will be addressed. According to Curran (1997), without some form of lease guarantee, the availability of investment capital for offshore cage culture will be limited and will, therefore, hinder the development of the industry.

Currently, the United States has exclusive economic zones, where the government has absolute rights for the purposes of exploring, exploiting, conserving, and managing both living and non-living natural resources of the seabed, subsoil, and ocean waters. Curran (1997) indicated that it has been proposed that offshore cage culture be an alternative to traditional fishing existing in these exclusive economic zones. There are no specific policies in the United States that govern the use of the exclusive economic zones for offshore cage culture. In particular, there are no policies providing security of tenure for these types of operations. For example, in 1992, a Marine Board Committee of the

National Research Council examined opportunities for growth in offshore cage culture in United States federal waters (Curran, 1997). The Committee concluded that no formal framework exists to govern the leasing and development of private commercial aquaculture activities in public waters. Currently, mariculture permits are proceeding on an *ad hoc*, or impromptu, basis.

The United States Ocean Dumping Act allows the deposit of materials for the purpose of developing, maintaining, or harvesting fisheries resources (Curran, 1997). Nevertheless, this most likely does not cover fish food waste or disease preventative drugs, which are necessary parts of an offshore cage culture operation.

According to Curran (1997), the systematic approach to the design of an access system for United States offshore cage culture should include two main points. The first point is a legal description of the ocean space. The second is the establishment of priorities and policies that include property rights, revenue generation, performance requirements, information management, environmental protection, and fairness considerations.

The issue of private ownership must also be carefully considered. According to De Alessi (1997), it is the single most important predictor of resource productivity and conservation. De Alessi also stated that technological innovation will be a critical factor in the development of an offshore aquaculture industry, and private ownership is what will drive much of this technological advancement. An example of how innovation and private ownership are related is Washington State's oyster industry. Washington is the only state in the United States that leases subtidal lands for a fee, and the oyster industry there has been highly innovative. This industry has been able to withstand a decline in the native oyster, cope with serious pollution problems, and has introduced new varieties to Washington. This is quite different when compared to Maryland, which has relied on the state to manage their production and consequently has had declining harvests (De Alessi, 1997). De Alessi believed the reason for the decline is that the cage culture employees were more interested in government-sponsored bailouts and subsidies for oyster bed maintenance than in taking steps to improve their harvest. However, in Maryland, there is opposition to the system used in Washington by people who are either doing well or do not believe that they will be better off under a new system. Therefore, it is critical for the offshore aquaculture industry to demand secure tenure arrangement from the beginning. De Alessi believes offshore aquaculture entrepreneurs should fight for leases that last as long as possible and for a minimum of political or regulatory intervention.

While political assistance is often an attractive opportunity, especially for a growing industry, De Alessi (1997) insists that it is generally detrimental in the long run. Maintaining financial support and beneficial regulations requires constant attention. It also creates an outlook for the future filled with uncertainty, and there is always the potential for a reversal of fortune. An example of how political assistance is not always beneficial occurred in an open ocean abalone farming company called Pacific Ocean Farms Ltd. that was located in California. The company leased approximately 50 acres, 2.5 miles offshore of Monterrey and used fiberglass boxes called condominiums to raise abalone. Business was prospering until the State of California intervened. First, the government rejected a proposal to increase the number of abalone condominiums because they did not have garages. Clearly, this is using the literal definition of the term condominium against the company. Next, all of the company's divers were required to use the same gear required of oil rig welders, which would be costly to do and was unnecessary. Finally, according to the owner of Pacific Ocean Farms Ltd., the State forced the company to reveal its trade secrets in order to renew its permit. Then, the State created its own hatchery system. Due to all the purported difficulties the company encountered, it is not surprising that Pacific Ocean Farms Ltd. no longer exists (De Alessi, 1997).

There is also an environmental issue involving the secure tenure of ocean waters. The focus of the attention of environmentalists on aquaculture is the issue of pollution and habitat destruction. However, secure ownership arrangements can address these problems as well. Aquaculture operations not only create some pollution, but are subjected to the effects of it as well. The industry depends on clean water in order to produce a quality product. According to De Alessi (1997), the creation of an aquaculture operation also ensures monitoring of the environmental quality of the site.

Furthermore, concerning the issue of liability, De Alessi (1997) insisted that statutes and regulations are one way to impose liability and costs on producers, but another more effective method is to increase ownership rights and rely on the current legal system to resolve conflicts.

7.2 Permits and Regulations Required for Aquaculture Operations

As stated in the previous section, the present permitting and regulatory environment for marine aquaculture in the United States is a major limitation to its development. According to Mr. Richard DeVoe (2000), from the South Carolina Sea Grant Consortium, there are currently as many as eleven federal agencies having direct involvement in aquaculture and ten others indirectly involved. In addition, fifty statutes exist that have a direct impact on aquaculture, as well as over 120 statutory programs that significantly affect aquaculture development.

However, DeVoe (2000) stated that only a limited number of permitting and licensing requirements are directly enforced by federal agencies. Rather, federal agencies often delegate the responsibilities to state agencies. Therefore, the majority of laws and regulations that authorize, permit, or control aquaculture are usually found at the state level. DeVoe also claimed that state regulatory programs are often more restrictive than federal guidelines and regulations enforced. The federal agencies, which establish the ground rules that the state agencies must follow, have created vague, confusing, and poorly formulated regulations, or none at all. This has produced inconsistencies in the development and application of regulations at the state level and has lead to the lack of uniformity that currently exists.

The complexity, DeVoe (2000) explained, is the result of the involvement of numerous federal, state, and local agencies responsible for marine aquaculture. This has led to an array of planning acts, policies, and regulations. Federal laws are applied differently in various geographic regions of the country, and the industry remains concerned about the lack of coordination. A deficiency in future and long-range planning also exists. In general, every permit or license is prepared on a case-by-case or *ad hoc* basis. This also means that each permit or license is considered individually by the issuing agency, and there is rarely any thought about the possible cumulative impacts (DeVoe, 2000.)

Another issue, according to DeVoe (2000) is that most local land use planning and zoning ordinances fail to acknowledge aquaculture as a legitimate land use, while those that do are not consistent with their classifications of aquaculture. Aquaculture has been classified as an industrial, commercial, and agricultural operation.

Aquaculture operations require high-quality water locations and protection from external pollution discharges. Therefore, they rely on the proper enforcement of pollution laws. The two major classes of pollutants that result from aquaculture facilities are organic materials and chemicals. Regulations by the Environmental Protection Agency provide exemptions from effluent discharge requirements under certain conditions. Nevertheless, DeVoe (2000) stated that these regulations are interpreted and enforced in varying degrees by different states.

Next, the area of aquaculture species must also be updated, DeVoe (2000) believes. So far, regulations specifically for cultivated species have not been developed. However, government agencies have placed restrictions on methods of harvest, sizes, and seasons for freshwater and marine species. Permits, licenses, and certifications may be required for fishing, harvesting, and equipment use, possession of, and packaging, selling, and transporting the animals (DeVoe, 2000).

Aquaculture facilities and hatchery management must adhere to regulations that, according to DeVoe (2000), are necessary in order to ensure the production of high-quality, disease-free product. Different state governments may also require permits or licenses to operate a fish or shellfish hatchery. In addition, some jurisdictions require fish breeding licenses and permits for acquiring wildstock for spawning. Finally, the importation of eggs, larvae, or fish may require certification of freedom from disease or parasites. The Occupational Safety and Health Administration regulations cover the safety of the workers and health issues. Nevermore, the unique aspects of aquaculture are not acknowledged (DeVoe, 2000.).

According to DeVoe (2000), the area of drugs, chemicals, vaccines, and pesticides is highly regulated by the government. Any drugs or chemicals used on food fish must be registered and cleared with the United States Food and Drug Administration (FDA). Similar to permitting, this too is a costly and time-consuming process. This along with the small market for the chemicals has lead to few drug manufacturers taking the time to register the products. Therefore, it is not surprising that only a few drugs or chemicals have been approved for use. Vaccines are regulated by U.S. Department of Agriculture and must be certified separately for each species cultured. The U.S. Environmental Protection Agency (EPA) regulates pesticides, herbicides, and any other chemicals used for predator control (DeVoe, 2000).

The processing and sale of aquaculture products is also critical. DeVoe (2000) claimed that some governments have policies that exempt the aquaculture industry from minimum size and weight requirements, which provide marketing advantages to the aquaculture industry. Regulations that aquaculturists may face include licensing, operational, and labeling requirements, administered by the U.S. Food and Drug Administration with the intention of informing and protecting the consumer. Nonetheless, uniform standards throughout the industry are needed. A federal seafood inspection program using the Hazard Analysis Critical Control Point (HACCP) methodology has been implemented for seafood and aquaculture operations.

Aquaculturists must be aware of the rules and regulations that they may have to follow when obtaining financing. As with any business, there are regulations in place for investment, financing, taxation, marketing, and insurance.

Although the federal government does not control the permitting or regulating process as much as individual state governments, there are a few federal agencies that have an important effect on the aquaculture industry. The first is the U.S. Army Corps of Engineers (ACOE), which has had the assignment of regulating waterways in the United States since 1890. DeVoe (2000) stated that through the years, the focus of their regulatory activities has shifted from protecting navigation to the consideration of the public interest for the protection and utilization of water resources. The ACOE has jurisdiction over the obstruction or alteration of navigable waters under Section 10 of the Rivers and Harbors Act of 1899. A Section 10 permit is required for all prospective culturists whose operations involve the placing of a structure in navigable waters (DeVoe, 2000.)

Next, the Environmental Protection Agency (EPA) has statutory authority on all permits that fall under Section 404 of the Clean Water Act. Nevertheless, administrative responsibility has been given to the ACOE on behalf of the EPA. A Section 404 permit is required for any activity that involves the discharge of dredge or fill material into navigable waters. Also, the EPA regulates effluent discharges into U.S. waters, in order to ensure that aesthetic and recreational quality are maintained and improved. DeVoe (200) stated that the EPA has created the National Pollutant Discharge Elimination Systems (NPDES), which requires that anyone discharging wastewater into U.S. waters apply for a discharge permit. NPDES regulations are generally administered at the state level for aquatic animal production facilities, which are defined for warm water species as aquatic animals in ponds, raceways, or similar structures that discharge 30 days per year. However, this does not include closed ponds that discharge only during periods of excess run off or facilities that produce less than 100,000 pounds of product per year (DeVoe, 2000.)

The Federal Insecticide, Fungicide, and Rodenticide Act is also under the EPA and regulates the use of pesticides. There is currently no formal permit for this, but the use of unregistered chemicals by a culturist could result in penalties and severe fines. Some chemicals even require application only by a professional who must be registered with the EPA (DeVoe, 2000)

Another important federal agency is the National Oceanic and Atmospheric Administration (NOAA) Office of Ocean and Coastal Resources Management. NOAA created the Federal Coastal Zone Management Act of 1972 (CZMA), which has jurisdiction of any aquaculture operation located within the coastal zone of the United States. CZMA has funds provided to states and territories to develop and implement coastal management programs (CMP). The latter are comprehensive state programs that were designed to identify and protect coastal resources and minimize any environmental impacts associated with activities proposed within the coastal zones of the state. In 1996, the CZMA was amended to include a new authorization for states to use a portion of their CZMA funding for the adoption of procedures and policies to evaluate and facilitate the site selection of public and private aquaculture facilities in the coastal zone. This revision enables states to develop, administer, and implement strategic plans for marine aquaculture. According to DeVoe (2000), only a handful of states have taken advantage of this opportunity.

The U.S. Fish and Wildlife Service (FWS) is a lead agency for several laws and permits that affect the aquaculture industry. FWS is also the main agency in issuing the Fish and Wildlife Import/Export License, which is required for any person who imports or exports animals with a value exceeding $25,000 per year for purposes of breeding or sale. It takes 60 days to process an application, and there is a license fee of $125 per year and $25 for each import or export. A completed "Declaration for Importation or Exportation of Fish and Wildlife" clearance form must also be completed and submitted to the FWS inspector at the port of entry for approval, required to obtain a shipment release from the U.S. Customs Service.

Based upon the Federal Food, Drug, and Cosmetic Act of the FDA, use of drugs as additives in feeds as well as drugs for the treatment of diseases and parasitic infestations in aquatic animals sold for human consumption must be regulated. DeVoe (2000) stated that very few approved drugs are available for culturists to use to fight disease caused by bacteria, viruses, parasites, and fungi. The drug itself must be approved by the FDA based on the research conducted by the manufacturer. The use and dosage of the drug must be approved for aquaculture applications. Misuse of drugs can result in serious fines, as well as products being declared unfit for human consumption or products being confiscated from the market. There is an Investigation New Animal Drug (INAD) exemption to ease the approval process for "minor use" compounds in major agricultural industries. The FDA has recently tightened the requirements for INAD due to a concern over the effects on public health and lack of a drug residue-monitoring program for the aquaculture industry.

DeVoe (2000) stated that jurisdiction over aquaculture related issues is divided among several congressional committees as well. Under the Senate, the following committees are involved: Agriculture, Nutritional, Forestry, Commerce, Science, Transportation, Energy and Natural Resources, Environment and Public Works, and Labor and Human Resources. Under the House of Representatives, the following committees are implicated: Agriculture, Commerce, and Resources. Each of these committees has different mandates and responsibilities, which may overlap at times, and each has its own agenda and perspective. Once again, reaching agreement on issues has proven difficult, and the situation in general has not changed significantly over time.

The federal government has attempted in the past to assist the aquaculture industry. The National Aquaculture Act of 1980 was passed with the objective of promoting aquaculture in the United States. The plan was to accomplish this through a declaration of a national policy and the development and implementation of a National Aquaculture Development Plan. The Plan conferred the responsibility for the development of aquaculture to the private sector, but also assigned responsibilities to three federal agencies, the Departments of Agriculture, Commerce, and of the Interior.

The National Aquaculture Act also created the Joint Subcommittee on Aquaculture (JSA), which serves as a federal interagency coordinating group to increase the overall effectiveness and productivity of federal aquaculture research, technology transfer, and assistance programs (DeVoe, 2000). The JSA currently receives no direct funding. Thus far it has created one version of a National Aquaculture Development Plan in 1983. The 1980 act was reauthorized in 1998 as part of the Farm Bill. As noted by DeVoe, the recent failure of legislation explicitly extending and funding the 1980 act suggests that difficulties persist in seeking a consensus on a government policy for aquaculture.

The future of marine aquaculture in the U.S. greatly relies on the improvement of the permitting and regulatory system. Problems are apparent not only at the federal level, but at the state level as well. Progress is occurring throughout the country; however, it is at a slow pace. The federal government is currently in a conflict of interest position. On one side, it acts as the enforcer of laws through regulatory requirements aimed at protecting consumers, natural resources, and the environment. On the other side, it plays the role of administrator of programs that support and promote the growth of the industry. This resulting tug-of-war is further complicating the development of the industry.

DeVoe (2000) felt that there are three steps that need to be taken in order to improve upon the current situation. His first recommendation was to re-evaluate and reaffirm the nation's aquaculture policy. DeVoe claimed that the United States continues to look to the coast and ocean for recreation, tourism, and other economic pursuits rather than for aquaculture. There exists an idea of "why change when we can import seafood from overseas?" Therefore, the United States must carefully assess the current situation and decide whether it wishes to aggressively pursue a policy that actively promotes the aquaculture industry. Without a strong commitment and leadership by the government to work toward this goal, future development of the aquaculture industry will be difficult to attain. Finally, DeVoe felt that the role of the JSA needed to be strengthened. JSA's current functions are to coordinate activities and improve communication among different agencies involved in the regulation of aquaculture operations. The JSA presently functions without a budget, active participation by several of the member agencies is inconsistent, and there is no formal voting structure or dispute resolution process in place. The current status of the JSA needs to be expanded to include policy development and implementation. DeVoe also claimed that there is a need for a stable source of funding and staff assistance in order to improve coordination and consistency of policy development and implementation. It would also be beneficial if the JSA included the involvement of key representatives from the marine aquaculture industry. As suggested by DeVoe, one of the JSA's goals should be to design a streamlined planning and permitting framework for marine aquaculture activities in the coastal waters of the nation. Emphasis should be placed on coordination between state and federal agencies in addition to the marine aquaculture industry. Development of a management and regulatory framework for offshore aquaculture activities in consultation with all relevant federal and state agencies should also be a goal of the JSA. Finally, DeVoe suggested that the JSA should conduct an assessment of all current federal funding programs to determine the nature of activities and assess whether they are meeting the needs of the industry and the public.

Due to the Commonwealth status of Puerto Rico, additional specific regional regulations exist. For example, the Department of Natural and Environmental Resources (DNER) of Puerto Rico (2000) revised the regulations for fishing activities on the island in October 23, 2000. Article 16 indicates that all solicitants of an aquaculture permit must submit a proposal that clearly describes the characteristics of the site and potential impacts associated with the project (DNER, 2000). Proper statistics regarding the quantity and species cultured are required and can be examined at any time by authorized DNER representatives. All operations must conform to the United States Coast Guard regulations for proper lighting and signaling for vessels in federal waters. In addition, Article 16 guarantees a protected zone of 60.6 meters around each cage in which diving is prohibited by unauthorized people, fishing is restricted, and securing a vessel to the cage or anchoring unauthorized boats is illegal (DNER, 2000).

The regulation also states that if monitoring indicates a serious water-quality problem or detrimental environmental condition, the aquaculture operation must be adjusted accordingly to reduce the impact (DNER, 2000). The article suggests modifying the amount of feed applied, fish densities, or the distance below the cages to promote appropriate water circulation. Section three of the article states that a pre-operational environmental inspection of the site is required, as well as a monitoring program during operation (DNER, 2000). Results must be submitted in a report to the Department. The assessment of the site intends to monitor potential changes in the quality of the water and sediments as a result of the aquaculture operation. The frequency of the monitoring program and the protocols and procedures used must be approved previously by the DNER. Finally, Article 16 indicates that a daily summary of the number of incidental deaths of wildlife around the aquaculture operation must be presented on the tenth day of each month. Deaths of endangered species must be reported immediately to the Department. The regulations of the Department of Natural and Environmental Resources of Puerto Rico attempt to maintain the safety of the environment as a result of the activities of the aquaculture operation in addition to protecting the site from vandalism. The environmental monitoring program imposed by the Department, although frequently costly and time-consuming, is very useful, for it can help predict environmental problems that may severely affect the health of the fish cultured in the cages. Hence, it is strongly encouraged that operations abide by these regulations since failure to do so will result in a fine. Knowledge of these laws and regulations is critical for the success of any aquaculture operation.

CHAPTER 8: SOCIOECONOMIC ASPECTS OF OFFSHORE CAGE CULTURE

Cage aquaculture produces high-value fish for human consumption, generates many direct and indirect jobs, and provides social benefits. An offshore cage culture operation encompasses numerous activities including construction, engineering, manufacturing, management, legal, and research & development positions. Thus, employment opportunities are created that require skills ranging from entry-level to professional positions. Additional jobs are generated in processing plants, feed mills, ice plants, cold storage plants, and in companies involved in the transportation and distribution of the product and raw materials. The labor requirements of offshore cage culture operations create the need to consider the social implications and concerns of implementing a technology that both directly and indirectly affects so many people. For example, the interactions among fishermen, divers, boat operators, administrative staff, and processing plant employees are crucial to the efficient operation and success of a fish farm. In addition, the cost and economics of the operation of an offshore cage system are determined by the labor and equipment needs. The following sections discuss the pricipal socioeconomic concerns of such a venture.

8.1 Social Considerations Regarding Cage Culture

Braginton-Smith & Messier (1998) believe that the major concern of the operators of an offshore facility involves monitoring and security, since these facilities represent a large capital investment. Thus, the investment must be protected as much as possible. Access to the offshore cages is difficult and nearly impossible during periods of inclement weather. This is very different from inshore facilities where access and inspection are possible at all times. An additional security concern includes possible collisions with other vessels, both shipping and fishing. Further issues include intrusion by marine mammals, such as whales, human intrusion, and monitoring concerns. In addition to security concerns and environmental monitoring, there are many other factors of which an aquaculture technician must be aware.

8.1.1 Training Required for Cage Maintenance

As described by the New Brunswick Community College (NBCC) (2001), in New Brunswick, Canada, duties of an aquaculture technician include raising fish eggs and young fish, maintaining optimal water quality, practicing disease prevention, analyzing growth and production data, harvesting fish from cages or ponds, installing and maintaining pumps, filters, and other related equipment, operating fishing vessels to transport feed to site, designing and constructing cages, pens, and tanks, and SCUBA diving to inspect equipment.

According to NBCC (2001), people interested in the aquaculture industry should be dedicated and reliable, responsible and self-disciplined, be mechanically inclined, physically fit, not afraid of the sea, possess skills in biology and mathematics, and a willingness to work long hours. NBCC reported that the jobs that are available in the field of aquaculture include sea farm attendants, oyster growers, fish taggers, shellfish harvesters, fisheries technicians, hatchery workers, feed production workers, sales and marketing, and operators of a fish farm. The average starting salary for aquaculture technicians is between $18,000 and $25,000 per year (NBCC, 2001).

According to Gary Loverich (Refer to Appendix L), chief engineer of Ocean Spar Technologies, LLC, the only training that would be required for offshore cage culture would be a week of work with someone who is familiar with the practices of the operation. The divers must be very well trained, but the workers that maintain the cage and care for the fish would not need a rigorous training program.

Sebastian Belle (Refer to Appendix K), of the Maine Aquaculture Association, further discussed the training and education required for offshore cage culture. He stated that aquaculture and cage culture curricula are primarily based on some sort of ground experience. He emphasized the fact that many people obtain their bachelor's or master's degree thinking that they have the expertise to run an aquaculture facility. He remarked, however, that the best way to approach the offshore cage culture industry is to start in the trenches, and work from the ground up. Mr. Belle stressed that work experience based on a strong education is vital to success. He added that not many college programs offer guidance on production practices and planning or physiological impacts. Emphasizing the importance of work experience, Sebastian Belle stated that most of the information learned is theoretical and does not apply to the real world, especially when species, location, and other factors change in any type of aquaculture operation. However, in order to gain the technical knowledge necessary for offshore cage culture, some type of formal education will be necessary.

The curriculum offered at the New Brunswick Community College (2001) covers topics such as general aquaculture, the biology of fish, water quality, water treatment, hatchery culture, sea cage culture, fish disease, disease prevention and treatment, feeding and nutrition, spawning, grading, transporting, harvesting, aquaculture equipment, maintenance skills, basic accounting, economics and marketing, and boating skills. The programs at this college allow students to gain experience through fifteen weeks of on-site industry training. Students are strategically placed in this program in order to become familiar with different operating cycles of the aquaculture industry. These courses last approximately 48 weeks, beginning in September of each year. Admission to this program requires a high school or equivalent diploma (NBCC, 2001).

The Institute of Aquaculture (2001) at the University of Stiring, in Scotland, has had a graduate aquaculture program since 1976. This program is designed to train students in areas such as fish and shellfish biology, husbandry, systems design and economics, extension techniques, and environmental management necessary to establish, manage, and appraise aquaculture enterprises and development projects (Institute of Aquaculture, 2001). Figure 8.1 depicts the jobs that graduates from the Institute of Aquaculture have pursued. These occupations range from fish farmer and fishery department to development work (Institute of Aquaculture, 2001).

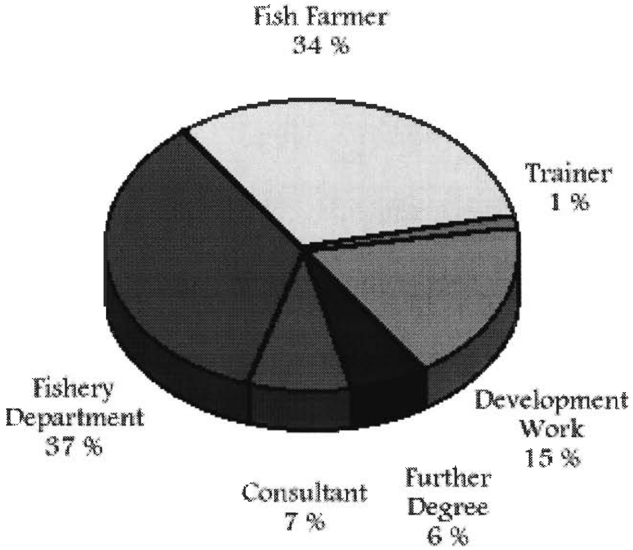

Figure 8.1 Jobs pursued by graduates from the Institute of Aquaculture at the University of Stiring, Scotland

Source: Institute of Aquaculture at the University of Stirling

The University of Stirling also has a program to teach short courses, provided there are at least eight people interested in a given subject. In recent years, short courses have been offered in areas such as aquaculture extension, fish diseases, and computers in aquaculture. A professional group looking to update its skills or learn something new about a specific aspect of aquaculture, such as offshore cage culture, should contact the University of Stirling to discuss their training needs and suggest a short course (Institute of Aquaculture, 2001).

8.2 Economic Considerations for Offshore Cage Culture

Capital and operating costs are highly variable and, according to Lawson (1995), these costs could be greater than similar-sized land-based systems depending upon cage sizes, species cultured, and local conditions. For instance, McElwee (1997) stated that the fluctuating price of fish in domestic and international markets has an effect on total costs and profit margins. The author mentioned that cages, nets, ropes, chains, moorings, ancillary equipment, feeds, staff, medications, vaccines, licenses, fingerlings, net-washing and repair facilities, and insurance fees are indeed financial considerations that contribute to the huge initial start up costs that frequently do not qualify for grant aid. Nevertheless, Lawson argued (1995) that cage culture is the most economical means of culturing such species as salmonids, yellowtail, and grouper in marine waters, and might be a comparatively profitable means of producing other species.

Cage design depends on a number of factors including fish species, environmental conditions, costs, availability of materials, and management skills (Lawson, 1995). McElwee (1997) stated that the most important feature of the cages will be how they are moored, which in turn is dependent on sediment type, previous mooring experience, average weather conditions, actual type of mooring used, depth of water, and equipment available. Cage design and features will determine the price of the cage system and the cost of installation and maintenance.

Helsley (1997) indicated that the problems facing the commercialization of offshore cage culture include stiff regulations, lack of funding, and the perception of many policy makers that when the economics are right, the technology will be developed by private industry. In the meantime, the fish stocks continue to decline. Therefore, pilot scale tests will be necessary to prove new technologies and encourage development and implementation of offshore cage culture. Finally, McVey (1997) believes it is necessary to integrate offshore aquaculture with existing fishing operations in order to maximize and optimize seafood production.

Helsley (1997) stressed the importance of evaluating local and regional economic cost/benefit ratios of full-scale development. In addition, he emphasized the need to investigate the environmental effects of the accidental release of fish from offshore aquaculture systems.

McVey (1997) stated that the world population is expected to reach 8.3 billion by the year 2025, and the seafood demand based on population alone would be nearly 162 million tons or roughly twice the amount that is available today. He also added that worldwide aquaculture production increased nearly 230 percent from 1985 to 1994. However, McVey was concerned that too much production of one species could lead to a rapid decline in market value. For example, species such as sea bream, sea bass, hybrid striped bass, and salmon have suffered declines in market prices by as much as 50 percent due to excess production.

Braginton-Smith & Messier (1998) indicated that market conditions for finfish products in the United States were very competitive. The authors believe that as aquaculture expands into developing nations, this competitiveness is expected to increase.

Braginton-Smith & Messier also believe that the costs involved in purchasing, maintaining, and operating offshore cage culture facilities are higher than that of inshore facilities. The authors therefore believe that future offshore aquaculturists will need to explore new and novel ways for reducing costs and increasing productivity.

8.3 Previous Economic Analyses of Offshore Cage Culture Operations

James McVey & Granvil Treece, aquaculture specialist, (1998) summarized and discussed the events that took place at the Third International Open Ocean Aquaculture Conference in Corpus Christi, Texas May 10-15, 1998. Although this information is unsubstantiated, it does provide a valuable reference for comparisons of the economic competitiveness of various offshore cage culture operations.

According to McVey and Treece (1998), one speaker discussed the expenses associated with offshore aquaculture, indicating that a minimum production level of 200 tons of finfish per year were necessary for a venture to appear worthwhile, and that it would have to include a hatchery producing an estimated 100 tons annually to reach the break-even point. They indicated that such a project would require a minimum production of 18.5 kilograms of fish per cubic meter sold at $10 per kilogram of fish. McVey & Treece also mentioned that in Japan, flounder production had reached 45.5 kilograms per square meter. Another speaker at the conference indicated that a minimum capital investment of $1.5 million with an estimated annual operating cost of $2 million would be required for a hatchery to support an offshore project.

McVey & Treece (1998) reported that it was suggested that an entire offshore project would cost $7.5 million, with a startup cost of $2 million for the base, $1.1 million for the hatchery, and $2.5 million for the offshore operation. The speaker estimated that twenty to twenty-five people would be employed with a payroll of approximately $1 million per year and $2.2 million per year in operational costs. The speaker added that two large boats would also be required. According to McVey & Treece, an estimated 2.5 to 5 percent of the feed used is not consumed by the fish and unnecessarily wasted. The authors also estimated that a processing plant must process 5,000 tons of fish annually to be economically viable.

McVey & Treece (1998) reported that tenure is critical to the success of private aquaculture in the coastal zone. They indicated that one participant at the Third International Open Ocean Aquaculture Conference advised starting at the market price and determining a species with a profit margin that would allow for mistakes. He also cited the importance of personnel, human management, and the development of a farming production plan with a sensitivity analysis. This speaker, according to McVey & Treece, emphasized the fact that as investment in rearing volume increases, less profit is produced. In addition, the authors added that transportation costs play an important role in the success of a commercial venture and stressed the importance of having a continuous source of juvenile fish for stocking the cages. The aforementioned examples provide a frame of reference for the following economic analysis of the implementation and operation of an offshore aquaculture operation in Puerto Rico.

CHAPTER 9: ANALYSIS OF OFFSHORE CAGE CULTURE IN PUERTO RICO

The offshore aquaculture industry entails a large initial investment in the form of capital expenditures for cages. Payback analysis is used to determine the time required for an investment to generate earnings that are equal to the cost of the initial investment. A venture that can recover the investment capital quickly has the advantage of reinvesting in new revenue-producing projects and potentially generating a greater profit. The availability of funds provides the most benefits for future investments. Payback analysis is frequently used in conjunction with other methods to indicate the time commitment of funds. This method is a good illustration of an industry's profitability potential (Chase, Aquilano, & Jacobs, 1998).

9.1 Analysis of Seafood Market in Puerto Rico

Mutton snapper is currently a major candidate species for offshore cage culture in Puerto Rico. As indicated in Table 9.1, Puerto Rican fishermen captured over 41,000 kilograms of mutton snapper in 1999. This catch represented 10.5 percent of the total snapper catch.

Table 9.1 Landings reported by species and by gear in Puerto Rico in 1999. All data values are expressed in kilograms.

	Beach Seine	Fish Trap	Lobster Trap	Gill Net	Bottom Line	Troll Line	Long Line	Cast Net	Total
Lane Snapper	1,422	32,477	98	14,203	23,572	292	15,463	685	87,585
Yellowtail Snapper	1,869	10,353	2	6,433	104,233	1,482	3,099	58	127,529
Silk Snapper	0	23,619	0	0	77,658	0	1,330	0	102,607
Mutton Snapper	550	10,294	14	4,989	23,855	375	921	48	41,046
Other Snapper	942	5,653	0	5,624	1,7021	651	338	5	30,914
	Total Snapper Catch				**389,681**				

Source: Office of Agricultural Statistics, Department of Agriculture, Puerto Rico.

Although local fishermen catch snapper, Puerto Rico imports a large amount of this fish to meet the demand. Table 9.2 lists the countries that export to the Island and the quantity and value of the imported snapper.

Table 9.2 Imports of snapper into Puerto Rico from foreign countries by country of origin for the fiscal year 1999. Quantities are expressed in kilograms.

Country	Quantity	Value
Brazil	23,128	$61,437
Colombia	16,165	$49,179
Costa Rica	2,384	$14,726
India	15,876	$52,853
Indonesia	208,790	$657,001
Spain	114	$2,150
Thailand	17,568	$60,651
TOTAL	**284,025**	**$897,997**

Source: Office of Agricultural Statistics, Department of Agriculture, Puerto Rico.

An Ocean Spar SeaStation^{TM} 3000 cage system is capable of producing 41,303 kilograms of mutton snapper per year (Refer to Appendix H). A comparison of the total reported catch in 1999 and the quantity of mutton snapper produced in one Ocean Spar SeaStation^{TM} 3000 cage is depicted in Figure 9.1. As seen in Figure 9.1, the amount of mutton snapper that can be cultured in one ocean cage is greater than the amount caught by Puerto Rican fishermen in 1999.

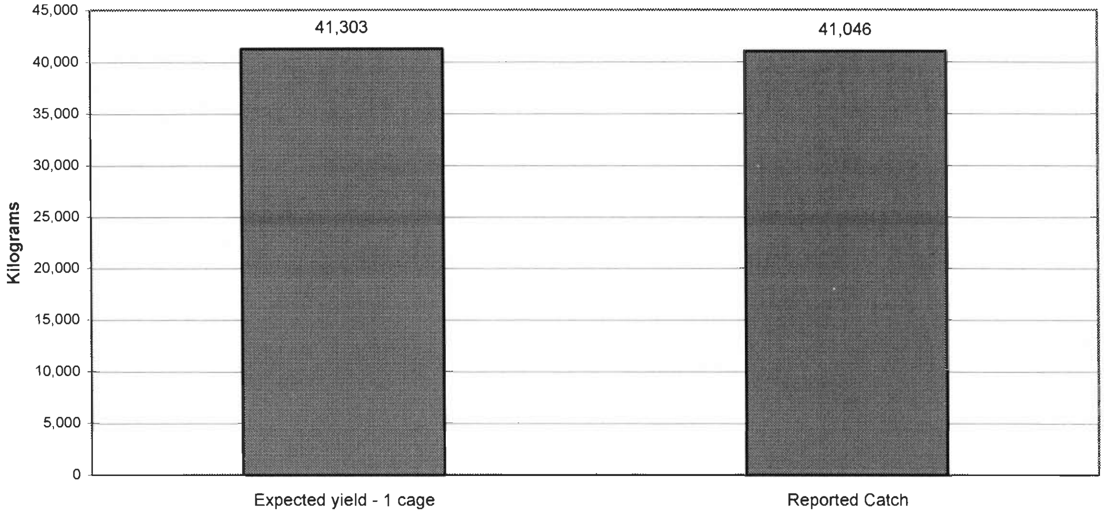

Figure 9.1 Comparison of the predicted output of mutton snapper in one SeaStation^{TM} 3000 cage and reported landings in Puerto Rico (1999). All data is expressed in kilograms.

Sources: Snapperfarms Inc. (Appendix H) and Office of Agricultural Statistics, Department of Agriculture, Puerto Rico.

The output of a one-cage system can surpass the current catch of mutton snapper on the island of Puerto Rico. Thus, if offshore cage culture is established in Puerto Rico, careful considerations must be made for the fishing industry. If all of the fish produced in an offshore cage culture system entered local markets, the increased supply of snapper would cause a decrease in the market value of the species. This may have an adverse effect on the income of the local fishermen. However, since the demand for seafood continues to increase as the world population increases, and overfishing has caused a decline in the fish supply, offshore cage culture would be beneficial to the seafood industry by providing a large supply of fish to meet the consumer demand.

Figure 9.2 illustrates the Puerto Rican snapper market in 1999. Approximately 58 percent of snapper is captured locally, and 42 percent is being imported.

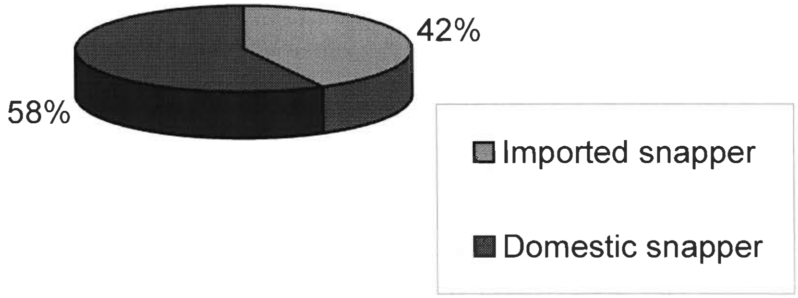

Figure 9.2 Puerto Rican snapper market in 1999.

Source: Office of Agricultural Statistics, Department of Agriculture, Puerto Rico.

The full yield of one SeaStation™ 3000 cage system would add 41,303 kilograms of fish to the Puerto Rican snapper market, if sold locally. If a one-cage operation accounts for 6 percent of the total market share (Refer to Figure 9.3), multiple cages would dominate the market and may harm the sales of local fishermen. Figure 9.3 was created from the data in Table 9.3.

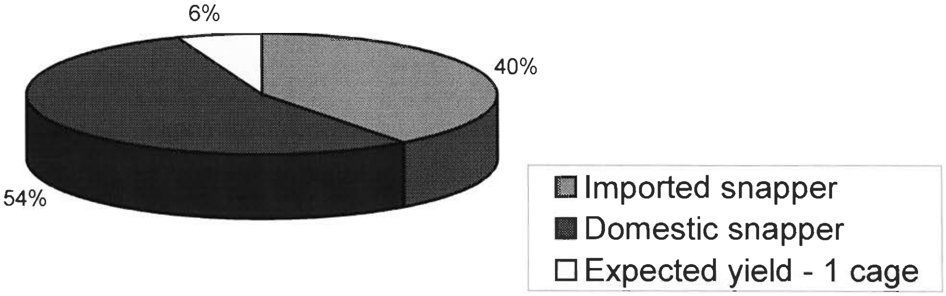

Figure 9.3 Anticipated market share of cage culture of red snapper in Puerto Rico.

Sources: Snapperfarms Inc. (Appendix H) and Office of Agricultural Statistics, Department of Agriculture, Puerto Rico.

Table 9.3 Comparison of the expected output of two SeaStation™ 3000 cages and the snapper market in Puerto Rico. All data is expressed in kilograms.

Source	Quantity
Imported Snapper	284,025
Domestic Snapper	389,681
Expected yield – 1 cage	41,303

Sources: Snapperfarms Inc. (Appendix H) and Office of Agricultural Statistics, Department of Agriculture, Puerto Rico.

9.2 Payback Analysis of Offshore Cage Culture in Puerto Rico

The fixed costs of a cage culture operation include the purchase, shipping, and installation of the cage (Refer to Table 9.4). Four five-ton anchors must be purchased locally to moor the cage to the ocean bottom. As indicated by Greg Sangster, of Ocean Spar Technologies, LLC (Refer to Appendix G), the price of $110,000 for the SeaStation™ 3000 includes technical support and installation by Ocean Spar engineers. The total cost for the purchase and on-site installation of one Ocean Spar SeaStation™ 3000 is approximately $117,700.00 as shown in Table 9.4.

Table 9.4 Initial costs for an Ocean Spar SeaStation™ 3000 including installation.

Ocean Spar SeaStation™ 3000 with installation	$110,000.00
Shipping expenses	$4,500.00
Four anchors	$3,200.00
TOTAL INITIAL COST PER CAGE	**$117,700.00**

Source: Ocean Spar Technologies, LLC (Appendix G).

According to Brian O'Hanlon (Refer to Appendix H), the stocking density of the Ocean Spar SeaStation™ 3000 is thirty-six mutton snapper fingerlings per cubic meter. Therefore, 97,200 fingerlings can be cultured in each cage. He stated that the average growth rate for mutton snapper in the cage is approximately 41.66 grams per month. Therefore, twelve months would be required to harvest the fish at a weight of 500 grams. As Brian O'Hanlon explained, mutton snapper can also be harvested at 700 grams, as the fish will quickly gain 200 grams in two additional months of culture.

O'Hanlon indicated that the mortality rate of 15 percent was derived from the experience of previous cage culture projects in Hawaii. This value was used to determine the number of fish at harvest. Since the mortality rate will cause a decrease in the fish population over time, the amount of feed required will also decrease. In order to account for the changes, the mean number of fish in the cage was calculated by averaging the initial and final populations within the cage. In order to achieve a given harvest weight, a certain amount of feed must be given to the fish. Growth depends on the feed conversion ratio, which is approximately 1.2:1 for mutton snapper. Therefore, using the average fish population, harvest weight, and feed conversion ratio, the cost of feed was calculated. Feed can be purchased at Burris, Inc. in Louisiana for $0.77 per kilogram.

Brain O'Hanlon reported that fingerlings can be purchased at the Florida Keys Aquaculture Center for $0.50 with shipping costs of $0.05 per fish. The cost of fingerlings was easily calculated by multiplying the cost per fish by the number of fish stocked within the cage.

In order to determine the cost of processing, packing, and shipping, the number of fish sold and harvest weight must be taken into account. Only 80 percent of the weight of the harvested fish will be suitable for market, since gutting will be required. According to Brian O'Hanlon, processing, packing, and shipping will cost approximately $1.10 per kilogram of fish. The total weight to be processed was calculated by multiplying the harvest weight by the number of fish sold. Furthermore, the cost was computed by multiplying the total weight by the price of processing per kilogram.

According to Gary Loverich (Refer to Appendix L), labor costs will remain the same for cage culture operations consisting of up to five cages. Therefore, for this analysis, labor costs remained consistent. Brain O'Hanlon stated that labor costs would be approximately $79,200 per year with a yearly insurance premium of $38,800 for each cage. Another cost that was taken into account was the mandatory environmental assessment, which includes the testing and research to ensure the operation is environmentally sound. This environmental assessment will cost approximately $12,000 per cage for every year of operation.

In order to calculate the net operating profit, the production costs and operating expenses were subtracted from the annual sales. The net operating profit determines the success of a business venture. Tables 9.5 through 9.17 are financial summaries of offshore cage culture operations using up to three cages and harvesting the fingerlings at 500 or 700 grams. The tables summarize costs and sales and provide a value for the net operating profit for each year of operation. The initial investment was expensed in the first year of operation, and an inflation rate of 3 percent was assumed for all calculations. This assumed inflation rate was based on past years and projections for the future.

As seen in Tables 9.5 and 9.6, this operation made use of one cage, and the fish were harvested at a weight of 500 grams. This required a substantial initial investment of approximately $157,000. Furthermore, since the operation resulted in a loss of over $40,000 per year, adjusted for inflation, this one-cage system would not be an economically viable venture.

Table 9.5 Financial summary of one year using one Ocean Spar SeaStation^{TM} 3000 cage with a harvest weight of 500 grams.

TOTAL VOLUME OF CAGE (m^3)	2,700
STOCKING DENSITY (fingerlings/m^3)	36
# CYCLES/YEAR	1.00
# FINGERLINGS PER CYCLE	97,200
# FISH/HARVEST (85% survival)	82,620
AVERAGE GROWTH RATE (grams/month)	41.66
# OF MONTHS PER CYCLE	12.0
AVERAGE HARVEST WEIGHT (grams)	500
KG HARVEST/CYCLE	41,310
KG HARVESTED (GUTTED = 80%)	33,048
MARKET PRICE PER (USD/KG)	$7.00
SALES PER CYCLE (USD)	$231,336.00
ANNUAL SALES (USD)	**$231,336.00**
# FINGERLINGS	97200
COST OF FINGERLING (USD)	$0.50
COST OF FINGERLING TRANSPORT	$0.05
# CYCLES/YEAR	1
COST OF FINGERLING/YEAR	**$53,460.00**
AVERAGE NUMBER OF FISH IN PRODUCTION	89,910
AVERAGE HARVEST WEIGHT (grams)	500
FEED CONVERSION RATIO	1.2
COST OF FEED (USD/KG)	$0.77
COST OF FEED/YEAR	**$41,538.42**
NUMBER OF FISH SOLD	82620
HARVEST WEIGHT (grams)	500
COST OF PACKING & SHIPPING PER KG	$1.10
PROCESSING, PACKING & SHIPPING	**$45,441.00**
COST OF PERSONNEL	$79,200.00
OTHER OPERATING COSTS	$38,800.00
ENVIRONMENTAL ASSESSMENT	$12,000.00
TOTAL OPERATING EXPENSE	**$130,000.00**
TOTAL COST OF PRODUCTION	**$270,439.42**
NET OPERATING PROFIT/YEAR	**$(39,103.42)**

Table 9.6 Payback analysis using one Ocean Spar SeaStation^{TM} 3000 cage with a harvest weight of 500 grams.

YEAR	2002	2003	2004	2005	2006
SALES	$231,336	$238,276	$245,424	$252,787	$260,371
Fixed costs					
Cage and Equipment	$117,700	$0	$0	$0	$0
Labor	$79,200	$81,576	$84,023	$86,544	$89,140
Insurance	$38,800	$39,964	$41,163	$42,398	$43,670
Environmental Assessment	$12,000	$12,360	$12,731	$13,113	$13,506
Variable costs					
Feed	$41,538	$42,785	$44,068	$45,390	$46,752
Fingerlings	$53,460	$55,064	$56,716	$58,417	$60,170
Processing, Packing, Shipping	$45,441	$46,804	$48,208	$49,655	$51,144
TOTAL COSTS	$388,139	$278,553	$286,909	$295,516	$304,382
NET PROFIT	**($156,803)**	**($40,277)**	**($41,485)**	**($42,729)**	**($44,011)**

As seen in Tables 9.7 and 9.8, this operation made use of two cages, and the fish were harvested at a weight of 500 grams. This required a substantial initial investment of approximately $234,407. Moreover, since the operation only generated a profit of approximately $1,000 per year, adjusted for inflation, this two-cage system would not be an economically viable venture since the payback period would be nearly 71 years.

Table 9.7 Financial summary of one year using two Ocean Spar SeaStation™ 3000 cage systems with a harvest weight of 500 grams.

TOTAL VOLUME OF CAGES (m^3)	5,400
STOCKING DENSITY (fingerlings/m^3)	36
# CYCLES/YEAR	1.00
# FINGERLINGS PER CYCLE	194,400
# FISH/HARVEST (85% survival)	165,240
AVERAGE GROWTH RATE (grams/month)	41.66
# OF MONTHS PER CYCLE	12.0
AVERAGE HARVEST WEIGHT (grams)	500
KG HARVEST/CYCLE	82,620
KG HARVESTED (GUTTED = 80%)	66,096
MARKET PRICE PER (USD/KG)	$7.00
SALES PER CYCLE (USD)	$462,672.00
ANNUAL SALES (USD)	**$462,672.00**
# FINGERLINGS	194,400
COST OF FINGERLING (USD)	$0.50
COST OF FINGERLING TRANSPORT	$0.05
# CYCLES/YEAR	1
COST OF FINGERLING/YEAR	**$106,920.00**
AVERAGE NUMBER OF FISH IN PRODUCTION	179,820
AVERAGE HARVEST WEIGHT (grams)	500
FEED CONVERSION RATIO	1.2
COST OF FEED (USD/KG)	$0.77
COST OF FEED/YEAR	**$83,076.84**
NUMBER OF FISH SOLD	165,240
HARVEST WEIGHT (grams)	500
COST OF PACKING & SHIPPING PER KG	$1.10
PROCESSING, PACKING & SHIPPING	**$90,882.00**
COST OF PERSONNEL	$79,200.00
OTHER OPERATING COSTS	$77,600.00
ENVIRONMENTAL ASSESSMENT	$24,000.00
TOTAL OPERATING EXPENSE	**$180,800.00**
TOTAL COST OF PRODUCTION	**$461,678.84**
NET OPERATING PROFIT/YEAR	**$993.16**

Table 9.8 Payback analysis using two Ocean Spar SeaStation^{TM} 3000 cages with a harvest weight of 500 grams.

Year	**2002**	**2003**	**2004**	**2005**	**2006**
Sales	$462,672	$476,552	$490,849	$505,574	$520,741
Fixed costs					
Cage and Equipment	$235,400	$0	$0	$0	$0
Labor	$79,200	$81,576	$84,023	$86,544	$89,140
Insurance	$77,600	$79,928	$82,326	$84,796	$87,339
Environmental Assessment	$24,000	$24,720	$25,462	$26,225	$27,012
Variable costs					
Feed	$83,077	$85,569	$88,136	$90,780	$93,504
Fingerlings	$106,920	$110,128	$113,431	$116,834	$120,339
Processing, Packing, Shipping	$90,882	$93,608	$96,417	$99,309	$102,288
TOTAL COSTS	$697,079	$475,529	$489,795	$504,489	$519,624
NET PROFIT	**($234,407)**	**$1,023**	**$1,054**	**$1,085**	**$1,118**

As seen in Tables 9.9 and 9.10, this operation made use of three cages, and the fish were harvested at a weight of 500 grams. This required a substantial initial investment of approximately $312,000. However, since the operation generated a profit of over $40,000 per year, adjusted for inflation, the payback period is nearly 8 years, which may not prove to be profitable.

Table 9.9 Financial summary of one year using three Ocean Spar SeaStation™ 3000 cage systems with a harvest weight of 500 grams.

TOTAL VOLUME OF CAGES (m^3)	8,100
STOCKING DENSITY (fingerlings/m^3)	36
# CYCLES/YEAR	1.00
# FINGERLINGS PER CYCLE	291,600
# FISH/HARVEST (85% survival)	247,860
AVERAGE GROWTH RATE (grams/month)	41.66
# OF MONTHS PER CYCLE	12.0
AVERAGE HARVEST WEIGHT (grams)	500
KG HARVEST/CYCLE	123,930
KG HARVESTED (GUTTED = 80%)	99,144
MARKET PRICE PER (USD/KG)	$7.00
SALES PER CYCLE (USD)	$694,008.00
ANNUAL SALES (USD)	**$694,008.00**
# FINGERLINGS	291,600
COST OF FINGERLING (USD)	$0.50
COST OF FINGERLING TRANSPORT	$0.05
# CYCLES/YEAR	1
COST OF FINGERLING/YEAR	**$160,380.00**
AVERAGE NUMBER OF FISH IN PRODUCTION	269,730
AVERAGE HARVEST WEIGHT (grams)	500
FEED CONVERSION RATIO	1.2
COST OF FEED (USD/KG)	$0.77
COST OF FEED/YEAR	**$124,615.26**
NUMBER OF FISH SOLD	247,860
HARVEST WEIGHT (grams)	500
COST OF PACKING & SHIPPING PER KG	$1.10
PROCESSING, PACKING & SHIPPING	**$136,323.00**
COST OF PERSONNEL	$79,200.00
OTHER OPERATING COSTS	$116,400.00
ENVIRONMENTAL ASSESSMENT	$36,000.00
TOTAL OPERATING EXPENSE	**$231,600.00**
TOTAL COST OF PRODUCTION	**$652,918.26**
NET OPERATING PROFIT/YEAR	**$41,089.74**

Table 9.10 Payback analysis using three Ocean Spar SeaStation$^{\text{TM}}$ 3000 cages with a harvest weight of 500 grams.

Year	**2002**	**2003**	**2004**	**2005**	**2006**
Sales	$694,008	$714,828	$736,273	$758,361	$781,112
Fixed costs					
Cage and Equipment	$353,100	$0	$0	$0	$0
Labor	$79,200	$81,576	$84,023	$86,544	$89,140
Insurance	$116,400	$119,892	$123,489	$127,193	$131,009
Environmental Assessment	$36,000	$37,080	$38,192	$39,338	$40,518
Variable costs					
Feed	$124,615	$128,354	$132,204	$136,170	$140,256
Fingerlings	$160,380	$165,191	$170,147	$175,252	$180,509
Processing, Packing, Shipping	$136,323	$140,413	$144,625	$148,964	$153,433
TOTAL COSTS	$1,006,018	$672,506	$692,681	$713,461	$734,865
NET PROFIT	**($312,010)**	**$42,322**	**$43,592**	**$44,900**	**$46,247**

As seen in Tables 9.11 and 9.12, this operation made use of one cage, and in order to optimize fish growth, the fish were harvested at a weight of 700 grams. This required a substantial initial investment of approximately $359,000. However, since the operation generated a profit of approximately $19,000 per year, adjusted for inflation, the payback period is nearly 17 years, which may not prove to be profitable.

Table 9.11 Financial summary of one year using one Ocean Spar SeaStation^{TM} 3000 cage system with a harvest weight of 700 grams.

TOTAL VOLUME OF CAGE (m^3)	2,700
STOCKING DENSITY (fingerlings/m^3)	36
# FINGERLINGS PER CYCLE	97,200
# FISH/HARVEST (85% survival)	82,620
# OF MONTHS PER CYCLE	14.0
AVERAGE HARVEST WEIGHT (grams)	700
KG HARVEST/CYCLE	57,834
KG HARVESTED (GUTTED = 80%)	46,267
MARKET PRICE PER (USD/KG)	$7.00
SALES PER CYCLE (USD)	**$323,870.40**
# FINGERLINGS	97,200
COST OF FINGERLING (USD)	$0.50
COST OF FINGERLING TRANSPORT	$0.05
COST OF FINGERLING/CYCLE	**$53,460.00**
AVERAGE NUMBER OF FISH IN PRODUCTION	89,910
AVERAGE HARVEST WEIGHT (grams)	700
FEED CONVERSION RATIO	1.2
COST OF FEED (USD/KG)	$0.77
COST OF FEED/CYCLE	**$58,153.79**
NUMBER OF FISH SOLD	82,620
HARVEST WEIGHT (grams)	700
COST OF PACKING & SHIPPING PER KG	$1.10
PROCESSING, PACKING & SHIPPING	**$63,617.40**
COST OF PERSONNEL	$79,200.00
OTHER OPERATING COSTS	$38,800.00
ENVIRONMENTAL ASSESSMENT	$12,000.00
TOTAL OPERATING EXPENSE	**$130,000.00**

Table 9.12 Payback analysis using one Ocean Spar SeaStation^{TM} 3000 cage with a harvest weight of 700 grams.

Year	**2002**	**2003**	**2004**	**2005**	**2006**
Sales	$0	$333,587	$343,594	$353,902	$364,519
Fixed costs					
Cage and Equipment	$117,700	$0	$0	$0	$0
Labor	$79,200	$81,576	$84,023	$86,544	$89,140
Insurance	$38,800	$39,964	$41,163	$42,398	$43,670
Environmental Assessment	$12,000	$12,360	$12,731	$13,113	$13,506
Variable costs					
Feed	$58,154	$59,898	$61,695	$63,546	$65,453
Fingerlings	$53,460	$55,064	$56,716	$58,417	$60,170
Processing, Packing, Shipping	$0	$65,526	$67,492	$69,516	$71,602
TOTAL COSTS	$359,314	$314,388	$323,820	$333,534	$343,540
NET PROFIT	**($359,314)**	**$19,198**	**$19,774**	**$20,368**	**$20,979**

As seen in Tables 9.13 and 9.14, this operation made use of two cages, and the fish were harvested at a weight of 700 grams. This required a substantial initial investment of approximately $640,000. However, since the operation generated a profit of approximately $119,000 per year, adjusted for inflation, the payback period is nearly 7 years, which may not prove to be profitable.

Table 9.13 Financial summary of one year using two Ocean Spar SeaStation^{TM} 3000 cage systems with a harvest weight of 700 grams.

TOTAL VOLUME OF CAGES (m^3)	5,400
STOCKING DENSITY (fingerlings/m^3)	36
# FINGERLINGS PER CYCLE	194,400
# FISH/HARVEST (85% survival)	165,240
# OF MONTHS PER CYCLE	14.0
AVERAGE HARVEST WEIGHT (grams)	700
KG HARVEST/CYCLE	115,668
KG HARVESTED (GUTTED = 80%)	92,534
MARKET PRICE PER (USD/KG)	$7.00
SALES PER CYCLE (USD)	**$647,740.80**
# FINGERLINGS	194,400
COST OF FINGERLING (USD)	$0.50
COST OF FINGERLING TRANSPORT	$0.05
COST OF FINGERLING/CYCLE	**$106,920.00**
AVERAGE NUMBER OF FISH IN PRODUCTION	179,820
AVERAGE HARVEST WEIGHT (grams)	700
FEED CONVERSION RATIO	1.2
COST OF FEED (USD/KG)	$0.77
COST OF FEED/CYCLE	**$116,307.58**
NUMBER OF FISH SOLD	165,240
HARVEST WEIGHT (grams)	700
COST OF PACKING & SHIPPING PER KG	$1.10
PROCESSING, PACKING & SHIPPING	**$127,234.80**
COST OF PERSONNEL	$79,200.00
OTHER OPERATING COSTS	$77,600.00
ENVIRONMENTAL ASSESSMENT	$24,000.00
TOTAL OPERATING EXPENSE	**$180,800.00**

Table 9.14 Payback analysis using two Ocean Spar SeaStation$^{\text{TM}}$ 3000 cages with a harvest weight of 700 grams.

Year	**2002**	**2003**	**2004**	**2005**	**2006**
Sales	$0	$667,173	$687,188	$707,804	$729,038
Fixed costs					
Cage and Equipment	$235,400	$0	$0	$0	$0
Labor	$79,200	$81,576	$84,023	$86,544	$89,140
Insurance	$77,600	$79,928	$82,326	$84,796	$87,339
Environmental Assessment	$24,000	$24,720	$25,462	$26,225	$27,012
Variable costs					
Feed	$116,308	$119,797	$123,391	$127,092	$130,905
Fingerlings	$106,920	$110,128	$113,431	$116,834	$120,339
Processing, Packing, Shipping	$0	$131,052	$134,983	$139,033	$143,204
TOTAL COSTS	$639,428	$547,200	$563,616	$580,525	$597,940
NET PROFIT	**($639,428)**	**$119,973**	**$123,572**	**$127,279**	**$131,097**

As seen in Tables 9.15 and 9.16, this operation made use of three cages, and the fish were harvested at a weight of 700 grams. This required a substantial initial investment of approximately $920,000. However, since the operation generated a profit of approximately $220,000 per year, adjusted for inflation, the payback period is nearly 5 years, which may prove to be the most profitable approach to offshore cage culture.

Table 9.15 Financial summary of one year using three Ocean Spar SeaStation™ 3000 cage systems with a harvest weight of 700 grams.

TOTAL VOLUME OF CAGES (m^3)	8,100
STOCKING DENSITY (fingerlings/m^3)	36
# FINGERLINGS PER CYCLE	291,600
# FISH/HARVEST (85% survival)	247,860
# OF MONTHS PER CYCLE	14.0
AVERAGE HARVEST WEIGHT (grams)	700
KG HARVEST/CYCLE	173,502
KG HARVESTED (GUTTED = 80%)	138,802
MARKET PRICE PER (USD/KG)	$7.00
SALES PER CYCLE (USD)	**$971,611.20**
# FINGERLINGS	291,600
COST OF FINGERLING (USD)	$0.50
COST OF FINGERLING TRANSPORT	$0.05
COST OF FINGERLING/CYCLE	**$160,380.00**
AVERAGE NUMBER OF FISH IN PRODUCTION	269,730
AVERAGE HARVEST WEIGHT (grams)	700
FEED CONVERSION RATIO	1.2
COST OF FEED (USD/KG)	$0.77
COST OF FEED/CYCLE	**$174,461.36**
NUMBER OF FISH SOLD	247,860
HARVEST WEIGHT (grams)	700
COST OF PACKING & SHIPPING PER KG	$1.10
PROCESSING, PACKING & SHIPPING	**$190,852.20**
COST OF PERSONNEL	$79,200.00
OTHER OPERATING COSTS	$116,400.00
ENVIRONMENTAL ASSESSMENT	$36,000.00
TOTAL OPERATING EXPENSE	**$231,600.00**

Table 9.16 Payback analysis using three Ocean Spar SeaStation^{TM} 3000 cages with a harvest weight of 700 grams.

Year	**2002**	**2003**	**2004**	**2005**	**2006**
Sales	$0	$1,000,760	$1,030,782	$1,061,706	$1,093,557
Fixed costs					
Cage and Equipment	$353,100	$0	$0	$0	$0
Labor	$79,200	$81,576	$84,023	$86,544	$89,140
Insurance	$116,400	$119,892	$123,489	$127,193	$131,009
Environmental Assessment	$36,000	$37,080	$38,192	$39,338	$40,518
Variable costs					
Feed	$174,461	$179,695	$185,086	$190,639	$196,358
Fingerlings	$160,380	$165,191	$170,147	$175,252	$180,509
Processing, Packing, Shipping	$0	$196,578	$202,475	$208,549	$214,806
TOTAL COSTS	$919,541	$780,012	$803,413	$827,515	$852,341
NET PROFIT	**($919,541)**	**$220,747**	**$227,370**	**$234,191**	**$241,216**

As seen in Table 9.17, this operation implemented one cage in the first year and an additional two cages in the following year. The fish were harvested at a weight of 700 grams. This operation required a substantial initial investment of approximately $359,000 the first year and $542,000 the second year. However, since the operation generated a profit of approximately $220,000 per year, adjusted for inflation, the payback period was nearly 6 years. This approach allowed for a less substantial initial investment during the first few years of operation by dividing the cost of the three cages over the first two years. However, since three cages are implemented, the operation still generates a considerable profit and results in a reasonable payback period.

Table 9.17 Payback analysis using one Ocean Spar SeaStation™ 3000 cage in the first year and two cages in the second year with a harvest weight of 700 grams.

Year	2002	2003	2004	2005	2006
Sales	$0	$323,870	$1,000,760	$1,030,782	$1,061,706
Fixed costs					
Cage and Equipment	$117,700	$235,400	$0	$0	$0
Labor	$79,200	$79,200	$81,576	$84,023	$86,544
Insurance	$38,800	$116,400	$119,892	$123,489	$127,193
Environmental Assessment	$12,000	$36,000	$37,080	$38,192	$39,338
Variable costs					
Feed	$58,154	$174,461	$179,695	$185,086	$190,639
Fingerlings	$53,460	$160,380	$165,191	$170,147	$175,252
Processing, Packing, Shipping	$0	$63,617	$196,578	$202,475	$208,549
TOTAL COSTS	$359,314	$865,458	$780,012	$803,413	$827,515
NET PROFIT	**($359,314)**	**($541,588)**	**$220,747**	**$227,370**	**$234,191**

The purchase of the Ocean Spar SeaStation™ 3000, including installation, requires a substantial investment. In order to determine the time required to recover from this investment, payback analysis was used. A venture that can recover quickly from an initial investment may prove to be economically viable. The factors that determine how quickly an offshore cage culture project will recover include the number of cages implemented and the length of the harvest cycles. As shown in our analysis, by increasing the number of cages, the amount of profit generated was also increased. However, the most effective method of generating more profit was to optimize fish growth by extending the harvest cycles by two months, allowing the fish to gain an additional 200 grams. In conclusion, the most profitable approach as indicated by this analysis was to implement three cages and harvest the mutton snapper at a weight of 700 grams.

CHAPTER 10: CONCLUSIONS AND RECOMMENDATIONS

Upon completion of our preliminary research, we believed that aquaculture could be used as an alternative to the current fishing practices of the village. However, the fishermen viewed aquaculture as a supplement, rather than an alternative to traditional fishing. Therefore, the transition from fishing to aquaculture would be unlikely. Nevertheless, the village was open to any assistance that our project team could provide.

The main factor inhibiting the implementation of aquaculture was the lack of land available to the village. The village uses facilities owned by the municipality of San Juan and is situated adjacent to approximately five acres of undeveloped land, which is also under the jurisdiction of the municipality. Currently, the municipality has plans to develop this land for tourism. Through discussions with various professionals and experts, we concluded that the municipality would be very reluctant to relinquish this land for the purpose of an aquaculture operation. Furthermore, the Puerto Rican Department of Natural and Environmental Resources restricts the location of aquaculture facilities. Operations are prohibited near major highways and within a defined proximity to the waterfront. Unfortunately, the fishing village of San Juan is located adjacent to both a major highway and the waterfront, and thus any aquaculture operation would be prohibited.

In addition to these legal restrictions and municipal plans, an intensive aquaculture facility would cost in excess of $600,000 and require 40 acres of land for profitable operation. Furthermore, extensive facilities require a minimum of 50 acres to be economically viable. Thus, our group concluded that aquaculture could not be profitably implemented for the fishing village of San Juan.

In the course of our investigations of intensive and extensive aquaculture, we learned of the possibility of offshore cage culture. This type of aquaculture has existed since the early 1980's in a variety of locations worldwide; however, it has never been implemented successfully in the Caribbean region. Thus, the focus of our project shifted to an investigation of the environmental, political, and socioeconomic aspects of offshore cage culture in Puerto Rico.

Upon completion of our offshore cage culture investigations, we concluded that such an activity is a feasible alternative to contemporary aquaculture in Puerto Rico. The island of Puerto Rico is faced with a variety of problems regarding land limitations. Thus, any industries that could efficiently use the Island's extensive ocean resources would be greatly beneficial to the Puerto Rican economy. Open ocean aquaculture effectively employs the previously unused aquatic resources.

Environmentally, offshore cage culture has the possibility of contaminating the site location. However, ocean currents are able to disperse any wastes produced and dilute them to harmless levels. Previous offshore cage culture operations, specifically the recent project in Hawaii, have had minimal environmental impacts. Nevertheless, through our investigations, our group concluded that site contamination in Puerto Rico is a risk, and careful monitoring programs should be established. In addition, we determined that the best site locations are those with the calmest seas, the lowest probability of hurricanes, and few marine hazards among other considerations.

Politically, the current permitting process is complex, time-consuming, and costly. Businesses have been waiting in excess of a year for the necessary permits to deploy their cage systems. Bureaucratic delays will surely impede the development of the offshore cage culture industry. Regulations and permits must clearly reflect the specific needs of the industry but also ensure the safety of the community and the environment.

Economically, offshore cage culture has the potential to be an extremely beneficial industry to the Commonwealth of Puerto Rico. Currently, Puerto Rico is heavily dependant on imported seafood products. If developed properly, an offshore cage culture operation has the potential to generate an enormous amount of seafood. A one-cage system growing mutton snapper can generate approximately 41,000 kilograms of fish per year. If sold in local markets, this amount of fish would represent 6 percent of the Puerto Rican mutton snapper market. Hence, multiple cages would have an enormous impact. Furthermore, cage culture can provide a readily available source of fish to supplement those caught through traditional fishing practices. Fishermen can catch those fish that congregate around the outside of the cages.

Cage culture can be a profitable enterprise. Multiple cages allow operating costs to be minimized and thus a profit to be generated. Our analysis indicated that a three-cage system harvesting mutton snapper at a weight of 700 grams would have a payback period of five years. Cage manufacturers, such as Ocean Spar Technologies, LLC, are developing plans to produce cage systems in a cost-effective manner. This will result in decreased cage prices and allow for a lower initial investment, enabling the operation to decrease its payback period.

Considering the potential of this technology and the information obtained through our research, we strongly suggest the following three-point plan for the further development of the open ocean aquaculture industry in Puerto Rico.

1. A pilot program should be developed with the aid of educational institutions and government agencies to demonstrate that offshore cage culture is commercially viable in the Caribbean.
    a. One Ocean Spar SeaStation^{TM} 3000 cage system should be implemented during the first year of operation to culture mutton snapper. Two additional cages should be added in the subsequent year. Cages should be placed off the western coast of Puerto Rico to take advantage of the calmest waters.
    b. A monitoring program should be established to measure the environmental effects of such an operation.
    c. This pilot program should first test the local markets in order to satisfy the demand for seafood and begin to export in later years.
    d. The pilot program should result in a management plan with the intent of optimizing feed conversion ratios and labor costs.
    e. The successful completion of the pilot program will attract investors and should allow the program to become a privatized operation.
2. The government should create a regulatory plan for the development of the offshore aquaculture industry.
    a. A specific government agency should be conferred the jurisdiction over all aspects of cage culture.
    b. The permitting and regulatory process should be simplified and streamlined. In addition, aquaculture experts should be involved in

developing and modifying this process and the pertinent aquaculture regulations.

3. The government should promote and expand an offshore cage culture industry.
    a. Pertinent government agencies should aid in assessing and determining suitable locations for future offshore cage culture operations.
    b. Members of the aquaculture agency should attend key conferences, such as the upcoming Open Ocean Four Conference in Florida, and collaborate with similar ongoing projects around the world.
    c. A careful plan should be developed based on market analyses and results of the pilot program in order to decrease the percentage of imported seafood.
    d. A training program similar to those offered at the Institute of Aquaculture of the University of Stirling and the New Brunswick Community College should be considered at the Colegio Tecnológico de San Juan in order to educate potential operators of aquaculture facilities in Puerto Rico and the Caribbean region.
    e. The government should promote the creation of a hatchery and a feed supplier on the island in order to decrease shipping costs for aquaculture operations and create more jobs in the offshore cage culture industry.

f. Research should be conducted to determine the feasibility of culturing other species in offshore cages.

Although originally targeting a local San Juan fishing village, we expect this project to have substantial impacts on both the fishing and aquaculture industries in Puerto Rico. Furthermore, we believe this three-point plan and report will serve as a guide to other Caribbean nations.

10.1 Recommendations for Future Interactive Qualifying Projects (IQPs) and Major Qualifying Projects (MQPs) in Puerto Rico

Based on time and resource limitations, our group was not able to fully investigate all aspects of implementing an offshore cage culture project in Puerto Rico. However, through the course of our intensive investigations of the fishing industry and the political, environmental, and socioeconomic aspects of cage culture, we were able to make a series of recommendations regarding future projects that can be conducted in these areas.

Currently the University of Puerto Rico is attempting to strengthen its aquaculture program by increasing their research of cage culture (Dr. Dallas Alston, Appendix B). We believe that students of Worcester Polytechnic Institute would partner very well with the University's research interests. The only impediment our group envisions to this partnership is the location of University's Marine Sciences Department in Mayagüez, approximately two hours from the WPI project center in San Juan. Although this might seem like a very significant barrier, we feel that with careful planning, this logistical obstacle can be managed effectively.

Five potential Interactive Qualifying Projects (IQPs), third year sociotechnical projects, our group envisions are as follows:

1. An investigation the long-term effects of excess feed and fish waste on the ocean floor and surrounding aquatic environment.
2. An assessment of the potential markets for the fish produced and the jobs created by a cage culture operation.
3. An analysis of the political and environmental regulations and permits required to implement such a technology in order to establish proper guidelines and streamline the process.
4. Development of a training program to assist fishermen in learning the skills required to maintain and operate cage systems. The aquaculture training programs of the Institute of Aquaculture of the University of Stirling and the New Brunswick Community College may be adapted or a distance-learning program may be considered.
5. A project suggested by Brain O'Hanlon, president of Snapperfarms, Inc., (Refer to Appendix H) involves the production of a feed using locally available materials and recycling of fish waste.

Potential Major Qualifying Projects (MQPs), senior year technical projects in students' own major, are also numerous. Some possibilities are as follows:

1. A management or industrial engineering MQP to examine the cage operation considering production, quality, and the economics of the industry.
2. The design of a distance monitoring system for the offshore cages that would allow for remote monitoring of all cage conditions and might eliminate the need for frequent labor-intensive measurements.

3. The design of an automatic feeding mechanism for the cages that would also minimize labor, including boat operators and trained divers, required for successful cage operation.
4. An analysis of current cage designs and the development an ideal cage system for the open ocean conditions of Puerto Rico.
5. Another project may make use of a computational model of the biological and environmental factors involved to describe and predict what occurs in an offshore cage system. This model can be calibrated to fit actual data and used to determine the amount of feed and appropriate conditions in the cage that will promote the growth of the fish. Such a model is of great importance in the assessment of the environmental effects of this technology.

These projects indicate that further research is required in many aspects of aquaculture and specifically, offshore technologies. Through collaboration and diligent efforts, the offshore cage culture industry has tremendous potential to flourish in Puerto Rico and the Caribbean.

APPENDIX A
Information about The Colegio Tecnológico de San Juan

The information presented in this appendix was obtained from Professor Elsie Candelaria, former Dean of the College's Department of Academic Affairs and the current Dean Milagros Rivera Lorenzi. They provided us with the strategic plan, mission statement, and historical background of this institution.

Mission Statement

"The Colegio's Mission is to offer post-secondary education and innovative educational programs geared toward promoting a holistic development of its students and the community, insuring access to residents of socio-economically disadvantaged sectors of the Municipality of San Juan. Our commitment is to the development of an educated individual that is competent on a personal, social and professional level." The previous statement was taken directly from the Colegio's strategic plan, which was last revised in 1999.

Philosophy

This institution of higher education integrates technological and humanistic movements. This institution strives to investigate alternatives and discover new possibilities. Their community is based on problem solving, self-improvement, and teamwork.

Autonomy

The Colegio Tecnológico has been relatively successful in achieving administrative autonomy, but remains attached to the Municipality of San Juan in financial and procedural matters. Many members of the Colegio would like to break away from the Municipality of San Juan and operate independently in the near future. Autonomy would allow the Colegio to grow and operate completely under its own discretion and judgment. The Colegio would then be able to manage its own budget, which would cause the operations to move more quickly and with less difficulty.

Historical Background

As the necessity for technically experienced personnel increased in the city of San Juan, gradually a need and a means for training new people who would be entering the workforce became clear. Consequently, the City of San Juan established the Colegio Tecnológico del Municipio de San Juan in January 1972. The Colegio was authorized by ordinance #45 of the Municipal Assembly, Series 1971-72, under the name, "Colegio Tecnológico de la Comunidad." The "Colegio Tecnológico" is the first post-secondary institution developed by a municipality in Puerto Rico. The name of the Colegio was then changed to "Colegio Tecnológico del Municipio de San Juan" under Ordinance, Number 37 of the Municipal Assembly, Series 1981-82. The Colegio grants certificates and associate degrees in many fields of study, such as Electronics, Information Systems, Secretarial Sciences, Accounting Instrumentation, and Nursing, for example. Several other courses including dental office management, speedwriting, and marine technologies have been offered occasionally.

The school has gained three accreditations. In June of 1978, the Middle States Association of Colleges and Schools accredited the institution. It was reaccredited in 1983 and again in 1997. Later, the Council of Higher Education extended accreditation. The institution received an additional accreditation by the National League for Nursing in June of 1990 and was reaccredited by the league in May 1996.

Current Layout and Enrollment

The size of the Colegio's campus is approximately one and a half acres, which contains three main buildings. Two larger buildings are used for academic classrooms and administration. The third building is primarily used for administrative purposes. In addition to the main buildings at the Colegio, there is a gymnasium and a theater that has a capacity of approximately 500 people. Another building contains the library and the cafeteria. Since 1990, the number of students attending the Colegio has fluctuated between 900 and 1100.

Goals and Objectives of the Colegio

The Colegio Technológico del Municipio de San Juan has three goals, each with its respective objectives. These goals and objectives were taken directly from the Colegio's Strategic Plan (1998):

Goal 1: To promote a holistic development of students.

Objectives:

1. To cultivate in the student self-esteem, self-assurance, and self-determination.
2. To develop a person with communication skills.
3. To develop a person that establishes positive interpersonal relationships in their daily life.
4. To develop a person with logical and quantitative reasoning skills.
5. To enable the student to make value judgment, make decisions and adapt to society's changes.
6. To develop in the learner appreciation for their cultural and historical heritage.

7. To cultivate the appreciation, preservation, and improvement of the environment. The natural world and personal health.

8. To develop a person that assumes leadership, fulfills their civic duties and responsibilities, and contributes to the economy of their country.

9. To develop in the student technological knowledge and its applications.

Goal 2: To provide varied, flexible and updated programs that respond to the needs of the community.

Objectives:

1. To facilitate access to study programs to students coming from socioeconomically disadvantaged areas.

2. To offer interdisciplinary education based on competencies in both regular and evening sessions.

3. To offer special programs dedicated to reinforce knowledge that allows the student to improve their background and complete a study program.

4. To offer academic programs in the areas of General Education, Business Administration, Health Related Sciences, Industry and Technology and others that may arise as a result of needs assessment.

5. To offer re-training opportunities to the Institution's personnel, graduate and members of the community, preferably from San Juan, through the Continued Education Program and professional development activities.

6. To direct investigations leading to improvement in the teaching quality of the institution.

7. To promote the evaluation and continuous review of academic programs and administrative processes.

8. To maintain the standards of excellence required by higher education accrediting agencies.

Goal 3: To maintain an academic and professional climate that stimulates a constant desire to improve among the members of the Colegio community.

Objectives:

1. To propitiate dialogue between members of the Colegio and the external community.
2. To promote positive attitudes that guarantee respect to divergent opinions and the rights of others.
3. To recognize excellence in performance to members of the institution.
4. To sponsor extracurricular and cultural events for both the collegiate and external communities.
5. To provide institutional security to members of the Colegio community.

Organizational Structure

The governing structure is a Board of Trustees appointed by the mayor of San Juan. The Board of Trustees selects the Chancellor. The Chancellor assures that the Colegio is striving towards the goals and objectives of the Colegio. Eight or nine members make up the Board of Trustees. These members represent the faculty, student body, and public interests. The function of the board is to guide the development of the Colegio.

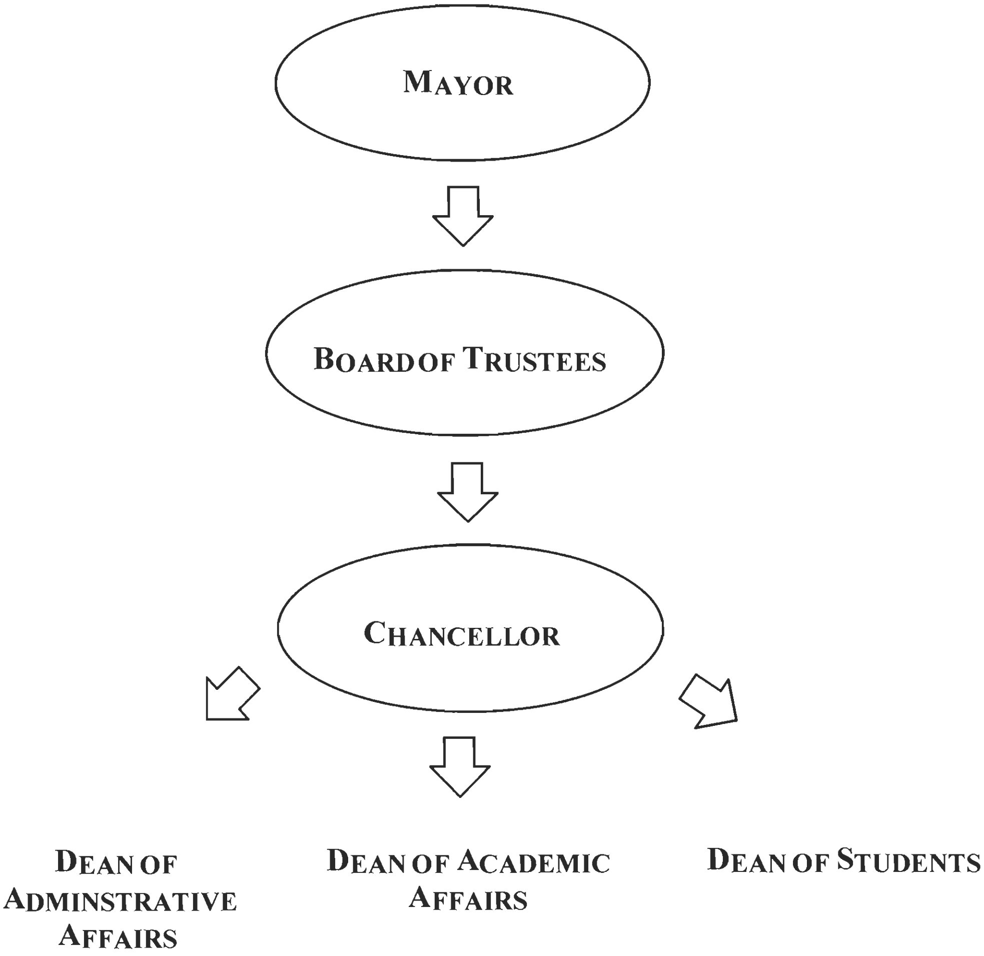

Figure A.1 Organizational chart for the administration of the Colegio Tecnológico de San Juan.

APPENDIX B
Summary of Interview with Dr. Dallas Alston

March 16, 2001
CIDACPR – Aquaculture Research Facilities in Lajas
University of Puerto Rico, Mayagüez

Dallas E. Alston, PhD
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University of Puerto Rico
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On Friday, March 16, 2001, two members of the WPI team traveled to Mayagüez to visit the aquaculture research facilities of the University of Puerto Rico. The team was accompanied by their project advisors.

The building contained eight holding tanks for tilapia and three larvae tanks for freshwater shrimp. The holding tanks contained "carpas", which are nets used to line the tanks in order to facilitate transportation of the fish. Tilapia of several sizes are maintained in these tanks before being introduced to the ponds. There were eight ponds at the facility that were 1,200 square meters (0.25 acre) each. These ponds are constructed so that there is a deep and shallow end to the pond. This characteristic allows the waste that is generated by the pond to accumulate on the deep end of the pond, thus allowing proper drainage through a standpipe. Furthermore, the inflow pipe and swivel drain allow for proper aeration and waste removals (Figure B.1.).

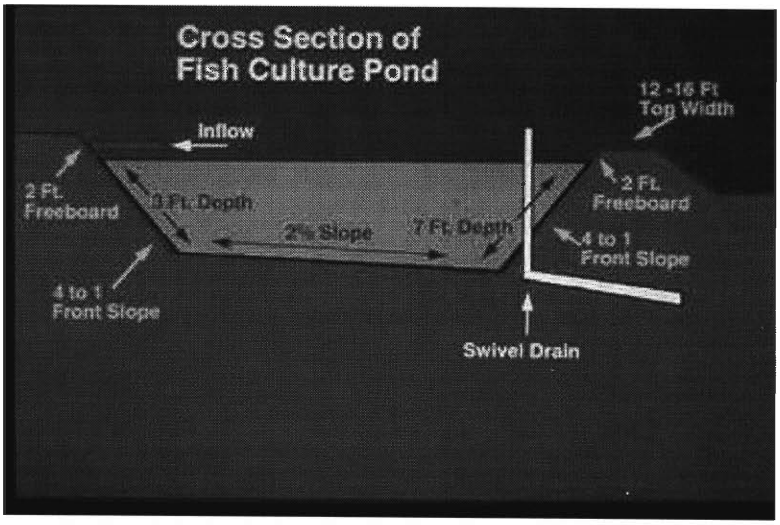

Figure B.1 Cross section of fish culture pond

In Puerto Rico, most extensive ponds use the westerly winds to promote the water flow and oxygenation. If stocking densities exceed pond capacity, aerators can be used. Dr. Alston indicated that one-acre ponds are considered commercial in Puerto Rico, but this size is relatively small by international standards. The ponds in this facility use clean water intended for crop irrigation and reuse it by filtering the water in a reservoir pond. Simple automatic feeders determine feeding regimes. Approximately 3 percent of the wet weight of the fish in a particular pond is an adequate quantity of feed per day. Algae growth can affect the dissolved oxygen concentrations of a pond and therefore should be removed accordingly. The carrying capacity of a pond will determine the optimum stocking density. Pond cages can be used to concentrate 250 fish in an area of one cubic meter. Nevertheless, one major drawback of cage culture is the possibility of theft. Tilapia is sold at a weight of two pounds. Dr. Alston warned that in order for extensive pond culture of tilapia to be profitable, 50 to 60 acres of ponds are needed, but he recommends at least 100 acres.

Although marine shrimp are more feasible, Dr. Alston discussed their choice of farming freshwater shrimp because of its high market value of $22.00 per kilogram of shrimp including the head. The three larvae tanks carefully control temperature, ammonia, dissolved oxygen and salinity. Hygienic conditions prevent the onset of diseases that are common in shrimp culture. Dr. Alston discussed the delicate balance between higher shrimp densities and healthy shrimp. He indicated that the larvae are very susceptible to changes in their environment. Diseases and high mortality rates have disabled operations for periods as long as six months. In extreme cases, all ponds must be drained and new shrimp strains must be used. Adequate shrimp densities will enable efficient operation.

Larvae hatch in the tanks and move towards a light source. Temperatures are kept between 28 and 30°C. They are fed artemia, custard, and vitamin supplements. Salinity is gradually decreased to acclimate the shrimp to a freshwater setting in a 28 to 35 day cycle. In extensive aquaculture operations, survivorship is approximately 45 percent. When the shrimp are acclimated, they are seeded in ponds according to their size. Shrimp can be cultured with tilapia, but water quality and pond capacity must be considered. Harvest occurs when the shrimp reach a weight of 45 grams. Regardless of market price, Dr. Alston mentioned that extensive shrimp culture is profitable if several large ponds are employed.

We then spent a considerable amount of time discussing the feasibility of extensive fish and shrimp farming. Dr. Alston indicated that land would be a major issue for the fishermen of San Juan, since they own less than five acres. He mentioned that 100 to 500 acres of ponds would be sufficient for the commercial operation of an aquaculture facility; otherwise, fish farming will only be a "hobby" and not an economically sustainable activity. After describing his research and credentials, Alston stated the possibility of an intensive operation involving circular tanks of 1,000 cubic meters. He provided us with a contact, Dr. Angel Olivares from the Department of Biological Sciences at the University of Puerto Rico, who has an intensive aquaculture system similar to the one Alston wants to implement. We discussed filtration systems, aerators, and waste removal systems that may be applicable. These facilities would require a substantial initial investment that might be financed by a research grant. This farming facility, although not particularly profitable for the fishermen, may provide an example for the further development of aquaculture on the island. Alston suggested contacting James Sarcozi from the University of the Virgin Islands to discuss the technical aspects of the intensive system and the possibility of coordinating efforts to create this pilot operation. Unfortunately, Dr. Alston does not think fishermen will be able to become successful fish farmers, since they have a "hunter" mentality whereas aquaculturists are "gatherers".

Dr. Alston then mentioned his current research regarding offshore cage culture of red snapper. These submerged cages have an area close to 3000 cubic meters. He believes that fishermen may be more likely to feed fish in these cages than to care for ponds. A proposal of this project has already been submitted, but the idea of using the fishing village of San Juan as a pilot study has never been considered. Offshore cage culture may be a practice more suitable for fishermen since it is closer to their current activities. Sea Grant has already provided information on this project. Finally, Dr. Alston provided insightful recommendations on the implementation of an aquaculture project for the fishing village of San Juan. These two alternatives may be successfully implemented if the appropriate funding and expertise is available.

APPENDIX C
Summary of Interview with Jesús M. Rodriguez

March 21, 2001
Centro Pesquero de San Juan, Puerto Rico

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San Juan, Puerto Rico 00908

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On Wednesday, March 21, 2001, the WPI student team traveled to a local San Juan fishing village consisting of twenty-six fishermen, ten of which are full-time. The village is located on government-owned land adjacent to the Parque Central. We first met the director of the village, Jesús Rodriguez. He gave us a tour of the facilities, including the fishermen lockers, docks, processing, plant, and store. Each fisherman is assigned one of forty-eight lockers to keep personal belongings and fishing gear. Many fishermen have been known to sleep in these personal areas.

The docks at the village were designed for small ships, since they are only 6 to 10 feet deep. This presents a problem for transportation of catch from the small boats to the processing facilities. Fishermen generally fish between the hours of 4pm and 7am. Their ages range from 54 to 78 years. Mr. Rodriguez stated that the level of interest in fishing has declined and the appeal to young people is almost non-existent, since financial rewards are not substantial and the industry has dwindled.

The fishing boats usually go four miles into the sea to begin fishing. A good catch would be approximately 80 to 100 pounds per fishing vessel. However, at times, poor catches may be lower than 75 pounds. Most of the catches include coli rubia, sierra, and chillo, but mero, palmo, and dorado are also caught. Due to seasonal weather variability, fishermen are only able to fish six months out of the year. A problem that has been encountered in the industry has been a lack of laws regarding the size of fish caught. According to Mr. Rodriguez, many fish are caught that are less than eight inches in length. Since these fish are not marketable, they are unnecessarily wasted. Furthermore, since these small fish are caught so early in their life cycle and are not able to reproduce, this increases the depletion of stocks in the ocean.

The majority of their fishing is done within the area from Vega Baja to Luquillo. Larger boats that are capable of deep-sea fishing produce catches ranging from 800-1000 pounds. Mr. Rodriguez stated that the only deep-sea fishing vessel that the village owned was stolen. The fishermen usually make approximately $2.50 per pound of fish caught, depending on the type of fish, while the village is sold to the public for approximately $3.50. Seven or eight local restaurants also purchase their fish from this facility. Mr. Rodriguez stated that in some cases, it is necessary to purchase fish from other villages or commercial vessels in order to satisfy consumer demand.

Mr. Rodriguez stated that the village was built on a 5-cuerda area of land (4.85 acres) owned by the municipality of San Juan. However, the main facilities occupied 3.1 cuerdas (3.01 acres) leaving 2.9 cuerdas (2.82 acres) for future expansion. The proposal for the fishing village was conceived in 1977; however, construction did not begin until 1995 and was finally completed in 1998. The plans included a restaurant, new docks, and a bait and tackle shop. The Municipality of San Juan intended to promote the development of tourism by attracting visitors to the fishing village. Unfortunately, according to Mr. Rodriguez, these plans have been delayed.

A copy of the plans for these facilities can be obtained at the Departamento de Urbanismo under the following heading:

Jimenez and Rodriguez
Barcelo A.I.A. Architects and Planners
EDA Project No. 01-19-03109

Mr. Rodriguez emphasized the fact that many changes have occurred due to political shifts. Therefore, political agencies that are intended to strengthen the fishing industry have been created and then dissolved leaving the fishermen without aid. He discussed the fact that CODREMAR, for example, was created to support the fishing industry but now no longer exists, for it is now part of the Sector Pesquero. Nevertheless, the Municipality is still concerned with the delicate situation of the fishing industry.

Upon our mentioning of cage culture as a supplement, Mr. Rodriguez showed evident interest but seemed concerned about the possibility of theft. He recalled previous cases of theft of lobster traps in the area. We further discussed cage culture with Mr. Rodriguez and a fisherman, Pedro Lopez Catala. Mr. Catala was primarily concerned with the amount of time and effort that aquaculture may require and would therefore take time away from fishing. The fishermen believed that regardless of the approach that is chosen, they would need to continue fishing. Furthermore, the two gentlemen expressed concern about the need for training and the possibility of seeking it at the Colegio Tecnológico. This would be especially beneficial if an alternative such as intensive aquaculture is desired. Mr. Rodriguez was genuinely interested in our proposal and expressed his desire to work with us. We concluded our interview by indicating our interest to work further with the fishing village after focusing the project to meet the needs of the fishermen.

APPENDIX D
Summary of Interview with Edgardo Ojeda Serrano

March 26, 2001
Sea Grant College Program
University of Puerto Rico, Mayagüez

Edgardo Ojeda Serrano
Asesor Marino
Sea Grant College Program / Pesquerías
University of Puerto Rico
Mayagüez, PR 00681-5000

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On Monday, March 26, 2001, a member of our project team interviewed Edgardo Ojeda Serrano from Sea Grant College Program at the University of Puerto Rico at Mayagüez. We had previously contacted him via email and telephone several times during the preliminary phases of the project at Worcester Polytechnic Institute. Mr. Serrano was, therefore, aware of the shift in focus of our project from traditional aquaculture systems to offshore cage culture.

Serrano discussed reasons why land-based aquaculture systems would not be feasible on the land of the fishing village of San Juan. Serrano described how the close proximity to a suburban area of San Juan would affect the quality of the water used in the aquaculture operations. He mentioned that several pollutants have been detected in waters of the region and the possibility of bioaccumulation of heavy metals in cultured fish is a major health risk. Since the land is also close to the fishing docks, gasoline and petroleum used for the engines of the boats could easily contaminate the water. According to Serrano, seawater can seep into the aquaculture system and affect the culture of freshwater fish, such as carp or tilapia. Therefore, costly filtering systems would have to be purchased in order to maintain appropriate water quality or use seawater for freshwater fish. Serrano emphasized that an extensive or even semi-intensive fish farming operation would not be economically feasible on less than five cuerdas (4.8550 acres) of land. In essence, the location of the land owned by the municipality of San Juan for the fishing village is not suitable for pond culture of freshwater species. Furthermore, Serrano mentioned that the expansion of the tourist industry would eventually absorb that land. Upon questioning him about the feasibility of a demonstration or pilot farm incorporating semi-intensive or intensive technology, Serrano warned that aside from also being subject to the limitations of land size, the fishermen are elderly and will experience difficulties learning the techniques. The socioeconomic aspects of the fishing industry complicate the transition to aquaculture, even if this is only considered a supplement to their current fishing practices.

We then discussed the possibility of offshore cage culture. Serrano participated in the creation of the proposal for the offshore cages near Isla Culebra. He is optimistic about such an endeavor for commercial purposes, but is skeptical about implementing it for a fishing village. Nevertheless, Serrano seems to indicate that the progress of the proposal for cage culture of snapper in Isla Culebra could lead to the implementation of similar projects around the island. He describes cage culture as a promising activity that could help revive the dwindling fishing industry Puerto Rico.

Serrano indicated that offshore cage culture is a new technology in Puerto Rico and has never been implemented on a full-blown scale since it still remains in the proposal stage. He suggested two species for cage culture: red snapper, *lutjanus aranis*; and red hind, *epinephelus guttatus*, called "cabrilla" in Puerto Rico. The project on Isla

Culebra has been delayed because of all the permissions and paperwork involved; however, Serrano seems to believe that this is only because it is the first project of its kind on the island. He also discussed how proposed changes in the regulations of the Department of Natural Environmental Resources of Puerto Rico concerning fishing would promote the implementation of offshore cages systems. Some of these amendments include regulations concerning limits on the size of fish caught and the distance, location, and type of aquaculture practices that can be implemented on the island. Mr. Serrano provided us with a copy of the proposed regulations and a pamphlet containing the forms and instructions necessary to begin any aquaculture operation in Puerto Rico. Finally, he provided a list of resources including several Sea Grant publications concerning cage culture that might be useful and directed us to the Administracion de Servicios y Desarrollo Agropecuario, ASDA, within the Department of Agriculture on the island. Upon leaving his office, Serrano mentioned that he is convinced that the fishing industry will eventually be revived once people begin to realize the demise of the industry and unemployment forces individuals to return to these practices. Ojeda Serrano invited us to come back or contact him if we need further assistance.

APPENDIX E
Summary of Phone Conversation with Dr. James McVey

March 30, 2001

Dr. James McVey
Program Director for Aquaculture
National Sea Grant College Program
National Oceanic and Atmospheric Administration
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Phone: (301) 713-2451 Extension 160

The conservation began with Professor Arthur Gerstenfeld introducing our project and group members to Dr. McVey. Adam Olean then spoke with Dr. McVey for approximately fifteen minutes.

Dr. McVey stated that Sea Grant was involved in an offshore cage culture project off the coast of Hawaii. This project was very successful and produced thirty-five tons of fish in approximately six months. Dr. McVey believes this is an enormous quantity of fish that will enter the marketplace. He also spoke about the Mediterranean region where Mediterranean seabass and seabrim are farmed in offshore cages. This additional quantity of fish entering the marketplace has caused the price of these species to decrease by fifty percent.

Dr. McVey felt that it is critical to determine the market for fresh fish on the island of Puerto Rico. He recommended investigating the tourists that frequent the island and how often they eat fish. He further suggested that we should determine what types of fish they prefer and how often they consume them. The season of consumption and the amount of fish that the locals consume will also be important factors in determining the dynamics of the Puerto Rican market. Personally, Dr. McVey feels that cage-cultured fish can be marketed as a very high quality fresh fish, describing it as a fish that can be placed on top of a "white table cloth".

Another important aspect is the location of the processing plant. Generally, when a fish is processed into fillets, fifty percent is discarded. Nevertheless, McVey indicated that this waste can be used to generate fishmeal, which is a crucial component in fish feed. Ideally all of this fish waste can be recycled.

Dr. McVey felt that we should consider the existence of feed plants in Puerto Rico. Do feed plants currently exist on the island, or will fish feed need to be imported? What are the costs of imported feed as opposed to local feed? Also, will cage culture in the Caribbean compete with or join the current fish suppliers? Currently ninety-five percent of Puerto Rican seafood is imported. Dr. McVey felt that as much profit as possible from a cage culture operation should stay on the producer level. Fresh fish versus frozen fish sales should also be considered. After this discussion about distribution channels, Dr. McVey concluded by telling us that time constraints would not allow us to consider all of these issues, but he hopes that he gave us some good ideas. He also mentioned that Dr. Wade Ronnabe of the University of North Carolina at Wilmington designed the hatchery for the Culebra project and might be of assistance.

McVey discussed the environmental considerations of cage culture. Numerous permits and on-site tests must be conducted before deploying the cages. This is the reason why the project at Culebra has not reached the operational stage. McVey provided contact information for the researchers involved in the project in Hawaii. He then discussed the need to obtain statistics on the market and production of fish in Puerto

Rico. Finally, he suggested a series of steps we must follow, and we concluded by arranging another phone interview on Tuesday, April 4, 2001. During that call we discussed the progress of our investigation and obtained more references from McVey.

APPENDIX F
Summary of Interview with Dr. Angel Olivares

April 10, 2001

Laboratorio de Peces
Invernadero #19
University of Puerto Rico
P.O. Box 21790, UPR Station
Rio Piedras, PR 00931-1790

Dr. Angel Olivares
Professor
Department of Biology
University of Puerto Rico

Phone: (787) 764-0000 Extension 7550

Dr. Olivares began by giving the WPI student team a tour of the intensive aquaculture system at the agricultural research center of the University of Puerto Rico, Rio Piedras. This system is used principally as a teaching facility for introductory-level biology classes. Dr. Olivares explained that he teaches non-biology majors the importance of nitrogen content, dissolved oxygen, and other factors and how these affect the growth of fish. The professor emphasized the importance of practical knowledge and therefore described how his course is designed to introduce concepts of science to non-biology majors.

Dr. Olivares designed and built this system six years ago. It is housed in a greenhouse and consists of four 2000-gallon tanks and a biological filter. Water is pumped at ninety gallons per minute into a bead-filter loaded with nitrifying bacteria. Dr. Olivares indicated that he teaches students how to calculate appropriate flow rates and bacteria concentrations required for adequate filtering of the water. He demonstrated that at peak growth stages, tilapia in tanks is capable of producing close to five milligrams per liter of ammonia and nitrites. The bead-filter is used to reduce the levels of these toxic substances to approximately one milligram per liter. The professor states that by allowing students to measure pH levels, dissolved oxygen concentrations, alkalinity, and other parameters, they then gain a better understanding of the role of these factors in the growth of living creatures. Dr. Olivares showed us the pumps, gauges, and tubes used to circulate and filter the water. He indicated that the system was not currently active, for he plans on including a tank with plants capable of utilizing the nutrients in the water. Aside from this objective, Dr. Olivares also desires to add two re-circulating tanks and a series of smaller tanks in order to cultivate smaller aquatic organisms. Dr. Olivares showed us an automatic feeder, worth about $75, and the air compressor necessary to aerate the tanks, costing close to $3,000. The professor ended the tour by stressing the costs required to run such a facility. Olivares indicates that filters, pumps, and air compressors all require electricity; and, regardless or re-circulation, water consumption is considerable. Upon asking him about costs, Olivares stated that his system was relatively inexpensive ranging between $40,000-50,000. Nevertheless, he warns that tilapia consume substantial feed: 500 pounds of feed for 2000-gallon tank every four to five months. Therefore, maintenance of such a facility is expensive.

We then discussed our interest in assessing the feasibility of an intensive aquaculture farm on the land of the fishing village of San Juan. Dr. Olivares stated that a commercial intensive aquaculture operation would require about forty acres of land. However, the San Juan fishing village could invest in a pilot farm that could lead to a large one. Dr. Olivares stated that such an operation would cost approximately 600,000-$700,000. In addition, the professor thinks that this operation would not be economically viable and would serve only as a demonstration. Dr. Olivares believes that the fishermen would require extensive training and would probably not be interested in taking part of a project that is not profitable. Dr. Olivares believes that environmental regulations would most likely prohibit the creation of an aquaculture facility in an urban area. Aside from stating concerns for the water quality in the area, Dr. Olivares discussed the threat of parasites from the brackish waters infecting freshwater tilapia. The professor described such a scenario and indicated that this is a common occurrence in tropical areas.

Dr. Olivares then stated that one of the main problems hindering Puerto Rico from becoming competitive in the aquaculture industry is the cost of labor. The professor indicated that the cost of labor in Puerto Rico is $5.70. In other countries, such as Columbia, Taiwan, and Ecuador, the cost of labor is much lower and the people work longer hours. Therefore, it costs much less to produce the same product. Dr. Olivares stated that in Puerto Rico it costs approximately $1.40 to produce one tilapia of market size, while in other countries it may cost as low as $0.75. Another example of higher prices is it costs approximately $40 for 1,000 post larvae prawns in Puerto Rico; however, in Columbia the price is $25. Dr. Olivares emphasized the need to investigate the cost of labor in Puerto Rico and incorporate these figures in our calculations. Finally, Dr. Olivares stated that another problem with intensive aquaculture is that it is typically intended for freshwater fish, and in Puerto Rico lacks a developed market for freshwater fish. Therefore, most of the fish cultured would have to be exported. Dr. Olivares concluded by stating that the land available for the fishing village of San Juan can only be used for a pilot intensive fish farm and not as an economically sustainable activity. The costs involved in starting and maintaining such an operation would be greater than the profits produced. Dr. Olivares therefore suggested that an intensive system would be feasible but not economically viable, and encouraged us to pursue offshore cage culture instead.

APPENDIX G
Summary of Phone Conversation with Mr. Greg Sangster

April 11, 2001

Greg Sangster
Ocean Spar Technologies, LLC
7906 NE Day Rd W
Bainbridge Island, WA 98110

Phone: (206) 780-0992 Extension 178

On April 11, 2001, a member of our project team conducted an unstructured phone interview with Greg Sangster of Ocean Spar Technologies, LLC. He provided information regarding startup costs for offshore cage culture.

One SeaStation™ 3000 cage system cost $90,000. With the necessary technical support and labor to install the cage, the price increases to $110,000. Other costs associated with the cage include $4500 shipping and the anchors. Each cage requires four five-ton anchors that cost between $700-800. The anchors are almost always purchased in the vicinity of the site location, as it is impractical to ship them. Ocean Spar Technologies, LLC does not sell the anchors and they must be purchased from another vendor. It is also the responsibility of the customer to provide the necessary boats and equipment to unload the cage, bring it out to sea, and moor the cage.

Ocean Spar Technologies, LLC is hoping to start producing cages in China would result in cheaper prices. Stocking densities of the SeaStation™ 3000 range from 10 to 30 kilograms per m^3 depending on the species cultured. Mutton snapper can be stocked at a density of 15-20 kilograms per m^3. If fish cannot be produced for $2 per kilogram, then the operation will not be profitable. Generally, mutton snapper with head on and gutted sell for $10 per kilogram.

Although the Ocean Spar cages seem expensive, they have a lifespan of ten years, which includes the netting. When this initial investment is distributed over time, the price is not as high as it seems. Feed costs are generally 54 percent of the total production cost.

Greg emphasized that we must consider the fact that when the fish produced are sold at market, this excess supply will cause a drop in price. Therefore, a lower margin will result. However profit is made by selling a large volume of fish to offset this lower margin. He cited the salmon industry as an example of this.

APPENDIX H
Summary of Phone and Electronic Mail Conversations with Brian O'Hanlon

April 17, 2001

Mr. Brian O'Hanlon
President Snapperfarms, Inc.
P.O. Box 325
Greenlawn, NY 11740
Email: brian@snapperfarm.com

Work Phone: (516) 707-0594
Home Phone: (617) 261-4180
(631) 271-4796

The following is the transcript of a structured interview we conducted with Brian O'Hanlon via electronic mail on April 17, 2001.

1. How long would a cage culture operation utilizing the SeaStation^{TM} 3000 cage and mutton snapper as the species selected take to reach a break-even point? How many cages are being used in this analysis?

With good financial planning and good management strategies, the operation can be profitable with one cage. With two cages fully stocked, we project that our project will break even in our second year of operation.

2. What markets would be targeted with any fish produced?

We plan to export the majority of our product. We do not want to compete with local fisherman for the markets in Puerto Rico. If we start introducing thousands of pounds of snapper into the Puerto Rican markets the market price can drop and hurt the fisherman. So, we plan to sell most of our product in New York, Miami, and other east coast cities. Eventually, we would like to look at other markets in the United States, Caribbean, South America, Europe, and Asia.

3. What is the status of the permitting process? Do you feel that it is too long? How long have you been waiting for approval?

Yes, it is too long. We have been working on this permit for over a year now. But we have to consider that this is a new technology and not many people in the regulatory agencies know that much about it. Things are moving along well for us now, we anticipate approval very soon. We made a mistake by submitting the application right before an election. That slowed us down. We feel that over the next few years, as the technology become well known; the permitting process will become much more streamlined.

4. What feed types do mutton snapper use? Are feeds readily available on the island or do they need to be imported?

We plan to import feed from Burris, a specialty feed company in Louisiana. As part of our project we are going to look at the feasibility of producing our own feed locally, in Puerto Rico using locally available materials. Burris Aquaxcel 5313 is 53 percent protein, 13 percent fat, 10 percent moisture, 13 percent ash, and 1 percent fiber.

5. Is insurance something that is being considered for purchase?

   Definitely! We are purchasing blanket coverage for our cages, equipment, and fish stock. The stocks are actually the most expensive part of the insurance. We don't know the exact rate yet, but we are looking at anywhere between $30,000 and $50,000 a year.

6. Is the government allowing snapper farms exclusive use of ocean waters?

   We do not know yet. We are discussing that with the permitting agencies.

7. Is there a location to store feed?

   A partner in the project is the Culebra Fisherman Association. The Association is providing land facilities and personnel. We are going to have a large cooler on the Association's property to store feed and other equipment.

8. How many personnel are needed to operate the cages? Is special training needed?

   This will vary. To operate one cage you would probably need a total of three people for every day of operation, one boat captain and two workers / divers. Certain duties, such as installing the cages, stocking the fish, cleaning the cages, harvesting the fish, and processing the product, require additional workers. For example, for our project we plan to have two extra divers when we stock, clean, harvest; and we intend to have ten people processing and packaging the fish.

9. Where are the fish being processed? Is the gutted out part being discarded or used to make fishmeal?

   Initially, during the first two years of our project, we will use the facilities of the Culebra Fisherman Association. As the project develops and expands, we plan to construct a processing facility. We want to recycle all possible waste. We plan to work with a local feed mill to try and develop feed using our scrap meat.

In addition, Mr. O'Hanlon described the costs associated with a one-cage operation. He stated that the stocking density of the Ocean Spar SeaStation^{TM} 3000 is thirty-six mutton snapper fingerlings per cubic meter. Therefore, 97,200 fingerlings can be cultured in each cage, considering a working volume of 2,700 cubic meters. O'Hanlon also mentioned that the average growth rate for mutton snapper in the cage is approximately 41.66 grams per month. Therefore, twelve months would be required to harvest the fish at a weight of 500 grams. As Brian O'Hanlon explained, mutton snapper can also be harvested at 700 grams, as the fish will quickly gain 200 grams in two additional months of culture.

O'Hanlon indicated that a mortality rate of 15 percent was derived from previous cage culture projects in Hawaii. Growth depends on the feed conversion ratio, which is approximately 1.2:1 for mutton snapper. O'Hanlon explained that feed for mutton snapper can be purchased at Burris, Inc. in Louisiana for $0.77 per kilogram. He also stated that fingerlings can be purchased at the Florida Keys Aquaculture Center for $0.50 with shipping costs of $0.05 per fish.

O'Hanlon further explained that only 80 percent of the weight of the harvested fish will be suitable for market, since gutting is required. According to Mr. O'Hanlon, processing, packing, and shipping will cost approximately $1.10 per kilogram of fish. Brain O'Hanlon stated that labor would account for approximately $79,200 per year with a yearly insurance premium of $38,800 for each cage. Another cost that was taken into account was the mandatory environmental assessment, which includes the testing and research to ensure the operation is environmentally sound. This environmental assessment will cost approximately $12,000 per cage for every year of operation.

APPENDIX I
Summary of Phone Conversation with Richard Taylor

April 19, 2001

Richard Taylor
Fisherman
Gloucester, Massachusetts

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On April 19, 2001, a member of our project team conducted an unstructured interview with Richard Taylor. As background information, in 1995, Richard Taylor received funding from the United States Department of Commerce to start a small shellfish cage culture research operation for sea scallops in Gloucester, Massachusetts, about 40 miles north of Boston, where he has been a fisherman for many years. Currently, Mr. Taylor is a member of three volunteer Advisory Panels, including Habitat, Aquaculture, and Scallop, for the New England Fishery Management Council, and is one of four appointed industry representatives on the Research Steering Committee, a joint industrial/government panel that determines research objectives and reviews proposals for funding. The National Marine Fishery Service has also hired him as a scallop fishery specialist for five separate scallop survey trips. He has also been working recently on a scallop research project in conjunction with Dr. Scott Gallagher at the Woods Hole Oceanographic Institution in Massachusetts.

Richard Taylor began commercial fishing in 1968, and after years of working on many vessels, Mr. Taylor bought a 25-meter scallop boat in 1990 that could easily handle the tanks for holding seed, large cages, and anchors necessary for the strong tides and currents off the shore of Massachusetts. Some scallops were distributed to grow on their own and then be harvested by the normal scallop dredge method to remove the cages from the economic equation. One reason for less focus on cage-based aquaculture was the enormous and unplanned success of the use of closed areas offshore for the rebuilding of scallop populations. Several large areas, totaling approximately 6,000 square miles, were shut down to mobile gear in late 1994 to protect dwindling fish populations. Those fish stocks have generally begun to increase, and the scallop biomass has improved by approximately three orders of magnitude to the point where there now exists more than anyone alive has ever seen.

Mr. Taylor stated that aquaculture is not necessarily a polluting technology. He believes that the major problem with aquaculture is the legal battles that are involved. Many people have been driven away from the aquaculture industry due to the difficulties involved with permits and regulations rather than environmental issues.

Mr. Taylor discussed the integration of fishermen in the aquaculture industry. There was a steep learning curve since fishermen knew all too well where to find the fish and how to bring them to market, but very little about the skills needed to keep them alive and have them flourish. Richard Taylor stated that there is one serious difference between fishermen and aquaculturists. Fishing is about an immediate return; the harder you work, the more money you make since each crew member is given a portion of the profits after each fishing trip. For the workers in an aquaculture operation, they are paid by the hour with little chance of having the big day where many fish are caught or a bad day where none are caught. Furthermore, in the aquaculture industry, workers must spend hours working and may only receive income at the end of the harvest season. Workers must feed their fish daily and wait an extended period of time before profit can be obtained. Unlike fishing, aquaculturists are rewarded for stewardship. Profit is obtained only when the fish are sent to market. Richard Taylor remarked that the best approach to marketing is to facilitate several aquaculture operations and arrange the harvest cycles so that marketing of the fish product can become a regular occurrence. Minimizing lag time between cycles is key to a successful aquaculture operation. Furthermore, aquaculture involves labor costs and other expenses, which may have to be provided by a corporate sponsor. Costs required for research time in the labs must also be considered. These costs are not necessary in the fishing industry. Richard Taylor discussed the advantages to training fishermen for aquaculture. These advantages are as follows:

1. Familiarity with the local waters, the local weather, preparedness, small boat handling, and safety at sea are learned over a long time.
2. Buy-in from fishermen is critical in terms of siting. If you put an aquaculture operation on top of an area that has long been a productive fishing area you start off on the wrong foot, so to speak, building opposition from the start.
3. Having an already capitalized vessel is a major economic asset in a startup operation. The economics are tight to begin with, especially since you have to purchase small fish, feed, and cages up front and pay for the labor to keep things going until you can sell the first batch of fish, which may be a matter of many months. Trying to capitalize a vessel on top of that without any sales for the long lag period just makes it worse.

After a considerable literature search, visits to researchers and aquaculturists along the east coast of the United States and calls to those he could not visit, Mr. Taylor and his crew built cages out of the coated wire mesh used locally for lobster traps, added a steel frame for strength, and cast anchors out of excess concrete available at a local mixing plant. The projects were not very successful for scallops, for they are very sensitive to drying out and warm or freezing temperatures, but these attempts provided insight into animals that will work, such as oysters, mussels, and several clam species. Additionally, the funding coincided with major cutbacks in the local fisheries and there was serious opposition to "newfangled government sponsored projects". The funding is now long over, but he continues to be active in various groups trying to institute future ideas into the management process. Mr. Taylor stated that the most critical issues to consider for cage culture are:

1. The inclusion of existing fishermen in your project: the more the better. They already have capitalized vessels and the local knowledge and other skill sets to deal with marine operations.
2. A secure area for a 'farm', selected with the help of fishermen. The site selected must not disrupt existing fishing activities.
3. A dependable source of seed for the species cultured.
4. A carefully detailed economic analysis or business plan that lays out the direct costs of seed, labor, and associated gears that must be balanced against the future sales to produce a profit. In short, if you had enough money to scale up a pilot operation, would it be a good investment or use of funds. Boat and vessel operation costs have barely been mentioned but are also significant.

5. Political and permitting support from government and local bodies. Where this idea (shellfish growth) has taken hold is in regions where the regulatory bodies have dedicated areas and the will to 'make it happen'. Often the existing body of law almost prevents it from occurring.

He further discussed other important factors such as the optimization of feed conversion. A feed conversion ratio of nearly 1:1 would be excellent. Importing the feed is a possibility, but it may be expensive, so shipping and import costs must also be optimized. One-year harvest cycles would be the best approach rather than three-year cycles, since this approach will minimize risk and maximize market time. He emphasized that economics are very critical and that the time from project startup to marketing must be minimized. Furthermore, shorter harvest cycles will decrease the chances of an entire harvest being lost to disease or theft.

Mr. Taylor stated that the best approach to implementing cage culture is to start small-scale, since this would be less expensive. Once enough experience has been obtained, the operation can expand. A ship of at least 35 to 40 feet would be required to maintain a cage culture operation. Mr. Taylor had a 75-foot vessel for his operation, but this ship cost $500 per day in gasoline alone.

He stated that site-selection is key and site problems must be addressed first. In Maine, for example, they have cages called diapers, which they wrap tarp underneath and around the cage to make sure waste and feed do not escape. He stated that since Maine has 40-foot tides, lack of adequate aeration is not an issue. Nevertheless, Mr. Taylor warned that this issue might be a problem in locations without such high tides.

APPENDIX J
Summary of Phone and Electronic Mail Conversations with Harry Ako

April 19, 2001

Harry Ako
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Phone: (808) 956-2012

On April 19, 2001, a member of our project team conducted an interview with a professor of Molecular Biosciences of the University of Hawaii, Harry Ako. Professor Ako is currently working on a cage culture project in Hawaii that is attempting to initiate the first successful open ocean aquaculture venture in the United States. He has also had experience with cage culture in Norway.

Professor Ako stated that the best approach is to start a small operation that is easy to maintain. He remarked that small cages should not be used, but a simple operation would the best way to begin. Leaving the cages on the surface of the water would be an excellent approach to start off; however, if theft presents a problem, submerging the cages may be the only option.

Professor Ako discussed that cage culture requires very physical work and that most people retire from the industry by the age of thirty-five, since they are not able to handle the strenuous work. He emphasized that open ocean aquaculture is for dedicated people willing to work hard and possibly risk a lot of money. In addition, Ako stated that cage culture has existed for well over ten years in the Mediterranean, Asia, Norway, Scotland, and Chile.

Professor Ako indicated that the first objective is to determine a species to farm. From the species selected, the market, feed conversions, and biological concerns must be analyzed. Startup requires a net cage ($100,000), a boat ($40,000), feed ($100,000), fry or fingerlings ($30,000), and miscellaneous other expenses including labor. He warned that one must be careful with shipping costs, since they can become unnecessarily expensive. Another important concern that he mentioned was to investigate where to obtain fingerlings and feed in order to minimize costs. He believed a local provider of fingerlings and feed would be very helpful. Boats with aerated tanks are used to transport the fingerlings. However, this may become very expensive since the tanks are large. The process of obtaining permits has always been frustrating, he explained, since the technology is still in the development stages.

Professor Ako has been working in Hawaii on their offshore cage culture operation for two years and discussed some of the information about that project. The University of Hawaii project has cages that are 37 kilometers offshore and 12 meters below the surface of the ocean. A tube is used to feed the fish and stock the cages with fingerlings. The cages are submerged in order to avoid conflicts with other users of the ocean, protect the cages against any natural damage, and deter theft. Professor Ako explained that people would not steal what they cannot see. In Vietnam, they have placed dogs on the cages to prevent theft. Submerging the cages also preserves the beauty of the ocean waters. However, the depth has increased operating costs.

For the Hawaii project, only 60 percent of the fish placed in the cage survived until harvest. Since the mortality rate should not reach 40 percent, he believed that there is a problem with cannibalism, and they need to re-evaluate their feeding practices. Professor Ako stated that the cage could be expected to yield approximately 27,000 kilograms of fish in six months. They are trying to sell the fish for $1.80 per kilogram.

Most of the maintenance workers that have been hired are out-of-work fishermen. Three or four divers were hired to maintain the cages, and they are paid $15 per hour and work approximately 20 hours per week. When the cages were first placed in the water, the divers needed to clean the cages, but now, since reef fishes live around the cage, they eat the algae and naturally clean the cage. Furthermore, since the current in this area is measured at one knot, water exchanges completely through the cage twice a minute. Pollution is approximately 50 parts per billion, according to Professor Ako.

An interesting fact that Professor Ako discussed was that Hawaii has been making profit from the cages since tourists have paid money to see them and dive down to see the fish. Many organisms live underneath the cage. Due to the material that accumulates on the ocean floor, there is an increase in worms, which attract (pelagic) fish. Also, a Japanese species of fish, *Hamachi*, lives underneath the cage. Professor Ako is unsure as to why they live there, but he thinks they are eating the food that falls from the cages. At times, turtles and whales visit the cage. However, The cages present no conflicts with the wildlife. Since they are very strong and made of space age netting, no cases have been recorded of fish escaping from the cages in Hawaii. Therefore, the risk of the dilution of the genetic pool caused by escapees is extremely low.

Professor Ako described a social hurdle that they have overcome. Native Hawaiian groups announced that they were opposing their efforts because the open sea around the Hawaiian Islands was stolen from them. The problems with native Hawaiians have been going on since Hawaii became a state in 1959.

Professor Ako has also had experience with offshore cage culture in Norway, where open ocean aquaculture is the largest export industry after oil. Norway has a 2-year junior college program to teach fishermen the skills necessary for cage culture. The curriculum includes rudimentary feeding, boat repair, disease prevention, and moving cages. Farmers must obtain their license before they may practice cage culture since the government wants to ensure that no aquaculture facility is destroying the environment and causing problems for the industry. The people of Norway believed that one day, their oil resources would not always be so plentiful and they would need another source of income. Therefore, many people began working in cage culture. Each fish farmer in Norway is allocated an area of ocean space to practice cage culture. However, since the density of cages is so high, farmers are required to move their cages every two years to preserve the condition of the ocean floor and surrounding waters. The cages in Norway are located in very secluded areas to reduce user conflicts.

APPENDIX K
Summary of Phone Conversation with Sebastian Belle

April 20, 2001

Sebastian Belle
Maine Aquaculture Association
Box 148
Hallowell ME 04347

Email: sebastian.belle@state.me.us
Phone: (207) 622-0136

On April 20, 2001, a member of our project team conducted an unstructured phone interview with Sebastian Belle of the Maine Aquaculture Association. Sebastian Belle has been working in the cage culture industry for twenty-two years and began doing offshore projects eight years ago.

Sebastian Belle stated that the majority of offshore cage culture projects in the United States have been established for research purposes and few people have experience with the actual implementation. He added that cage culture experts in the United States will act as consultants for future projects but may not have the required experience to implement an offshore cage culture operation.

Mr. Belle discussed the training and education required for offshore cage culture. Aquaculture and cage culture curriculums are usually based on some sort of ground experience. He emphasized the fact that many people obtain their bachelor's or master's degree thinking that they have the expertise to run an aquaculture facility. Mr. Belle stated that the most effective way to implement a cage culture project in a small village is to carefully select people to send to educational programs and others to work in the aquaculture industry. Then, when these people return to the village, the village will have the technical and practical expertise that will be required to implement this technology. Mr. Belle believes the best way to approach this industry is to start in the trenches, and move from the ground up. He stresses that work experience based on a strong education is vital to success. He adds that not many college programs offer guidance on production practices and planning and physiological impacts. Furthermore, most of the information learned is theoretical and does not apply to the real world, especially when species, location, and other factors change.

Sebastian Belle mentioned a five-year apprenticeship program that exists in Norway, where students attend school for four years and gain work experience at a fish farm for a year. This program covers subjects such as fish biology and physiology, and the last year is a period of "grunt work," where students will work on an actual fish farm.

APPENDIX L
Summary of Phone Conversation with Gary Loverich

April 23, 2001

Gary Loverich
Chief Engineer/Chairman, Co-PI
Ocean Spar Technologies, LLC
7906 NE Day Rd W
Bainbridge Island WA 98110

Phone: (206) 780-0992 Extension 135

On April 23, 2001, a member of our project team conducted an unstructured interview with Gary Loverich, the chief engineer and chairman of Ocean Spar Technologies, LLC.

Mr. Loverich explained that it would be nearly impossible to generate profit using one cage in an offshore cage culture operation. He further stated that labor costs would remain the same for operations with up to five cages. Hence, it would be much more profitable to implement more than one cage. He explained that two men could maintain five cages working full-time. Gary Loverich explained that since the implementation of offshore cage culture will drive the market prices down, profit would not be obtained through increasing production. Profit is obtained through optimizing operations. Efficiency in areas such as feed conversion and labor is necessary to maintain an economically profitable industry.

He discussed that Ocean Spar Technologies, LLC has considered designing a special vessel that would be able to maintain 15 cages while only requiring two operators on the ship. This is an excellent example of the optimization of labor. He stated that the weather has an effect on many factors in offshore cage culture. Since workers may not be able to tend to the cages in severe weather, labor costs may be wasted. Furthermore, the weather may have an effect on the amount of cleaning that will be required of the cage. If biofouling of the cages presents a problem in a certain area, then the cost of labor would increase since the cages would need to be cleaned more often. He also mentioned that an excellent approach to offshore cage culture would be to have two crews. One crew would be responsible for cleaning and maintaining the cage and the other would be responsible for husbandry. Frequently, fish farmers become so concerned with the husbandry of their fish that they forget to clean and maintain their cages. This has become a major problem for many offshore cage culture operations. However, employing two crews ensures that all the duties, including cleaning, maintaining, and feeding, are completed.

Mr. Loverich remarked that the government has funded many cage culture operations while others have been privately funded. He stated that many people try to buy more inexpensive cages to minimize startup costs. Nevertheless, this becomes a problem because many cheap cages have fallen apart after one year in the water and frequently before a harvest all the fish have been lost due to poor cage design. Specially designed Ocean Spar cages usually last over 50 to 60 years with the nets being replaced every 10 years. These cages can withstand currents measuring a maximum of 2 to 2.5 knots.

Mr. Loverich mentioned that a 1:1 feed conversion ratio is very unlikely to obtain, and the highest that he has seen was a 1.25:1 while farming salmon. This salmon farm used three cages in Washington State and was able to produce a profitable venture. Mr. Loverich mentioned that feeding the fish by hand has always been an efficient practice.

Based on the behavior of the fish during feeding, the fish farmer can optimize the amount of feed given to the fish and determine when the fish may be sick.

Mr. Loverich stated that the only training that would be required for offshore cage culture would be a week of work with someone who is familiar with the practices of the operation. He believed that the cages are fairly easy to maintain and only require some mechanical ability and a willingness to take part in physical labor.

He believed that environmental concerns have played a major role in the industry. Mr. Loverich stated that it is very important to place the cages in deep waters so the cages do not pollute the small bays or other enclosures where there is relatively no water exchange. Furthermore, an area with high currents is favorable to disperse any effluents that may result from the cages. Mr. Loverich mentioned that in Hawaii, however, where there is minimal water exchange, there was only an insignificant trace of pollutants on the ocean floor and surrounding waters.

Finally, he discussed that Ocean Spar cages are fairly easy to move and can be submerged as low as 30 meters. Ocean Spar has been working with the Massachusetts Institute of Technology on an automatic feeder for the cages that may be used during inclement weather. However, Mr. Loverich believed that there are some advantages to visiting the cages on a daily basis. These advantages include being able to assess the health of the fish and the condition of the cage. Since Puerto Rico is located in a hurricane-prone area, he explained that an operation should be implemented in the calmest possible waters. This should be done for the sake of the crew since any disturbance in the water can complicate the maintenance of the cages.

APPENDIX M
Excerpt from the Washington Country Technical College Course Catalog
Aquaculture Program

Adapted from: http://www.wctc.org/camt.html (Refer to WCTC, 2001)

MCT100 INTRODUCTION TO AQUACULTURE OPERATIONS

This course provides the student with an introduction to the skills that are needed to function as an aquaculture worker. The skills to be taught will be cold-water safety/survival, knot typing and splicing, use of marine hardware and safe working loads, introductory net mending, ergonomic work practices and operational practices that will prepare the student for conditions and expectations at aquaculture growout sites.

MCT110 FINFISH HUSBANDRY

In this course the student will be introduced to principles common to all finfish species raised in the fresh or marine environment. Animal behavior, feeding regimes and technique, care and handling of product and personal hygiene with respect to the aquaculture environment will be discussed. In addition to biological considerations, the student will be introduced to the key points of system maintenance, predator control, operation of on site mechanical systems and observation that is critical in the day to day operation of an commercial aquaculture growout. Finfish will be emphasized.

MCT150 INTERNSHIP

This internship will be external to Washington County Technical College and undertaken as an employee of a commercial salmon growing company. Internships will be arranged for students to enable them to participate for a 45-hour commitment experiencing a variety of operational and working conditions common to the growout of Atlantic salmon.

MCT170 AQUACULTURE AUTOMATION

This sequence will introduce the participant to the common types of automatic equipment used in the feeding, grading, biological analysis and movement of cultured aquatic animals. Participants will also be introduced to current versions and simulated use of current farm management software that may be integrated with physical operation of equipment. Processing and shore-side handling equipment will also be covered. This course will cover aspects of microprocessor control, setup, calibration and minor repair of these systems.

MCT200 SHELLFISH HUSBANDRY with LAB

This course will focus on the culture and rearing of shellfish from natural and hatchery environments through growout. Course content will cover current viable growout systems from re-circulating to benthic and suspended in natural environment. Stock management will be overviewed from assisted spawning to natural spat occurrence and collection.

MCT210 AQUACULTURE TECHNOLOGY

In this course the student will be involved in the setup and operation of a shore-based animal holding system. Skills will involve design and construction of water transport, filtering, temperature, oxygenation and proper sizing of tanks and piping. Skills and knowledge will be introduced in waster flow and pressure as well as basic plastic and metal plumbing.

MCT240 FISH HEALTH

The student will examine parasites, bacterial and viral disease known to occur in the culture of aquatic animals. In this course, the student will be taught technique to prepare samples and perform basic analysis of samples for preliminary determination of aquatic animal health problems.

MCT250 INTERNSHIP II

This internship will be done at a shellfish or aquatic plant site. Procedure and objectives will follow the structure of the previous internship but in a shellfish/marine plant setting.

MCT270 AQUACULTURE PROJECT

This course will provide the individual student to become involved in a personal interest from a range of commercial or pre-commercial specie-related topics offered by the Aquaculture Technology staff. This will enable a student to research a specie or process that may address a technical problem in the commercial development of that specie or process. This course is only available to students who have completed all technical requirements of the AAS credential in Aquaculture Technology.

APPENDIX N
List of Abbreviations

ACOE	United States Army Corps of Engineers
CIDACPR	Centro de Investigación y Desarrollo de la Acuicultura Comercial en Puerto Rico
CMP	Coastal management programs
CMRC	Caribbean Marine Research Center
CZMA	Federal Coastal Zone Management Act of 1972
DNER	Department of Natural and Environmental Resources
EPA	United States Environmental Protection Agency
FAO	Food and Agriculture Organization
FDA	United States Food and Drug Administration
FWS	United States Fish and Wildlife Service
HACCP	Hazard Analysis Critical Control Point
HOARP	Hawaii Offshore Aquaculture Research Project
INAD	Investigation New Animal Drug
IQP	Interactive Qualifying Project
JSA	Joint Subcommittee on Aquaculture
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination Systems
OSHA	Occupational Safety and Health Administration
UPR	University of Puerto Rico
USCG	United States Coast Guard
USDA	United States Department of Agriculture

APPENDIX O
List of Interviews

Dr. Dallas Alston	Professor of Aquaculture	March 16, 2001	Appendix B
Jesús M. Rodriguez	Director of San Juan Fishing Village	March 21, 2001	Appendix C
Edgardo O. Serrano	Sea Grant College Program UPR Mayagüez	March 26, 2001	Appendix D
Dr. James McVey	Program Director for Aquaculture	March 30, 2001	Appendix E
Dr. Angel Olivares	Professor	April 10, 2001	Appendix F
Greg Sangster	Ocean Spar Technologies, LLC	April 11, 2001	Appendix G
Brian O'Hanlon	President of Snapperfarms Inc.	April 17, 2001	Appendix H
Richard Taylor	Fisherman	April 19, 2001	Appendix I
Professor Harry Ako	Professor of Molecular Biosciences	April 19, 2001	Appendix J
Sebastian Belle	Marine Aquaculture Association	April 20, 2001	Appendix K
Gary Loverich	Chief Engineer of Ocean Spar Technologies LLC	April 23, 2001	Appendix L

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