Environmental and Social Impact of Sustainable Offshore Cage Culture Production in Puerto Rican Waters

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Abstract

This project was the first large-scale environmental evaluation of open-ocean submerged cages in the Caribbean to assess the technological feasibility and possible environmental effects involved in adapting cutting-edge technology to culture Lutjanus analis (mutton snapper) and Rachycentron canadum (cobia) in submerged open-ocean cages in Puerto Rico. The study provides "base-line" information that will be useful as the open-ocean aquaculture industry expands. The information obtained from this project provides a basis for Puerto Rican authorities and the private aquaculture industry to evaluate the feasibility of this operation. This project used the "shotgun" approach to select the most important water and sediment quality variables and their effects on the local environment. The study determined if the cages served as fish aggregation devices (FADs), the concentrations of nutrients in the water and sediment; effects on the benthic community, and the rate of biofouling growth. Currents were monitored at the control site located 375 m from the cage site. Results indicated no evidence of anaerobic sediments beneath the cages, inorganic nitrogen near the cages was similar to background levels, macroinvertebrates populations and sediment were only affected directly beneath the cages just before harvest when feeding rates were highest. Many wild fish (40 species) were attracted to the cages. As more cages are installed, especially if stocking rates are increased, focus should be made on the sediment, especially just before harvest; possible effects on distant coral reefs, and to determine the positive or negative interactions by having wild fish attracted to the cages. Because biofouling grows rapidly (and needs to be cleaned biweekly), it should be evaluated to remove nutrients from the water column to ameliorate effects on the environment. Knowledgeable residents near the project had a positive attitude concerning the open-aquaculture project; however, 55% of the members of the general community of Culebra did not have general or specific knowledge about the open-ocean aquaculture project and did not have specific information about the advantages or disadvantages in relation to the impact on economy, fishing, fishermen, or community life. It is important to increase their knowledge by developing an informative program.

Project Summary

This project was the first large-scale environmental evaluation of open-ocean submerged cages in the Caribbean. This study is part of a demonstration project combining forces with the University of Miami, RSMAS, Snapperfarm, Inc., and the University of Puerto Rico to assess the technological feasibility and possible environmental effects involved in adapting cutting-edge technology to culture Lutjanus analis (mutton snapper) and Rachycentron canadum (cobia) in submerged open-ocean cages in Puerto Rico. The study provides "base-line" information that will be useful as the open-ocean aquaculture industry expands. One Ocean Spar Sea Station 3,000 m^3 cage was stocked with 4,000 L. analis (1.3 fish/m^3) and the other with 12,000 R. canadum (4/m^3). Because the R. canadum is expected to grow about 4 kg or more within one year, they should be

stocked at a lower density than that of the L. analis. Because of the smaller size of the L. analis, their stocking rate was low. Rachycentron canadum are stocked at 4-6 fish/m3 and harvested at 6-10 kg/fish in Taiwan, so stocking rates were similar to those used in Taiwan. The information obtained from this project provides a basis for Puerto Rican authorities and the private aquaculture industry to evaluate the feasibility of this operation. This project used the "shotgun" approach to select the most important water and sediment quality variables and their effects on the local environment. The study determined if the cages served as fish aggregation devices (FADs) to increase natural fish biomass at the cage site. Benthic macroinvertebrate populations were studied to determine effects of nutrient wastes on the sediment biota. The rate of accumulation and coverage of biofouling organisms attached to the surface of the cage netting were assessed because they obstruct water flow through the cages, add additional weight to the cage, and increase net drag. Currents were monitored at the control site using an InterOcean S4 for one year.

The study covered the period from June, 2002 until October, 2003 and studied two Ocean Spar Sea Station™ 3000 m^3 submergible cages installed in 28-m deep water stocked during August 2002 with either L. analis (4,000) and R. canadum (12,000). Fish were fed ad libitum (by having a diver monitor the feeding response). The FCR after one year of culture was 1.95 because Snapperfarm extended the harvest procedures over an extended period due to several operational factors. A nitrogen budget indicated 3800 kg of nitrogen (in feed) fed to caged fish resulted in 18% retained in the fish crop, 66% excreted as ammonia, 3% from in fish mortality, and 13% unaccountable (but assumed to be feces and feed wastes). Snapperfarm operated the submerged cage site as a commercial venture throughout the study.

The mid-water currents of the control site monitored with the InterOcean S4 were characterized by the following: northwestward flow (towards 300°-320° true) during flood tide (as the sea surface elevation increases); southeastward flow (120°-140° true) during ebb tide; strong semidiurnal (two cycles per day); and weaker diurnal (one cycle per day); tidal components with maximum amplitudes of 20-30 cm/sec; mean, or low-frequency, northwestward flow with a year-long mean towards 301° true at 8.4 cm/sec; tidal ellipses elongated along bottom contours to the point of nearly a straight line so that changes in direction occur very quickly; little transport towards land; and velocity vectors swing back and forth across the offshore hemisphere. Currents assisted with the dispersion of solid and dissolved nutrients released from the cages.

Bimonthly chemical and macroinvertebrate sampling was performed at some or all of fifteen stations at the cage site or at a control site. Data Sonde 4a from two Hydrolabs determined chlorophyll a, conductivity, temperature, dissolved oxygen concentration, and turbidity at 15-min intervals at the cage site or at the control site. Sampling stations were selected at 20 and 40 m north, south, and west from the center of the R. canadum cage; and north, south, and east of the L. analis cage. The west station of the L. analis cage was shared with the east station of

the R. canadum cage, equidistant (about 15 m) from the rim of each cage. Other stations were located beneath each cage next to the cage ballast and at a control site (control) located 375 m south of the cage site. There were no significant differences in the following variables indicating fluctuations appeared to be seasonal, affecting the cage and control site more or less equally: ammonia-N, nitrite-N, nitrate-N, or phosphate concentrations in the water column; organic matter or organic nitrogen in the sediments; organic matter among sampling stations; organic nitrogen beneath the cages; total carbon beneath the cages; macroinvertebrate abundance among sampling stations (excluding beneath the cages) sampling stations 40 m from the cage bottom-center indicates abundance of macroinvertebrates remained similar to the background level at the control site; Shannon species diversity index and species evenness index on the benthic macroinvertebrates did not change over time

There was no evidence of anaerobic sediments beneath the cages. Sediment organic matter concentrations ranged from 4.0 - 6.2% at the cage and control sites. Abundance of benthic macroinvertebrates at the control site was only significantly higher when compared with the bottom center of the cages. Thus, effects on macroinvertebrates were localized to directly beneath each cage (close to the ballast).

A monthly visual census was made of the composition and relative abundance of fish aggregating at the cage site before the cages were installed, after the two cages were installed in August 2002, and after fish were stocked and cultured from September 2002 until April 2004.. A high diversity and abundance of fish were found near the cages; 15,636 fish were counted, representing 40 species, 23 families, and 6 orders. A mean of 869 fish representing 13 species were counted during each census compared to 26 fish and 5 species at the site before cage deployment and 6 fish representing 3 species at the control site after cage deployment. About 43% of all counted fish are commercially valuable; 94% (of the 43% counted) are used for human consumption (10 pelagic species and 8 reef species) and the remaining 6% are species frequently exploited by the aquarium industry. Twelve species included juvenile individuals. The pelagic and reef fishes may represent an expansion of the resources available to the fishermen and therefore a possible increase in fishing potential. More research is needed to determine if the wild fish assemblage is benefiting directly or indirectly from additional nutrients from the aquaculture activity or if the cage structures naturally accumulate organisms and are simply serving as a substrate.

Coverage of biofouling organisms attached to the surface of each cage was used to determine the composition of marine biofouling organisms attached to the cages, percentage coverage, and growth rate of biofouling. The percent coverage of biofouling for each cage was statistically similar among stations in non-shaded and shaded areas, with a mean coverage above 50%. No differences were found for percentage coverage of downstream versus upstream samples; no differences were found for un-shaded samples versus shaded

samples. However, the type of organisms attached to the un-shaded and shaded locations of each cage varied. Accumulation of biofouling (coverage) was highest during summer (June), with the least biofouling occurring in February 2003 (the coldest month). At first, two main groups dominated the biofouling coverage (macroalgae and hydroids); however, by the end of the study (one year after cage installation), the nets were mainly colonized by small mollusk, rug (alga-hydroids) and ascidians (Ascidea). Because biofouling grows rapidly (and needs to be cleaned biweekly), it should be evaluated to remove nutrients from the water column to ameliorate effects on the environment.

Even though the results of this study indicate little environmental effect, the fact that feed is added to an open-ocean condition implies potential for eutrophication, especially as the industry expands. Because of the tremendous amounts of water flowing through the cages, monitoring nutrient additions to the water column will probably be fruitless; thus, focus should shift to effects on the biota in the benthos under and near the cages. The attraction of reef and pelagic fish to a cage site potentially increases the wild-catch fishery resource. As more cages, especially if stocking rates are increased, are installed, focus should be made on the sediment, possible effects on distant coral reefs, and to determine the positive or negative interactions by having wild fish attracted to the cages.

A significant percent (55%) of the members of the general community of Culebra did not have general or specific knowledge about the open-ocean aquaculture project and did not have specific information about the advantages or disadvantages in relation to the impact on economy, fishing, fishermen, or community life. It is important to increase their knowledge to support their attitudes toward open-ocean aquaculture and to involve Culebra residents in social and economic changes regarding aquaculture. Therefore, an informative program should be developed, taking into consideration the socio-demographic characteristic of the Culebra population, as well their emphasis on social relationships. The positive attitude observed among the knowledgeable Culebra residents toward the project is a key element in the implementation of a program to inform other residents concerning information about the aquaculture project.

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Final Report

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Introduction

Increased populations have resulted in terrestrial ecosystem degradation and depletion of natural resources, resulting in many countries struggling to maintain their food production (Bagarinao 2000). Overexploitation of marine resources and increased population has caused worldwide fisheries depletion, including those of the Caribbean. Fisheries operations in Puerto Rico have exceeded maximum sustainable yield due to ocean pollution, over-fishing, and destruction of suitable habitat for native species. Because of these factors, combined with a relatively narrow underwater shelf, the Puerto Rican fishery cannot increase its catch. As a result, Puerto Rico produces less than 5% of its seafood (Matos-Caraballo 1998). Furthermore, the local fishery has not supplied more than 5% of the demand for seafood during the last 30 years.

The Puerto Rico population generally prefers marine fish to those of freshwater; they especially prefer lighter colored fish or those with a reddish color. As an island, Puerto Rico should benefit from its location, surrounded by the Atlantic Ocean and the Caribbean Sea, and should have competitive fisheries production. Because the island is small and crowded with 3.9 million inhabitants, the terrestrial environment has been heavily impacted. Large expanses of land are occupied by many private and commercial activities, including housing, commercial centers, industrial areas, and highways (López-Feliciano 1999). The complex infrastructure has resulted in deforestation, soil erosion, water pollution, and air pollution. There are few tracts of land suitable for aquaculture purposes, leaving room only for efficient land-based freshwater or marine aquaculture operations. Open-ocean submerged cage aquaculture is a new technology promising high yields of fresh seafood, which may help supply part of the seafood demand.

Cultured organisms are generally concentrated in relatively small areas while constantly receiving large amounts of feed, part of which is directly or indirectly released to the surrounding environment as excreted wastes or un-consumed feed. Thus, the environmental impact of large-scale fish production systems has caused concern to some regulatory agencies and groups. However, the contribution of aquaculture to total aquatic pollution is minimal compared with the domestic, agricultural, and industrial sector. Some countries such as Taiwan have suffered environmental degradation and diseases due to the rapid

expansion of land-based aquaculture and over-pumping of groundwater for fishponds. In the mid-nineties, some countries decided not to encourage future land-based fish farming, and shifted their interest toward open-ocean cage culture. We use the term “open ocean” instead of “offshore” because of legal definitions concerning the distance from shore when relating to “offshore” operations. Thus, open-ocean cage sites describe the oceanic conditions, not the distance from shore. The sites are usually subject to high-energy conditions (wind, waves, and currents).

A great bulk of information is available concerning environmental degradation of inshore cage aquaculture operations; however, the environmental information on offshore cages operations is limited or non-existent since this is relatively new technology. With the recent development of suitable technologies for open-ocean submerged culture cages, impact of pollution of inshore waters can be alleviated by culturing species in open-ocean areas formerly unusable by the aquaculture industry. The use of emerging technologies such as recirculating systems and open-ocean cage systems for aquaculture (Fig. 1) are promising since many of the environmental concerns related to traditional aquaculture systems could be resolved. Proponents of open-ocean aquaculture commonly argue that open-ocean aquaculture facilities will result in less environmental degradation than near-shore aquaculture facilities because waste should be significantly diminished in open-ocean sites where wastes are quickly diluted by strong currents flowing into deeper waters. However, there are important exceptions to this assertion. Wastes from open-ocean aquaculture facilities located in areas with relatively shallow or relatively weak currents can cause environmental damage (Goldburg et al. 1996). Accumulated wastes beneath cages produce changes in sediment chemistry and physical characteristics leading to a shift in the macrobenthic faunal diversity and biomass. Thus, maintaining optimum management strategies and stable environmental conditions will be important to long-term sustainability of the open-ocean aquaculture industry.

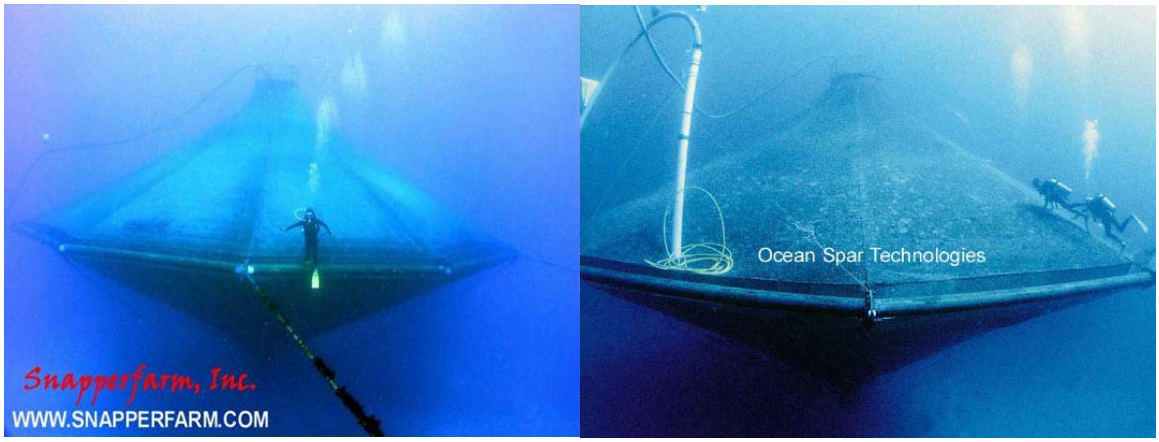


Figure 1. Open-ocean submerged cages in Snapperfarm (left) and Hawaii (right).

Because marine aquaculturists share the same resource (oceanic water) with other marine aquaculture enterprises and other oceanic users, laws should be designed to encourage sustainable marine aquaculture management techniques (Bakela 2000). Thus, any legislature assigning leased areas to marine aquaculturists should ensure environmental sustainability. Viable regional projects should adapt to emerging technologies to minimize environmental effects and promote environmental conservation while improving the economic value of the industry and stabilizing the trade of aquacultured products.

Impact of waste feed on the environment

Because cages are essentially ecologically open systems, wastes are inevitably released into the surrounding environment (Chen et al. 2000). Wastes from intensive aquaculture systems primarily consist of uneaten food, metabolic waste (feces and urine), chemical wastes, and feral animals (Chen et al. 2000). Semi-solid wastes are discharged directly into the environment from marine cage systems. They may settle on the sea bottom or a portion may be attached to particulate material, thus increasing sedimentation. Sedimentation is dependent on the settling velocity of solids, which in turn is dependent on their physical properties (i.e. food pellet shape and density), current velocity, water turbulence, and depth at cage sites. The sedimentation may result in ecological issues such as the impact of bioactive compounds, interactions with the food web, perturbations on local wildlife, habitat destruction, interaction between escaped farm stock and wild species, and alteration of the biodiversity of the area (Civili and Caparis 2000). Waste loading beneath the cages may produce changes in sediment chemistry and physical characteristics leading to a shift in the macrobenthic faunal diversity and biomass.

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). This is partly related to the difficulty of establishing reliable information because of the complexity and interactions such as cage size, stocking density, feeding rates, water quality, and different site conditions.

In aquaculture operations, if too much feed is provided, there will be wasted feed (Asgard et al. 2000; Myrseth 2000), resulting in a high feed conversion ratio; if too little feed is given, it will be utilized for maintenance and less for growth. Thus, balanced diets are essential to maximize amounts of feed eaten and metabolized into fish flesh, resulting in decreased amounts of uneaten feed and feces released to the environment. Feeds must include all the essential ingredients for rapid growth, be water stable to prevent leaching of feed nutrients, and be highly digestible. Instead of seeking highly technical solutions to solve environmental problems because of increased feeding rates and wastes released, the aquaculturist have to provide an excellent quality feed with appropriate feeding rates and feeding strategies.

In general, impacts from aquaculture wastes may occur over several spatial and temporal scales are localized to less than 100 m from the cages operation. Localized impacts may be detrimental to the caged fish and may affect nearby wild populations from a few hundred meters to a distance of a kilometer (Chen et al. 2000), depending of the quality of the feed, water currents and other factors. Reports indicate the effects are generally restricted to areas in the immediate vicinity of fish farms (Anonymous 1987; Gowen and Bradbury 1987), probably due to dispersal of waste food and fecal materials (Frid and Mercer 1989; Lumb et al. 1989). Pelleted feed usually cause less effect on the environment than trash fish feed. Furthermore, some localized impacts such as fouling may operate over much longer time scales. It is noted herein that most of the environmental studies have reported effects of the cages systems to distances less than 100 m from the cages. However, most studies of the environmental impacts of cage aquaculture have been developed for inshore waters and temperate regions. Several indicate increases in the suspended solids and nutrients (ammonia, organic nitrogen, and carbon), and a decrease in dissolved oxygen concentrations (Chen et al. 2000) and redox potential in sediments near cages.

Even though there has been rapid growth in marine fish farming in open-ocean tropical and subtropical regions, there are few studies related to environmental effects. Open-ocean tropical conditions are distinct compared to inshore and temperate regions, so the environmental response will be different. It could be expected that warmer temperatures will result in a faster response by the flora and fauna outside of the cage to deal with impacts such as increased nutrients entering the environment. Additionally, strong current conditions in open-ocean environments provide excellent water exchange rates and serve to quickly dilute released nutrients.

Waste deposition in the sediments may overwhelm the assimilative capacity of the benthos and result in the formation of anaerobic bacterial mats and anoxic conditions, which may perturb the benthic community. However, this impact may be negligible in open-ocean environments due to strong currents and high volume of water. Thus, the current pattern of the cage site, including occasional powerful currents and storms play an important role in waste dispersal and should be fully understood and evaluated to gauge effects from waste loading.

Although oceanic currents can quickly dilute organic wastes, accumulation of excess food and fish wastes can be deposited underneath cages or near them, thus affecting the benthic communities. Benthic fauna are sensitive to environmental disturbances (Pearson and Black 2001) and are especially sensitive to organic matter enrichment. Changes may occur in species number, organism abundance, and community biomass (Méndez 2002). Polychaetes usually are good indicators of organic enrichment, especially the family Capitedallidae, in areas with decreased species richness and increase of individual abundance (Tsutsumi 1987; Méndez 2002; Bybee and Bailey-Brock

2003). Benthic fauna are also characterized and distributed in relation to the sediment grain size classification and interstitial spaces (Méndez et al. 1986; Wieser 1969).

Organic matter causes enrichment, resulting in changes in the number of species, the abundance of organisms, and biomass of the communities (Méndez 2002). This study characterizes the distribution and temporal dynamics of the macroinvertebrate population near the cages and provides information related to the taxonomic composition of the benthos at this Caribbean region. No studies have been reported concerning macroinvertebrates present near Culebra Island nor in Puerto Rico. Several studies of this nature were done in Canada, Norway, Greece, the United States, Spain and Japan (Hargrave et al. 1997; Lu and Wu 1998; Karakassis 2000; Hansen et al. 2001; Bybee and Bailey-Brock 2003; Grizzle et al. 2003), especially concerning inshore aquaculture operations.

Fishmeal is included in most marine fish feeds; however the environmental impact results an estimated 3 mt of wild fish required to produce 1 mt of farmed salmon. Aquaculture utilized 70% of the world fish oil and about 35% of the world's fish meal (Staniford 2002). Research to substitute a portion of fishmeal with soy or cottonseed meal shows some results, but apparently some fishmeal needs to be added for palatability. Thus feeds should be purchased that incorporate as little fishmeal as possible.

Because fish are cultured under crowded conditions not experiences in natures, they are susceptible to a variety of parasites and diseases are often propagated. These problems are exacerbated in conditions with poor water quality (Tonguthai and Leong 2000). Because there are few effective treatments for open-ocean cage culture systems, constant monitoring should be practiced to avoid massive losses or related environmental problems. Best management practices must be implemented to assure aquatic animal health.

Biofouling effect on the cages

Biofouling occurs as a result of settlement and growth of sedentary and semi-sedentary organisms on artificial structures placed in water (Venugopalan and Wagh 1990). Specifically, marine biofouling occurs on artificial surfaces submerged in seawater such as on ship's hulls, seaside piers (Davis & Williamson 1995) and aquaculture structures, and involves processes to consolidate biomass. The first phase of aquaculture biofouling is the accumulation of an organic 'conditioning' film consisting of chemical compounds (mostly protein proteoglycans and polysaccharides), making the surface wettable (Abarzua & Jakubowski 1995). Bacteria and diatoms then begin bio-corrosion by secreting a layer of mucus-polysaccharides (Tosteson 1988), thereby providing a suitable substrate for other organisms such as fungi and protozoa to attach to the substrate. The transition of the biofilm to a more complex community includes primary producers, consumers, and decomposers. Growth continues with macro-

algae and the attachment of marine invertebrate larvae in response to specific cues for them to attach to the biofouling substrate where they begin their metamorphosis to adults (Davis & Williamson 1995).

Biofouling on open-ocean cage netting is a serious marine aquaculture problem and may rapidly cover the cage mesh, thereby requiring frequent expensive cleaning procedures (Hodson et al. 2000). When biofouling reduces the size of the holes in the net, water interchange through the net is retarded, resulting in inferior water quality within the cage which may delay fish growth. Fouled netting increases drag, causes structural fatigue, and may harbor disease-causing microorganisms. Increased drag exacerbates cage deterioration due to wind conditions, waves, and currents. Hurricanes amplify the impact, possibly to the point of cage collapse, especially in currents that reach 150 cm/sec. Hence, effective management practices must include scheduled clean procedures to eliminate biofouling. These procedures greatly increase operational costs.

Culture species

Most cultured species require good water quality for maximum health and growth; however some species are significantly more tolerant of poor water quality than others (Hambrey 2000). Some species, including some flatfish species, need excellent water quality not generally satisfied in temperate open-ocean conditions.

Lutjanus analis (mutton snapper, family Lutjanidae), which is endemic to the Caribbean, was selected for growout in open-ocean cages by Snapperfarm, Inc., at their site south of Culebra Island, Puerto Rico. Because it is native to the region, this commercially valuable ameliorates problems from genetic inbreeding between farm stock and wild species in case of fish escape. Hatchery technology to produce L. analis fingerlings has been somewhat successful.

A second species, Rachycentron canadum (cobia), was also selected for its fast growth in several fish-culture cage studies in Taiwan (Liao 2003). Its distribution is worldwide (except for the Eastern Pacific), primarily in pelagic waters. This species has commercial value and the technology for fingerlings productions has been developed in several hatcheries in the United States. Although rare or uncommon in Puerto Rican waters, it is caught by fishermen and was observed during our environmental assessment near the Culebra cages.

Juvenile L. analis were cultured for commercial production at the Aquaculture Center of the Florida Keys in collaboration with researchers of the University of Miami Rosenstiel School of Marine and Atmospheric Science. After culturing L. analis, the University of Miami decided to also culture R. canadum fingerlings. Thus, 12,000 R. canadum and 4,000 L. analis were stocked in each of two cages during August 2002. Because of the smaller size of the L. analis, their stocking rate was low. Rachycentron canadum are stocked at 4-6 fish/m3 and harvested at 6-10

kg/fish in Taiwan (Su et al. 2000), so Snapperfarm's stocking rates were similar to those used in Taiwan. This provided our team with the opportunity to compare the environmental effects of two fish species and fish biomass (related to feed input) at the Culebra site. Harvest of R. canadum began in July 2003. The effect of the culture of these species on the water column and the sediment was evaluated from June 2002 until November 2003 by monitoring physical, chemical, and biological variables, especially relevant biotic and abiotic variables that are indicators of eutrophication. These indicators include changes in levels of nitrogenous compounds (ammonia, nitrite, and nitrate), phosphate, and chlorophyll-*a* concentration, organic carbon, organic matter, organic nitrogen in the sediments, and videotaping of the wild fish prior to, during, and after the operation to determine visual cues of the area during the culture period. Besides the bimonthly environmental sampling of this proposal, Snapperfarm conducted daily routine observations as they cultured and harvested fish. The water current of the area, the biofouling attached to the cages, levels of oxygen, turbidity, salinity, and temperature were also monitored.

Objectives

The overall goal of this project was to determine the environmental effect of finfish open-ocean cage culture on tropical marine waters located near Puerto Rico, USA. This proposal joined forces of the University of Puerto Rico, the University of Miami, and a private enterprise, Snapperfarm, Inc., to determine the environmental feasibility of open-ocean cage culture of R. canadum and L. analis.

Materials and methods

Deployment of open-ocean cages

The mid-water currents of the control site (375 south of the cage site) monitored with the InterOcean S4 were characterized by the following: northwestward flow (towards 300°-320° true) during flood tide (as the sea surface elevation increases); southeastward flow (120°-140° true) during ebb tide; strong semidiurnal (two cycles per day); and weaker diurnal (one cycle per day); tidal components with maximum amplitudes of 20-30 cm/sec; mean, or low-frequency, northwestward flow with a year-long mean towards 301° true at 8.4 cm/sec; tidal ellipses elongated along bottom contours to the point of nearly a straight line so that changes in direction occur very quickly; little transport towards land; and velocity vectors swing back and forth across the offshore hemisphere. Currents assisted with the dispersion of solid and dissolved nutrients released from the cages. For more details see the "water column: flow regime" section in "results and discussion" section.

Two 3000 m^3 Ocean Spar submerged growout cages (Fig. 2) were purchased from Ocean Spar Technologies Inc. by Snapperfarm, shipped, and assembled from June to July 2002. The two open-ocean cages were located about 3 km south of Culebra

Island, Puerto Rico in 28-m deep water with each cage top submerged 8 m below the surface. The frame of the growout cages consists of a central spar, surrounded by a round steel rim 25 m in diameter. The rims of the two-growout cages were separated by about 30 m. Each frame is covered with taut netting attached to spoke lines conforming to the Sea Cage's shape. Zippered doors in the net provide easy diver access. The cage system can be lowered and raised by varying the buoyancy of the spar and lowered or raised in less than 5 min. The cage can be lowered when a hurricane approaches the area. Although the real impact of a hurricane is unknown, it is not expected to damage the main components of the cages (the spar and steel rim). Because the cage is rigid, it can be towed to avoid unfavorable growing conditions. The cage volume is affected minimally during towing. Each cage has five mooring systems, three on the southeast side, and two on the northwest side. The three mooring systems on the southeast side add extra protection from expected hurricanes that normally sustain a southeast to northwest track. Harvesting thus far has been by hand by crowding fish and capturing them in nets.

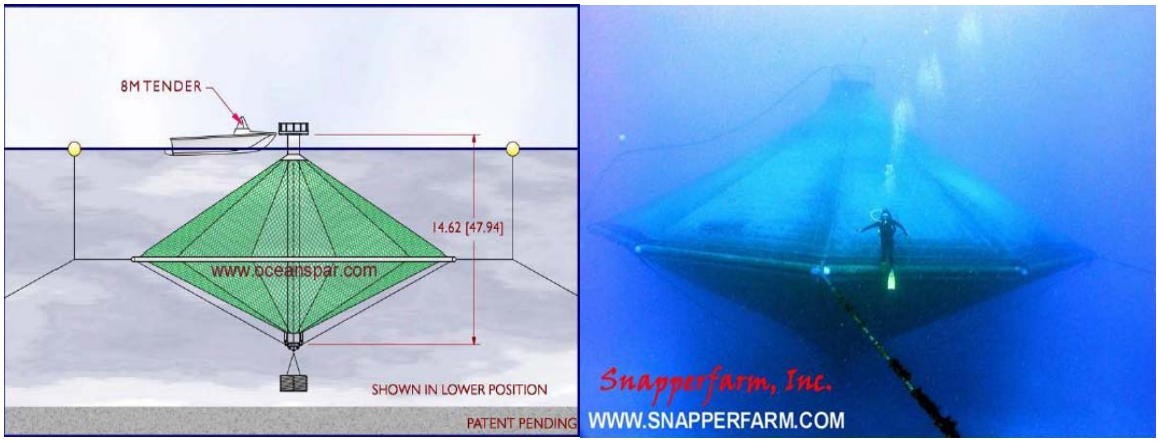


Figure 2. Ocean Spar cages. The right picture is one of the Snapperfarm cages.

Nursery nets (3 mm) were installed inside the growout cages (attached to the central spar) to maintain the small fish within the cage. They were stocked with fingerlings shipped from the Aquaculture Florida Center of Miami Keys to San Juan, Puerto Rico, transported by truck to Fajardo, and shipped to the cage site about two miles south of the coast of Culebra Island (Fig. 3). The fingerlings were stocked into the nursery nets by gravity flow through a 7 cm flexible hose. During this period, the fish were fed until satiation twice daily as observed by divers. After two months, the fish were released from the nursery nets into the growout cage.

One cage was stocked with 4,000 L. analis (1.3 fish/m^3) and the other with 12,000 R. canadum (4/m^3). Because the R. canadum is expected to grow about 4 kg or more within one year, they should be stocked at a lower density than that of the L. analis. Because of the smaller size of the L. analis, their stocking rate

was low. Rachycentron canadum are stocked at 4-6 fish/m3 and harvested at 6-10 kg/fish in Taiwan (Su et al. 2000), so Snapperfarm's stocking rates were similar to those used in Taiwan. During the culture period, the fish were fed ad libitum. Harvesting of R. canadum began after 10 months in June 2003. A second stocking of R. canadum was made into the L. analis cage after the first year of culture.

Figure 3. R. canadum fingerlings transported from Florida to Puerto Rico.

Sampling

Two cages were located along a line perpendicular to the prevailing southeast to northwest current 3 km south of Culebra Island, Puerto Rico. Sampling was performed at fifteen stations at the cage site (Fig. 4) and at a control site.

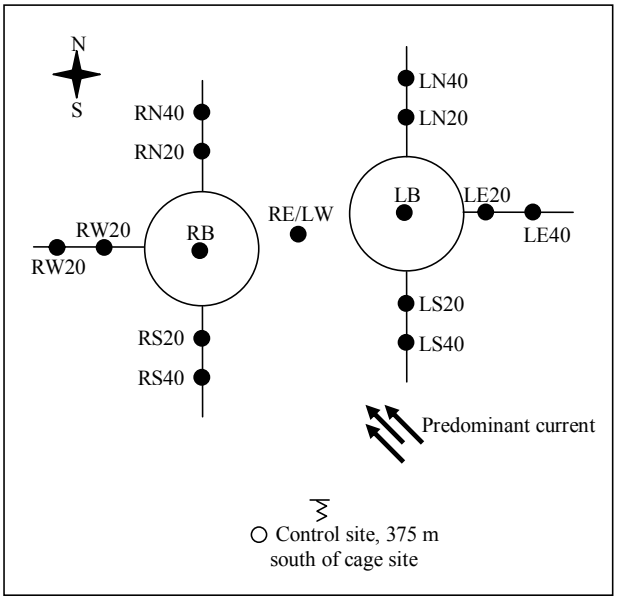


Figure 4. Fifteen sampling stations at the cage site, plus the control site.

Sampling stations were selected at 20 and 40 m north (RN), south (RS), and west (RW) from the center of the R. canadum cage; and north (LN), south (LS), and east (LE) of the L. analis cage. The west (W) station of the L. analis cage was shared with the east (E) station of the R. canadum cage, equidistant (about 15 m) from the rim of each cage and was designated (RE/LW). Other stations were located beneath each cage (LB beneath L. analis cage; RB beneath R. canadum cage) next to the cage ballast and at a control site (control) located 375 m south of the cage site. The prevailing current was from southeast to northwest, but with the ebb and flow of the tides, the current frequently changed directions. The 15 sample stations abbreviations, plus the control site is shown in Table 1.

Table 1. Abbreviation of the 15 sampling stations at the cage site, plus the control site.

RN20	R. canadum north, 20 m
RN40	R. canadum north, 40 m
RS20	R. canadum south, 20 m
RS40	R. canadum south, 40 m
RW20	R. canadum west, 20 m
RW40	R. canadum west, 40 m
RB	R. canadum beneath, 0 m
LN20	L. analis north, 20 m
LN40	L. analis north, 40 m
LS20	L. analis south, 20 m
LS40	L. analis south, 40 m
LE20	L. analis east, 20 m
LE40	L. analis east, 40 m
LB	L. analis beneath, 0 m
RE/LW	R. canadum/L. analis shared
control	control

Sampling regime

All samples were taken bimonthly, except for videos near the cages that were taken monthly. Data Sonde 4a from Hydrolabs determined chlorophyll a, conductivity, temperature, dissolved oxygen concentration, and turbidity at 15-min intervals. They were recovered, connected to a laptop computer to download data, cleaned, calibrated, and deployed on a monthly basis. In addition to the water quality monitoring, technical diving was performed monthly and underwater video cameras were used to determine if the cage site served a fish aggregating device (FAD), including the presence of large predators such as barracudas, sharks, dolphins, and whales. Fish were identified according to Humann (1994).

Bathymetry data were taken from the most recent bathymetry charts of the area near Culebra, Puerto Rico, and corroborated by depth soundings at the cage

site. Bottom type was characterized by collecting duplicate sediment samples near the cages in October 2002 and October 2003.

Duplicate benthic samples for chemistry/grain size analysis were each taken with a PVC core sampler (diameter 5 cm, 10 cm long) at each of the 15 sampling stations, plus at the control site. Duplicate macroinvertebrates samples were each taken with a PVC core sampler (8.8-cm diameter, 10 cm length) at each of the following stations: CN20, CS40, CW40, CB0, SN40, SS40, SE40, SB0, CE/SW, and control. Either distance from the cage center to 20 or 40 m was measured using tape attached to the center of the cage. Divers swam either north, south, east, or west from the cage center until they reached either the 20 or 40 m station where random core samples were taken (chemistry/grain size or macroinvertebrates). The sample depth for each core sample was 10 cm based on reported literature that little information is gained by sampling deeper than 10 cm (Laverde-Castillo 1990; Morrissey et al. 1992).

Duplicate samples were taken from the water column with an alpha bottle sampler lowered from the edge of the boat at each sampling station (described above), except beneath the cage (28 m depth) where they were taken by filling sample bottles while diving. Sample depths included the bottom (27-m depth) selected to be at approximately the same depth as the cage bottom, mid-depth (16 m depth) for the middle of the cage, and top (8 m depth).

For statistical analyses (see below), data were analyzed in reference to the predominating current which had more transport in a northwest direction. Thus, N and W stations were compared to S and E stations and were designated downstream and upstream, respectively.

Benthic samples: grain size analysis

Grain-size analyses determined if the cages affect the grain type at the cage site over time or if there were differences among benthic stations from each sampling station during October 2002 and October 2003. Each sample was dried in a conventional oven at 75 C to a constant weight (Holme and McIntyre 1984). Duplicate samples of 100 g each were analyzed by using the gravimetric method for 15 min with a column of graduated sieves (2, 1.25, 0.63, 0.45, 0.112, and 0.06 mm). Each portion retained on each screen was weighed to determine the percentage of each grain size based on phi units of each type grain and classified using the Udden-Wentworth method (Wentworth 1922: Holme and McIntyre 1984; Bremec 1990; Guzmán 1993; Córdoba 1997). The transformation to phi units simplifies statistical analysis expressed in millimeters as used by various researchers (Folk 1980; Méndez et al. 1986). Phi (ϕ) was determined by utilizing the following formula (Tucker 1988):

$$\phi = - \log_2 (d) \text{ where d is the grain diameter in mm.}$$

Benthic samples: inorganic nitrogen (ammonia, nitrite, and nitrate)

Each field sample was placed in a plastic bottle and preserved with ice to reduce or eliminate bacterial activity. The samples were frozen until analyses were performed. Interstitial water of each sample was thawed and poured into approximately equal portions into four 15-ml assay tubes. Two of the tubes were used for ammonia-N analysis and two for nitrite-N analysis. Ammonia-N was determined by colorimetric analysis following the indophenol method (Standard Methods 1998). The nitrite-N concentrations were also determined by colorimetric analysis, following the nitroprusiade method (Standard Methods 1998). Another portion of the interstitial water was poured into two 50-ml assay tubes and subsequently each sample was passed through a packed cadmium column to reduce the nitrate-N to nitrite-N. These reduced samples were analyzed by the nitroprusiade method.

Benthic samples: phosphate

Each benthic field sample for phosphate was placed in a plastic bottle and preserved with ice to reduce or eliminate bacterial activity. The samples were frozen until analyses were performed. Interstitial water of each sample was thawed and poured into approximately equal portions into two 15-ml assay tubes. Phosphate concentration was determined by colorimetric method, following the molibdate reactive phosphorus method (Standard Methods 1998).

Benthic samples: organic matter

Each field sample was placed in a plastic bottle and preserved with ice to reduce or eliminate bacterial activity. The samples were frozen until analyses were performed. Two sub-samples taken from thawed sediment samples were placed into crucibles previously cleaned and dried to determine organic matter of the sample by using the gravimetric method (Holme and McIntyre 1984; Páez-Osuna et al. 1984; Guzmán 1993; Standard Methods 1998).

Benthic samples: organic nitrogen and total carbon

Field samples were stored in plastic bottles and preserved with ice to reduce bacterial activity. The samples were frozen until analyses were performed. Two sub-samples taken from thawed sediment samples were placed into crucibles previously cleaned and dried to determine organic nitrogen and total carbon using the gas chromatography method (Standard Methods 1998). Sediment organic nitrogen and total carbon concentrations were measured instead of COD (chemical oxygen demand).

Benthic samples: macroinvertebrates

Field samples were filtered through a stainless steel sieve with 0.5 mm mesh openings (Holme and McIntyre 1984), preserved with 4% formalin with Rose Bengal stain (to stain benthic organisms) (McVee and Brehm 1982; Guzmán 1993; Manté et al. 1995). Fixed and dyed samples were spread on a tray and organisms separated from the sand were classified as polychaetes, crustaceans, mollusks, echinoderms, or nematodes, and preserved in 70% ethanol. Using dissecting (Olympus SZ ST) and compound (Bausch & Lomb) microscopes, the organisms were further identified to the lowest possible level (except for Polychaeta: Capitellidae, and mollusks which were identified to species). Because some Capitellidae are indicators of benthic disturbance, they were classified to the species level. Taxonomic keys for polychaetes used references by Day (1967), Fauchald (1977), and Salazar-Vallejo et al. (1988); for Crustacea, Barnard (1969), Kensley and Schotte (1989), and Ortiz (1992); and for mollusks, Diaz and Puyana (1994). The Shannon-Wiener diversity species index, evenness species index, and species richness index were calculated by considering only families with more than 3% relative abundance and by using the formula:

Shannon-Wiener index (H') = - Σ Ln(Pi), where Pi = relative abundance of macroinvertebrates families.

Evenness species index (J') = H'/Ln (S), where S = family abundance or family richness.

Water quality: D.O., temperature, chlorophyll-a, turbidity and salinity

Dissolved oxygen concentrations, water temperature, chlorophyll-a concentrations, water turbidity, and salinity were monitored continuously at 15-min intervals by the Hydrolabs. Turbidity measurements were taken instead of total suspended solids. One Hydrolab was installed on the rim of the R. canadum cage and another was installed at the control site to determine if the changes in the variables were due to the cage's effect or seasonality. The Hydrolabs were recovered monthly to download information into a portable computer. Once the data were collected, sensors were recalibrated, and the Hydrolabs was reprogrammed and reinstalled at their respective site to continue the data logging process. The Hydrolabs were calibrated by using the appropriate standards for their sensors.

Water column: inorganic nitrogen (ammonia, nitrite, and nitrate)

Each field sample was immediately poured into a dark plastic bottle for ammonia-N, nitrate-N, and nitrite-N for later determination in the laboratory. Each water sample was preserved with 5 drops of H_2SO_4 and preserved with ice to reduce or eliminate bacterial activity. The bottles were then transported to the laboratory for analysis.

For ammonia-N and nitrite-N determinations, each water sample was thawed, shaken briefly, and poured into approximately equal portions into four 15-ml assay tubes. Two of the tubes were used for ammonia-N analysis and two for nitrite-N analysis. Ammonia-N was determined by colorimetric analysis following the indophenol method (Standard Methods 1998). The nitrite-N concentrations were also determined by colorimetric analysis, following the nitroprusiade method (Standard Methods 1998). For nitrate-N analysis, a portion of the thawed water sample was shaken briefly and poured into two 50-ml assay tubes and subsequently each sample was passed through a packed cadmium column to reduce the nitrate-N to nitrite-N. These reduced samples were analyzed by the nitroprusiade method.

Water column: phosphate

Each field sample was placed in a plastic bottle and preserved with ice to reduce or eliminate bacterial activity. The samples were frozen until analyses were performed. Each sample was thawed, shaken briefly, and poured into approximately equal portions into two 15-ml assay tubes. Phosphate was determined by colorimetric analysis following the Molibdate method (Standard Methods 1998).

Water column: wild fish fauna

The main purpose of this component was to provide qualitative and quantitative descriptions of the composition and relative abundance of wild fish associated with the open-water submerged cage systems. Emphasis was placed on evaluating the aggregation effect among the months observed and on using the information to predict effects on the local fisheries.

A monthly visual census was made of the composition and relative abundance of fish aggregating at the cage site during three distinct periods. The first occurred before the cages were installed, starting in June 2002; the second occurred after the two cages were installed in August 2002 (but before feeding began because the fish had not been stocked); and the third occurred after fish were stocked and cultured from September 2002 until April 2004. Species and relative abundance were filmed with a digital video camera (Sony) for 10 minutes from top to bottom around each cage. To designate the confines of the filming process, fish were counted within an imaginary vertical cylinder with a volume of 25,863 m^3 around each cage from surface to bottom and which radius extended approximated 17.5 m from the center of the cage (about 5 m horizontal distance from the cage rim) (Fig. 5). The area sampled did not include the volume occupied by the cage, so wild fish were only censused outside of each cage. Additionally, videos were taken on three occasions at the cage and control sites (on the same day) to compare relative abundance and composition of fish.

Water column: biofouling

Coverage of biofouling organisms attached to the surface of each cage was used to determine the composition of marine biofouling organisms attached to the cages, percentage coverage, and growth rate of biofouling. Sample netting, each measuring 1050 cm2 (corresponding to 409 cm2 of settleable threads surface) using the same material of the cage netting, were fastened to the surface of the cage surface. Six samples netting were placed 1 m above (un-shaded) and 1 m below (shaded) the cages' rim on the upstream and downstream sides of each cage (Fig. 6). Every two months, one-sample netting from each position was collected by diving (Fig. 7), preserved with 4% formalin solution, and transported to the laboratory for analysis.

Each sample netting with accumulated biofouling was photographed with a digital camera (Olympus C-50-50) and analyzed with Map Maker (Version 1) software to calculate the coverage percentage (Fig.8). Individual organisms were classified by major groups (ascidians, bryozoans, sponges, etc.) and families.

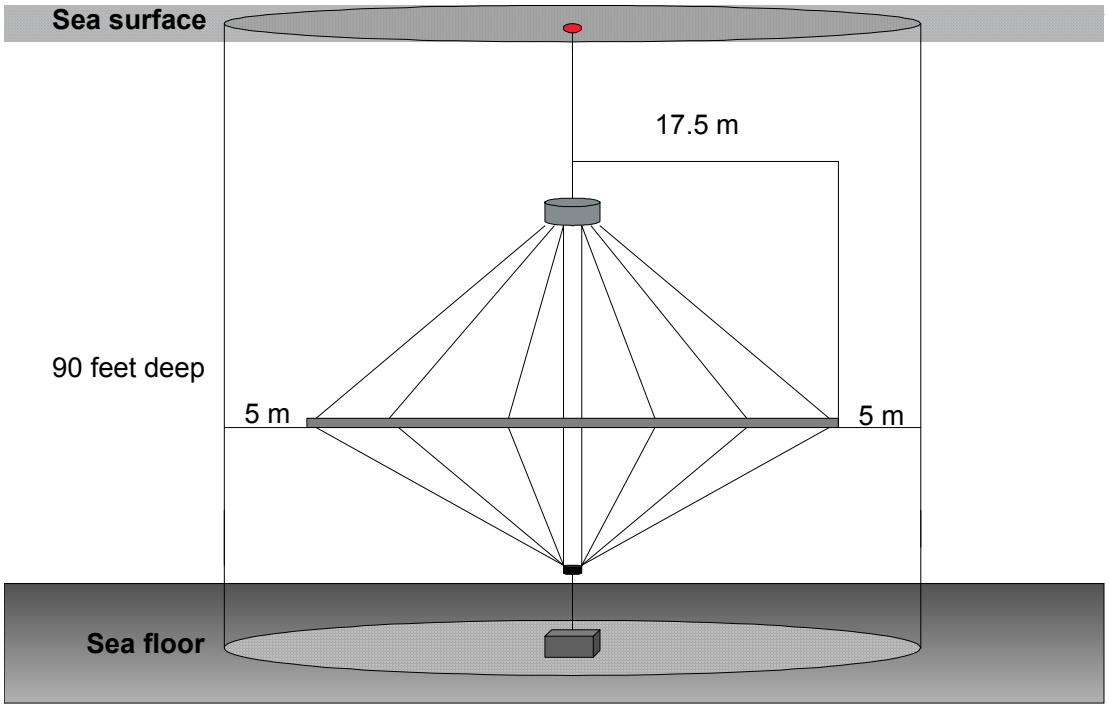


Figure 5. Volume of water censused for determination of fish composition and abundance by using video.

Water column: parasites and disease

Dead fish were removed and preserved for laboratory analysis of parasites and other detectable diseases. Additionally, fish samples were analyzed at the start and end of the experimental period for carcass analysis.

Water column: tidal and influence from weather

Weather information was retrieved daily from a meteorological weather station located at Ceiba, Puerto Rico (the Roosevelt Roads Meteorological Station, http://www.wunderground.com/US/PR/Roosevelt_Roads.html) for mean values of the following variables: mean tide, air temperature, heat index, dew point, wind speed, and relative humidity.

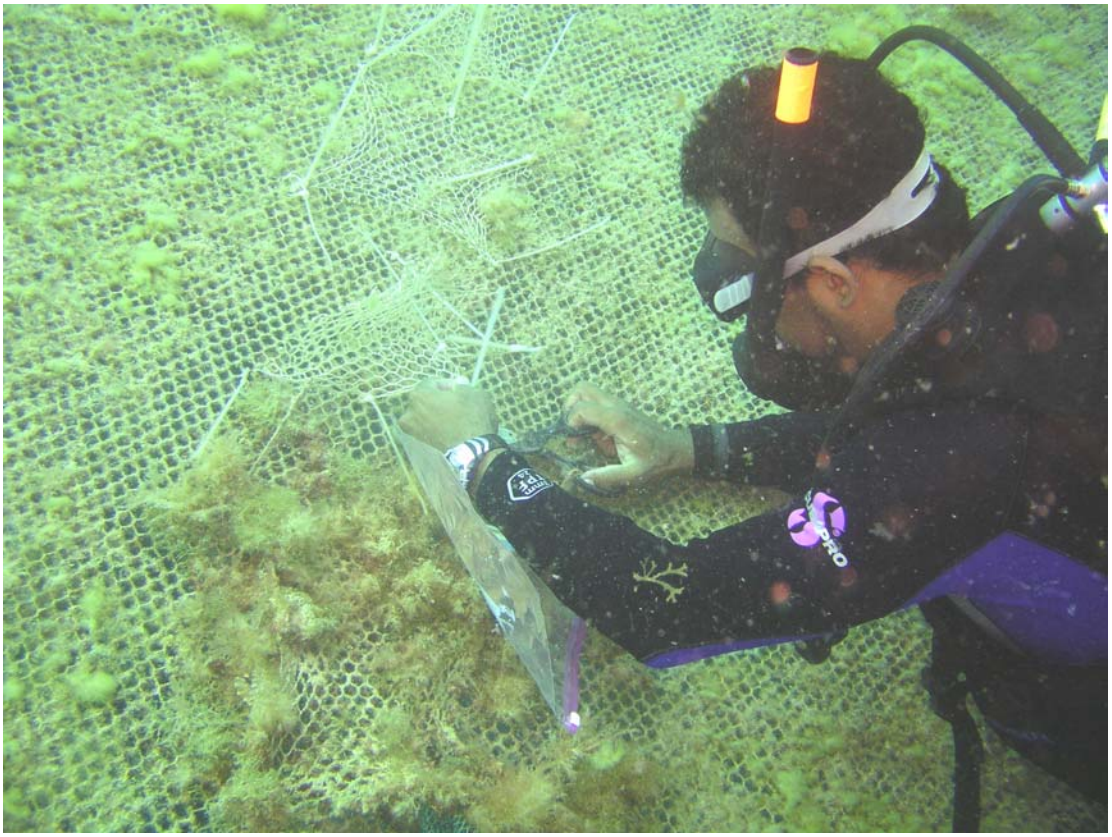


Figure 6. Biofouling sample netting fastened to cage netting.

Figure 7. Biofouling netting recovery.

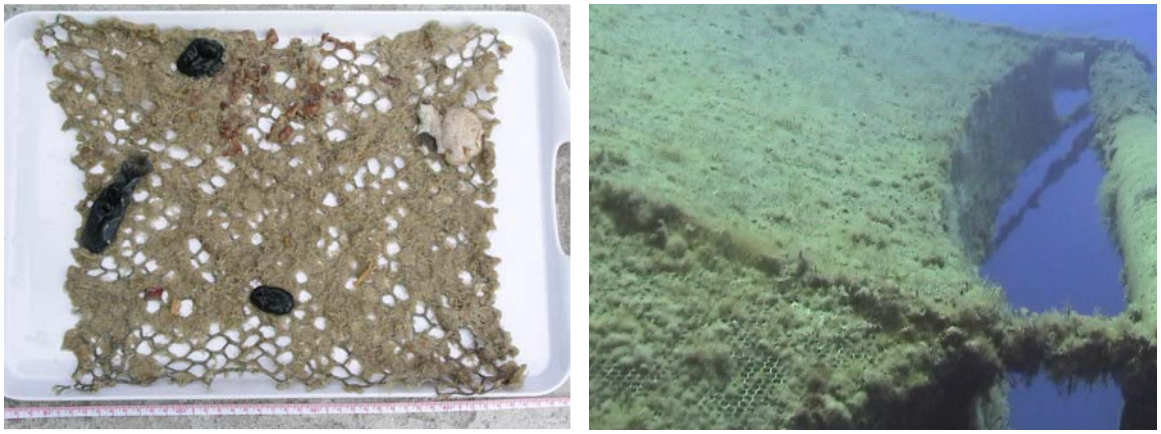


Figure 8. Biofouling sampling net photographed to measure the netting coverage. Biofouling on the surface of the cage itself.

Table 3. The S4 configuration parameters

Sampling frequency	2 Hz
Averaging interval	60 s
Cycle interval	15 minutes
S4 depth	14 m
Bottom depth	27 m
Mooring type	taut-wire

Water column: flow regime

The water flow was monitored by using a long-term current meter monitoring program conducted in the vicinity of the Snapperfarm, Inc. open-ocean cage aquaculture site in waters off western Culebra Island. Ocean Spar Technologies, Inc, designers of the Sea Station cages, conducted the first deployment as part of the cage placement and mooring protocol. Then the Open-Ocean Cage Aquaculture (OOCA) Group of the University of Puerto Rico, Mayagüez campus (UPRM) has additionally monitored mid-water currents for one year at the Culebra environmental monitoring control site indicated in Fig. 9, and by using an InterOcean S4. Please check the following web page to look for additional information concerning S4 current meters: http://www.interoceansystems.com. The S4 velocity data were corrected for magnetic variance. Recycling events of the S4 current meter were performed at approximately seasonal 3-month intervals (C02-C05 in Table 2). However, an internal power failure on October 9 prevented the instrument from recording useful data beyond this date during the C04 deployment. The full monitoring period therefore spans from April 2003 to April 2004 as indicated in Table 2. Data are missing for the period of October 9 – December 5, 2003.

UPRM-DMS' current meter (S4) is similar to an instrument used by Ocean Spar at the cage site. One notable difference is that UPRM-DMS' S4 is equipped with a thermistor and yields a temperature time series for the deployment period whereas Ocean Spars' instrument is equipped with a pressure sensor and therefore yields pressure (~depth) data. The UPRM-DMS S4 was previously used in Puerto Rico studies concerning transport through the Mona Passage, at La Parguera, and in a number of student research projects. Prior to the cage marine aquaculture study, the S4 was sent to InterOcean for maintenance and calibration, at which time all four external sensors were replaced and new firmware installed.
This report not intended to provide a full comprehensive description of the year-long data set, but rather it presents data from the final deployment period (C05) and provides closure to the 5-part Culebra Deployment Reports series. The reader is referred to Deployment Reports 1-4 for additional, more detailed, information for each deployment. Marine current variability at the Culebra site is very consistent, so this latest winter deployment (C05) does not provide much in the way of new information regarding trends and statistics; however, the response of the flow to approaching winter low-pressure, cold front, systems is a characteristic seasonal flow feature.

The mooring is located at the environmental monitoring control site south of Cayo Luis Peña, and southwest of Bahía de Sardinas (Fig. 9), approximately 375 m south of the Snapperfarm cages. As shown in Figure 9, bottom contours are aligned along a northwest to southeast axis (~ 300°-120° true). The S4 was mounted in a subsurface, taut-wire, configuration at mean depth of 14 m (47 ft)

(Fig. 10). The bottom depth at the site is 27 m (90 ft). The hard sandy bottom at this location is flat and mostly featureless, similar to the bottom at the cage site, and there are no nearby bottom structures that could generate bathymetric flow steering. The bottom contours are aligned along a northwest to southeast axis (~ 320°-140° true). The S4 configuration parameters are listed in Table 3.

Table 2: Culebra deployments.

Event	Name	Start	End	Days	Season
1	C01	30-May-02	06-Jun-02	7	
2	C02	10-Apr-03	20-Jun-03	70	Spring
3	C03	20-Jun-03	02-Sep-03	73	Summer
4	C04	02-Sep-03	08-Oct-03	35	Fall
5	C05	06-Dec-03	23-Apr-04	139	Winter

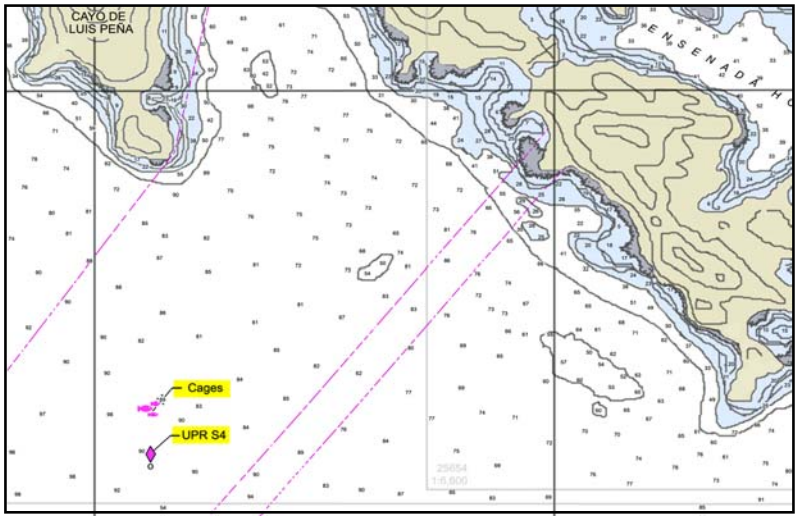


Figure 9. Location of cage and current meter sites.

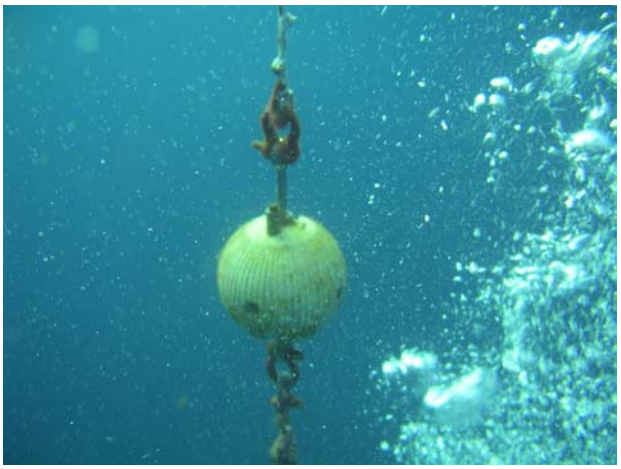
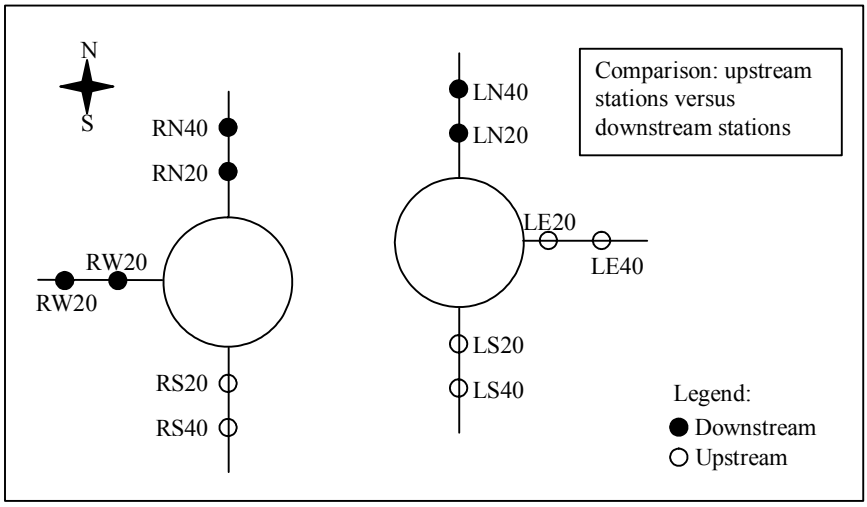
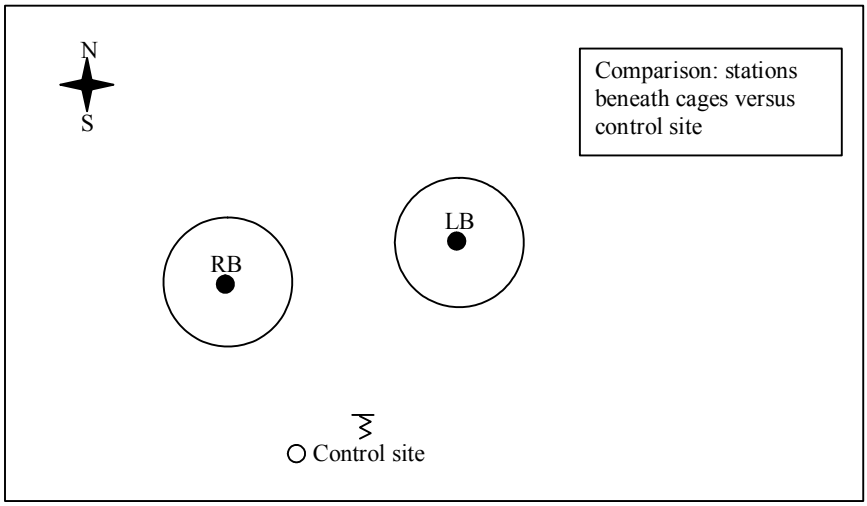


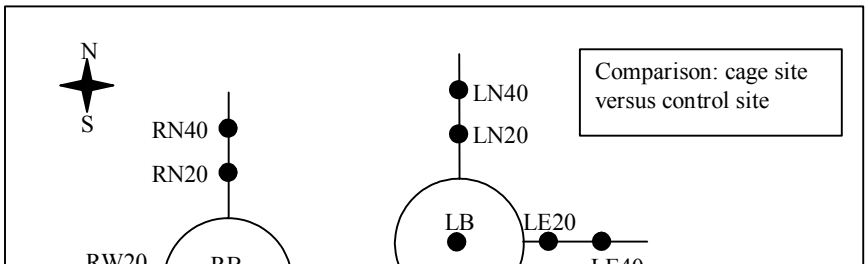
Figure 10. Current meter installed at the control site.

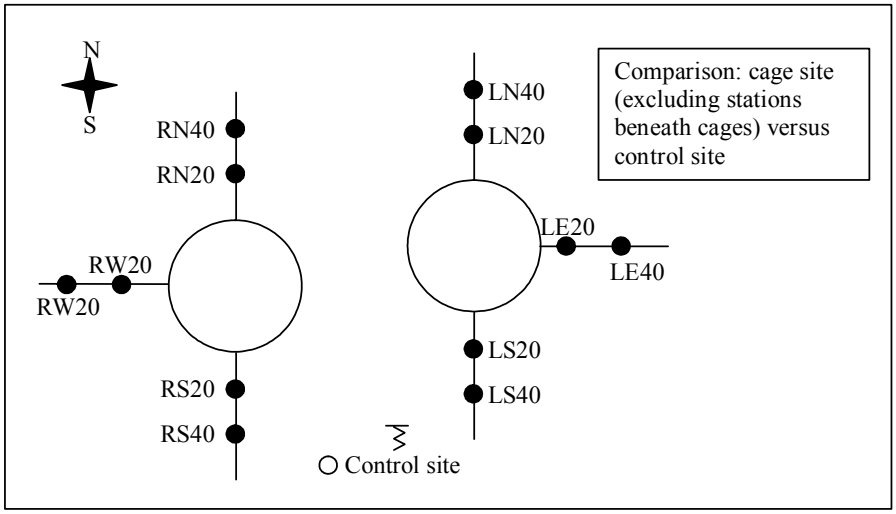
Statistical analyses

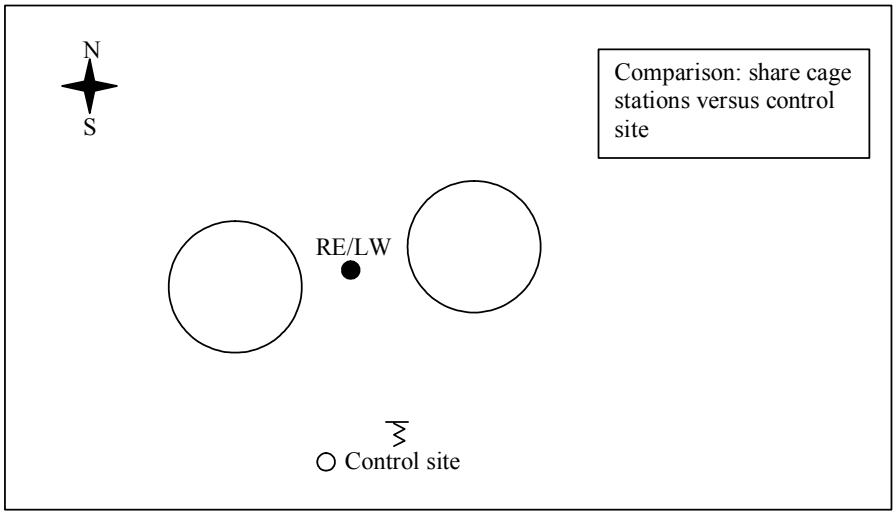
Data were analyzed using analysis of variance (ANOVA) with Infostat Software (Version 3.0.2, 2003). Comparisons between sites (cage versus control) (Fig. 11), sampling stations, and dates for the variables evaluated were made by contrast analysis (p = 0.05, and p = 0.01). The overall variables were analyzed as a factorial arrangement by dates, sampling stations, sites (cage versus control), and depth as the main factors. The sediments variables compared dates and sampling stations; the water quality variables compared dates, sampling stations, sites (cage versus control), and depth; and biofouling compared dates and net position on each cage. Pearson correlations were made among the most relevant variables.








N
S
RN40
RN20
RW20
RW20
RS20
RS40
LN40
LN20
LE20
LE40
LS20
LS40
Control site
Comparison: cage site (excluding stations beneath cages) versus control site


N
S
RE/LW
Control site
Comparison: share cage stations versus control site

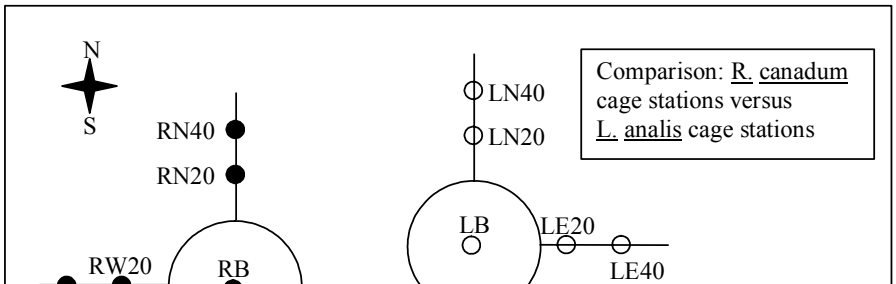

N
S
RN40
RN20
RW20
RB
LN40
LN20
LB
LE20
LE40
Comparison: R. canadum cage stations versus L. analis cage stations

Figure 11. Variables compared through contrast analysis.

Results and Discussion

General site information

During the pre-operative stages of this project, RSMAS University of Miami and Snapperfarm conducted detailed site assessment studies prior to site selection. The degree of exposure to currents and the depth of the open-ocean site selected for the Snapperfarm, Inc. demonstration projects indicated the threat of pollution could be reduced or insignificant. A previous trial conducted in Hawaii in 1999 by the Sea Grant College Program and the Oceanic Institute suggested environmental impacts of open-ocean aquaculture are negligible (Helsley 2000). The water depth and currents dissipated organic and inorganic pollutants that, otherwise, would have accumulated in shallow inshore areas with little current. No environmental footprints were detected in the area surrounding the Hawaiian cages. Solid wastes are dispersed in an open-ocean environment, especially in deep zones with strong currents. Snapperfarm, Inc. recognized that appropriate monitoring of the site prior, during, and after culture cycles provides essential information to minimize the environmental effects of the operation and to demonstrate sustainable management techniques. They recognized site selection and proper fish-farming management techniques are the most important criteria, playing key roles in preventing, minimizing and avoiding environmental pollution. Thus, their open-ocean site was selected for project development (Fig. 12).

Figure 12. Open-ocean site.

During Snapperfarm's site assessment, bottom type was characterized as predominantly sandy with patches of the calcifying macroalgae Halimeda spp. These crusty algae, which build a skeleton of calcium carbonate like corals, were the predominant genus noted during the area survey. *Halimeda* are well adapted to low-nutrient conditions and are typically found in tropical oligotrophic seas. Other macroalgae commonly found in association with high nutrient, eutrophic environment in the tropics (e.g. *Ulva* spp; *Gracilaria* spp) were not observed during the survey. These observations indicated the natural productivity in the selected area was low, which fulfills one of the most important site assessment criteria for open-ocean marine fish aquaculture. No coral reefs were observed near the cage site.

To minimize wastes, Snapperfarm, Inc. employ feeding strategies using high quality feeds with high digestibility and assimilation coefficients. Proper feeding is crucial because overfeeding translates not only to monetary losses, but also to an increase in solid wastes released into the environment. By using a high-quality feed with excellent water stability, the company expected a feed conversion rate (FCR) as low as 1:1, indicative of little or no feed waste. This assumption was made based on preliminary trials conducted by University of Miami scientists at the Aquaculture Center of the Florida Keys, Inc., which resulted in FCRs ranging from 0.79-1.4, with a mean FCR of 1:1. After incorporating these practices during their first culture cycle in Culebra, Snapperfarm found FCRs were higher (1.95) because they extended the harvest procedures over an extended period due to several operational factors. This resulted in larger R. canadum being harvested, even larger than their target marketable size. Snapperfarm suspected the fish reached maturity and invested energy in reproductive products instead of biomass (personal communication).

Benthic sample: grain size analysis

Grain-size classification was according to Udden-Wentworth (Wentworth 1922). The analyses (Table 4) indicated each station was classified as “sand” with either “fine” or “medium” grain size. Grains classified as “fine” have a diameter of approximately 0.125 mm (3.0 phi) and “medium” grains of 0.25 mm (2.0 phi). No temporal changes in the grain size were found from effects by the cages during the study (Table 5). Only one sampling station (LN40) showed variation in the grain size from October 2002 until October 2003. Similar results were reported by Molina-Domínguez et al. (2001) who indicated minor differences for sediment grain size of three sampling stations near cages at Grand Canary Island over a 1-year period. Cages can produce a decrease in downstream current velocity, allowing the settling of more fine particles close to the systems. However, only one station had a minor change over time, probably due to natural variations of bottom type at the LN40 station.

Table 4. Grain-size classification by Udden-Wentworth (Wentworth 1922).

Mm	µm	phi (ϕ)	Wentworth size class	Rock type
4096		-12.0		conglomerate/
			boulder	breccia
256	n/a	-8.0		
			cobble-gravel	
64	n/a	-6.0		
			pebble-gravel	
4	n/a	-2.0		
			granule-gravel	
2	n/a	-1.0		
			very coarse-sand	sandstone
1	n/a	0.0		
			coarse-sand	
0.5	500	1.0		
			medium-sand	
0.25	250	2.0		

			fine-sand	
0.125	125	3.0		
			very fine-sand	
0.0625	63	4.0		siltstone
			coarse-silt	
0.031	31	5.0		
			medium-silt	
0.0156	15.6	6.0		
			fine-silt	
0.0078	7.8	7.0		
			very fine-silt	
0.0039	3.9	8.0		claystone
			clay-mud	
0.00006	0.06	14.0		

Table 5. Grain size analysis for the area near the cages at the beginning and one-year later of the culture period.

R. canadum cage			L. analis cage		
	Sediment type		Station	Sediment type	
Station	October-02	October-03	October-03	October-02	October-03
RN40	fine sand	fine sand	LN40	fine sand	medium sand
RN20	medium sand	medium sand	LN20	medium sand	medium sand
RS40	n.s.	n.s.	LS40	fine sand	fine sand
RS20	medium sand	medium sand	LS20	medium sand	medium sand
RW40	fine sand	fine sand	LE40	fine sand	fine sand
RW20	n.s.	fine sand	LE20	n.s.	fine sand
RB	fine sand	fine sand	LB	medium sand	medium sand
RE/LW	fine sand	fine sand	RE/LW	fine sand	fine sand
			control	fine sand	fine sand

n.s.: no samples taken

Sediment grain size also affect organisms' distribution in benthos relating to available interstitial spaces between sand grains (Wieser 1969) and prevalent organisms.

Benthic samples: inorganic nitrogen (ammonia, nitrite, and nitrate)

No differences were found for mean ammonia, nitrite, or nitrate concentrations among sampling dates (Fig. 13). Mean values for dissolved ammonia, nitrite, and nitrate in the sediments at the cage site were similar to those at the control site (Figs. 14, 15, and 16, respectively), suggesting no accumulation of these nutrients near the cages. There was a positive correlation of mean ammonia concentrations in the sediment with nitrite concentrations in the water column, increasing as the other increases and vice versa. There was also a positive correlation during the study of nitrate in the water column with nitrate found in sediments.

Most environmental reviews relating to cage aquaculture emphasize benthic enrichment containing organic material beneath cages (Hall et al. 1990; Holmer 1991) and accumulation of nitrogenous and phosphorous compounds (Holby and Hall 1991). However, during our study, we observed no accumulation of these nutrients, probably due to strong currents and efficient feed retention by the fish. Most studies occur in bays where current velocity is slower than at the Snapperfarm cage site. Areas with little current are prone to accumulation of pollutants, especially increased sedimentation of organic materials. Although

there was little nutrient accumulation at the Snapperfarm site, they plan to increase stocking rates. Thus, additional studies are required to determine future nutrient accumulation as the company increases feeding rates. Optimal stocking densities should be determined because it contributes to the reduction of solid waste as fish efficiently consume feed, leaving little uneaten food. Remedial measures such as allowing the bottom to lie fallow (by moving the cages), utilizing polyculture techniques, or harrowing the bottom when conditions merit (such as just before harvesting when feeding rates are high) should be included in best management practices (BMPs). As cages are added at the farm, the cage array needs to be oriented to provide optimum flow parallel with the predominate transport.

Nutrient losses from aquaculture feeds have received attention because of the contribution of the nutrients to eutrophication. A variety of nutritional manipulations have been developed to minimize loss while maximizing nutrient utilization and growth of fish (Gatlin and Hardy 2002). Advancements in diet formulation, ingredient processing, feed manufacturing, and feeding strategies can substantially reduce the excretion of enriching nutrients. For example protein retention has doubled in Atlantic salmon farming (from about 22 to 45%). Similar goals should be established for tropical marine fish such as R. canadum.

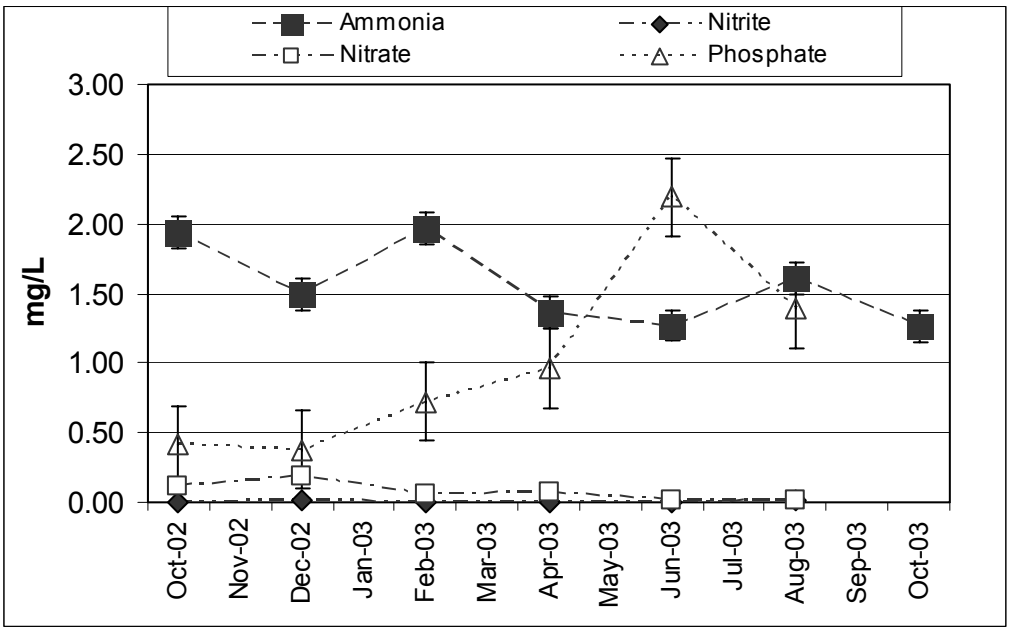


Figure 13. Temporal variation of the sediment nutrients concentrations

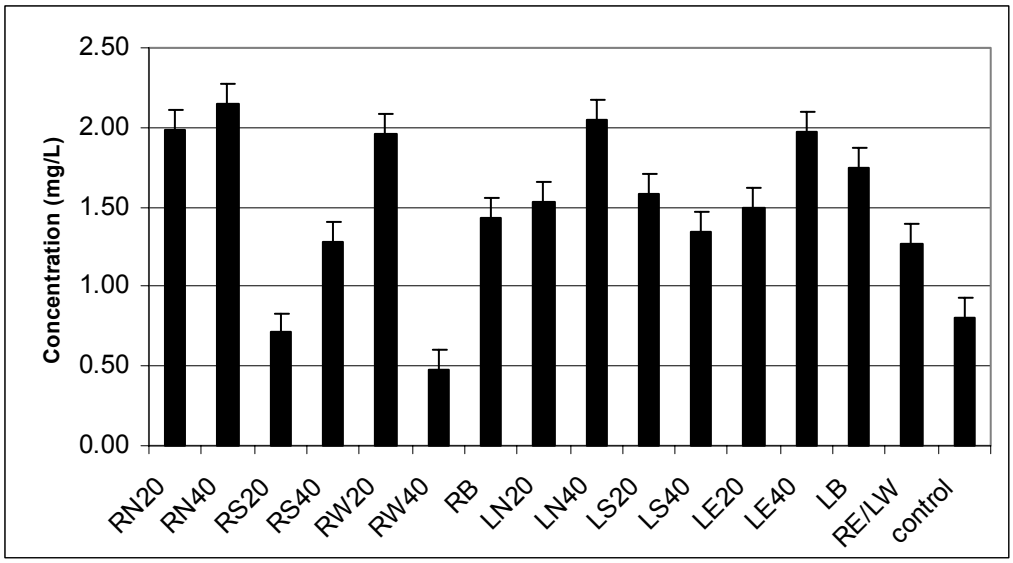


Figure 14. Sediment dissolved ammonia for stations at the cage and control sites.

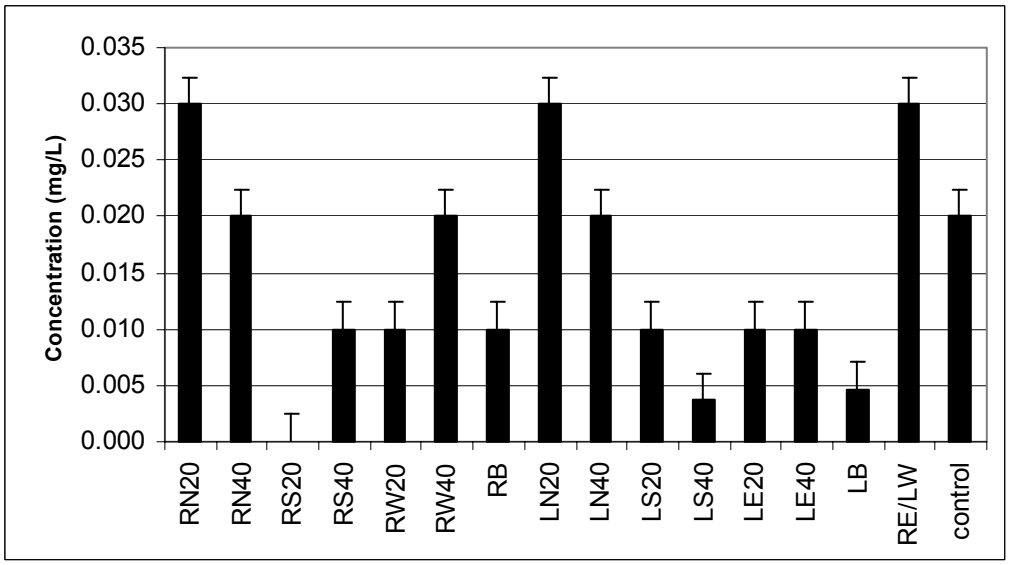


Figure 15. Sediment dissolved nitrite for stations at the cage and control sites.

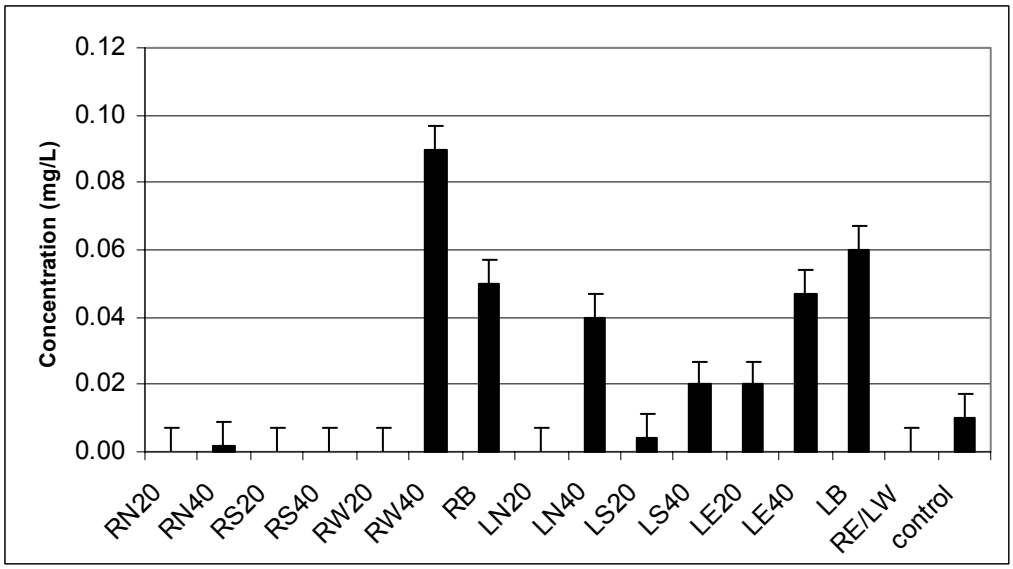


Figure 16. Sediment dissolved nitrate for stations at the cage and control sites.

Benthic samples: phosphate

Mean values for dissolved phosphate in the sediments at the cage site were similar to those at the control site (Fig. 17), suggesting no accumulation in the sediment. Even though some researchers reported accumulations of phosphorus at cage sites (Holby and Hall 1991; Karakassis 1998), no accumulation of phosphates at the cage site were found, which could be due to strong currents in the area. As stocking rates increase, these measurements should be continued because of increased feeding rates. Similar results has been reported by Molina-Domínguez et al. (2001) who found no differences in phosphate content of the sediment at 0, 60, and 200 m from the cages system. Karakassis et al. (1998) reported significantly higher sediment phosphate concentrations beneath the cages than for background levels. However, it must be noted again that most of these studies have been for inshore areas.

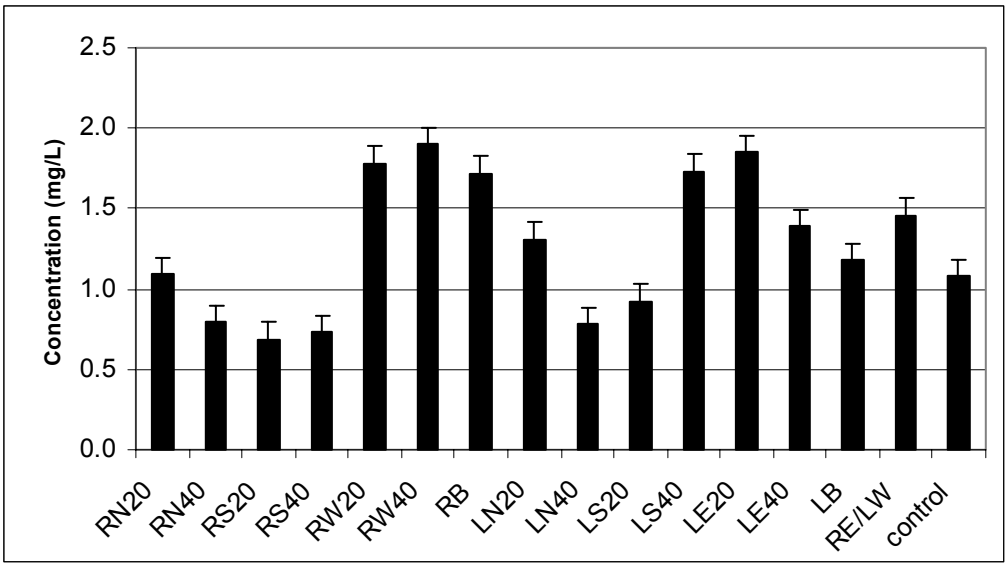


Figure 17. Sediment dissolved phosphate for stations at the cage and control sites.

Benthic samples: organic matter

Sediment concentrations of organic matter ranged from 4.0 - 6.2% at the cage site and the control site, but were not significantly different. Mean values are showed in Fig. 18. Significant differences in organic matter over time were encountered only during October 2003, the last month monitored, with concentrations greater than those of previous months (Fig. 19). There were no significant differences among sampling stations at the cage site versus the control site (Fig. 20), indicating organic matter concentrations at the cage site were similar to background levels found at the control site. This suggests there was no organic matter accumulation at the cage site. Contrast analysis indicated no differences in organic matter concentration of upstream versus downstream stations.

Similar concentrations of organic matter were found by Molina-Domínguez et al. (2001) in open-ocean cages with organic matter percentage oscillating from 3.5% (initial value) to 6.0% and were similar for all samplings stations analyzed during a year. Similarly, a 4-yr open-ocean aquaculture study off the coast of New Hampshire (Grizzle et al. 2003) indicated organic matter concentrations remained less than 3% and no significant impact was detected. Karakassis et al. (1998) reported localized high concentrations of organic matter (7.0 – 20.0%) in the first 4 cm of sediment depth beneath cages in the Mediterranean Sea; however, concentrations were similar to background levels at a distance of 25 m away from the cages. Effects are generally restricted to areas in the immediate vicinity of fish farms (Anonymous 1987; Gowen and Bradbury 1987), probably due to dispersal of waste food and fecal materials (Frid and Mercer 1989; Lumb et al. 1989). Karakassis (2000a) indicated that benthic impacts are more likely in

fine grained than in coarse sediments because of accumulation of organic material. Organic matter enrichment leads to accumulation near cages (Hall et al. 1990; Holmer 1991), anaerobic conditions, low redox potential (Hargrave et al. 1993). However, during our study, no significant organic material accumulation was observed near the cages, probably due to strong currents. As stocking levels increase, this study should be continued, especially because our data indicated the last month of our study had significantly higher sediment concentrations of organic matter.

Benthic samples: organic nitrogen and total carbon

The only month with significant increases in organic nitrogen and total carbon concentrations was June 2003 (Figs. 21 and 22, respectively). This concentration indicated increased biomass in the cages just before harvesting began during that month. Feeding rates reached their highest levels to support the biomass. This data suggests the need for future studies as farmers increase biomass in their cage growout. Studies should be designed to determine the assimilation rate by the surrounding environment to handle increased waste discharge. On a positive note, organic nitrogen and total carbon concentrations returned to normal levels by August 2003, only two months later. This was probably due to substantially less fish biomass in each cage, with subsequent reduced feeding rates.

During the study, neither organic nitrogen nor total carbon in the water column was different among sampling stations (Figs. 23 and 24, respectively). Thus, fluctuations in concentrations were mainly seasonal with fluctuations similar to background levels. Contrast analysis comparisons determined levels of organic nitrogen and total carbon beneath the cages (RB and LB) were similar to those at the control site. Some studies report sediment organic material (organic nitrogen and carbon) increase significantly near cages (Karakassis et al. 2000b; Brown et al. 1987; Hargreave et al. 1993; Holmer and Kristiansen 1992). Hall et al. (1990) reported higher concentrations of organic carbon near marine fish cages that were 200-300 µg/mg of sediment greater than in our study. However, the findings reported by Hall et al. (1990) indicated organic carbon concentrations were only significantly higher beneath cages, similar to our stations RB and LB. At a distance of 20 m from the cages, they reported concentrations were similar to the background levels. Even though currents probably disperse much of the nutrients, these studies should continue as farmers increase fish biomass in the cages with subsequent greater feeding rates. Data taken prior to the installation of an open-ocean fish farm in the North Eastern Atlantic (Madeira Archipelago) and employing a mass-balance approach indicated a considerable waste load beneath the cages. Andrade (1997) indicated no major impacts of the farm wastes on the sediment quality beneath the cages, suggesting wastes were mainly derived from feces rather than from uneaten feed pellets. He found organic carbon content was not significantly higher than values found for

adjacent clean sediment areas. The percentage of organic nitrogen upstream from the cages was significantly higher (0.46%) than downstream (0.39%).

Contrast analysis indicated the L. analis cage had higher total carbon than the R. canadum cage even though the former cage received less feed because of less fish biomass. L. analis grow more slowly. Because they were stocked at 4,000/cage, it would be expected that their growth would have been optimized and that feeding rates would be optimum. Apparently L. analis were less aggressive during feeding. By contrast, R. canadum were stocked at 12,000/cage; with their faster growth rates and aggressive feeding behavior, their feeding rates were higher than L. analis.

Total carbon and nitrogen leached as much as 22 and 26% from feed, respectively, after five minutes immersion in a study conducted in the Mediterranean, with fecal feces having a rapid loss of nutrients within ten minutes after immersion. However, feed quality and stability are important. Some researchers have not found significant differences in nutrient leaching of either carbon or nitrogen from six salmon diets after immersion in seawater for 20 minutes.

Assuming stocking rates will increase in future operations, organic nitrogen and total carbon concentrations need to be monitored closely. If negative effects occur, Stickney (2002) recommends removing the fish from the location and taking remedial steps such as harrowing the bottom and allowing sufficient time for recovery prior to restocking the animals at lower densities. High quality feeds designed for high digestibility and low rates of nitrogen excretion should be used. Also, maintain culture conditions at an optimum to reduce stress and disease problems while striving to maintain maximum growth rates. Polyculture could be employed in future operations to reduce the accumulation of nutrients and solids in the immediate vicinity of the cages. Cage culture operations in Japanese bays are complemented by algal and mollusk culture; the algae and mollusks benefit from the enriched water from the cages culture operations while the cultured fish benefit from improved water quality. The algae Gracilaria chilensis cultured on ropes in conjunction with salmon cage operations grew rapidly when placed 20 m from the fish cages (Stickney 2002).

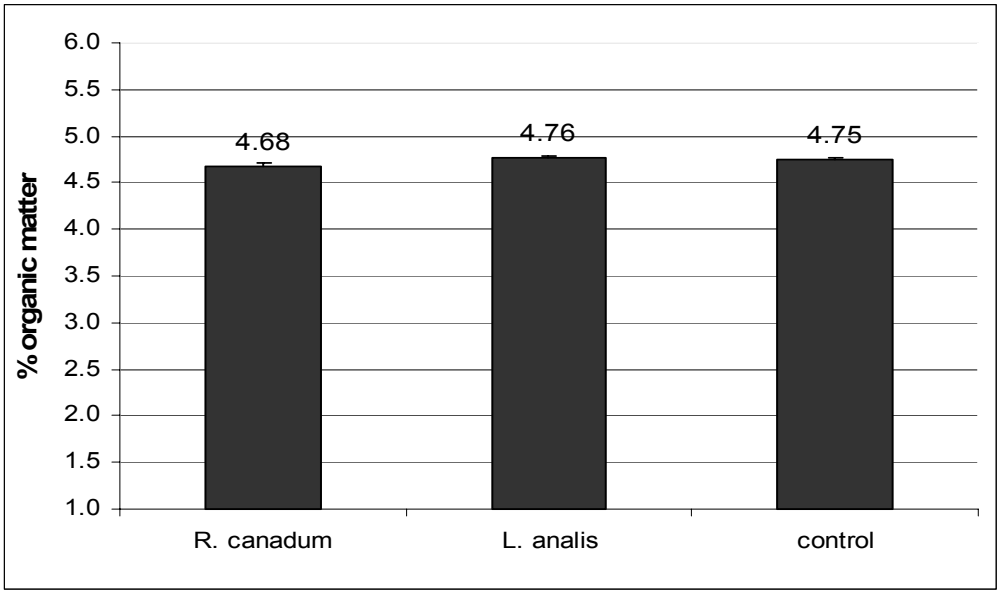


Figure 18. Sediment organic matter at the cages and control site.

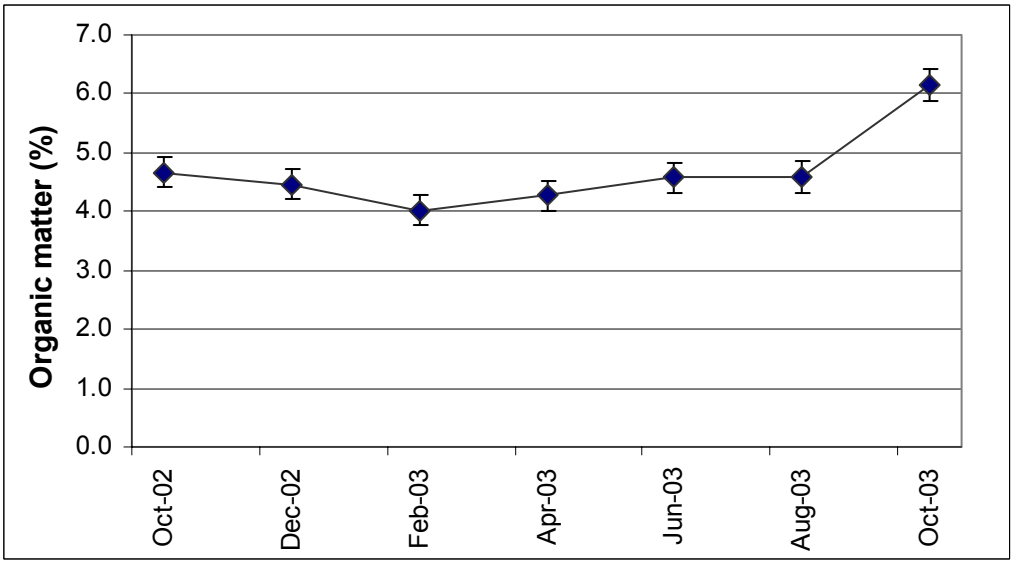


Figure 19. Temporal variation of sediment organic matter.

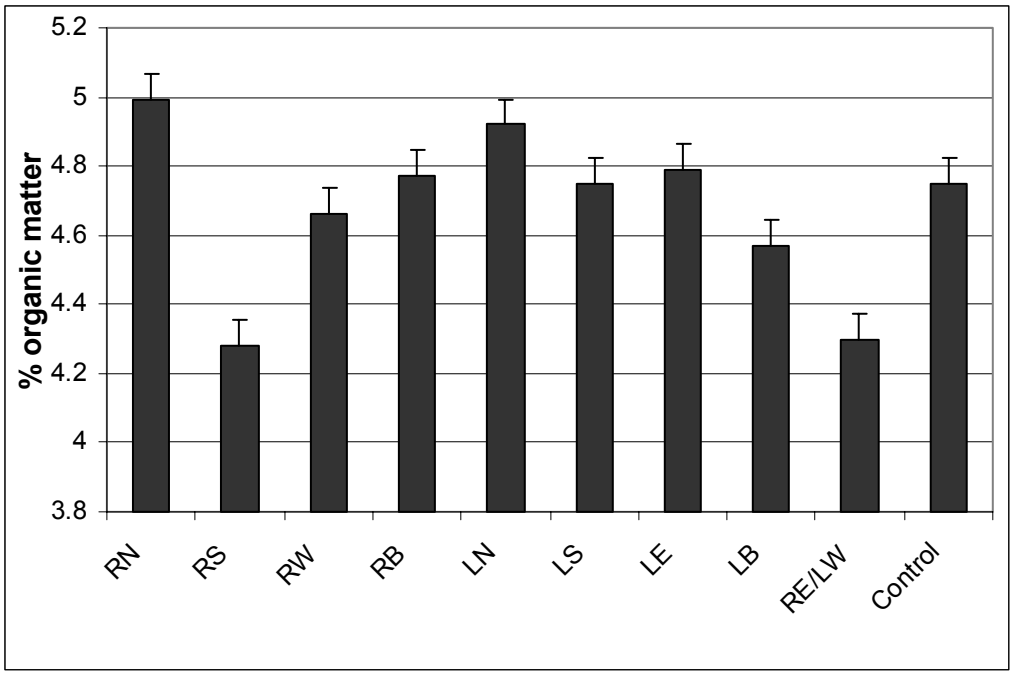


Figure 20. Sediment organic matter at the sampling stations and control sites.

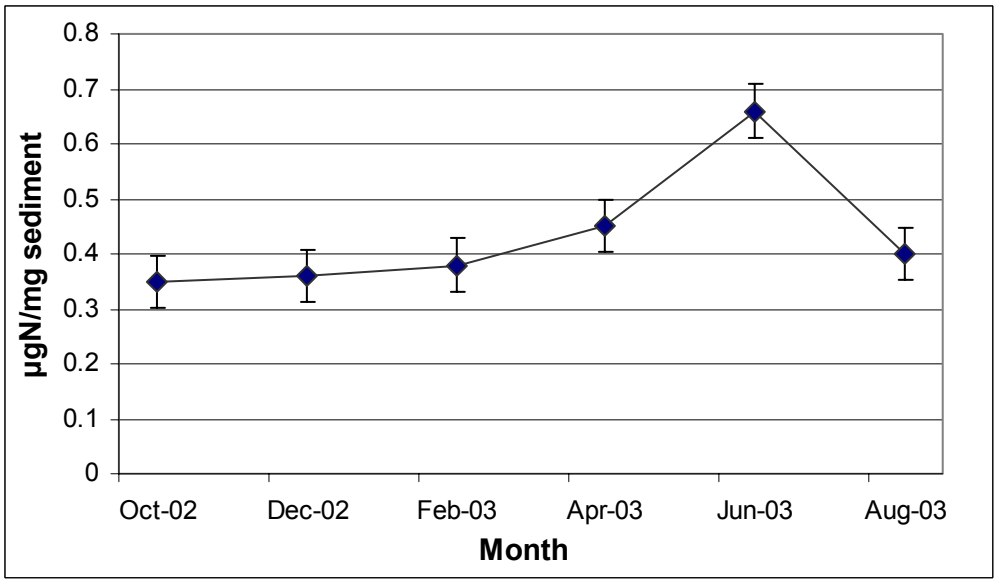


Figure 21.Temporal variation of sediment organic nitrogen.

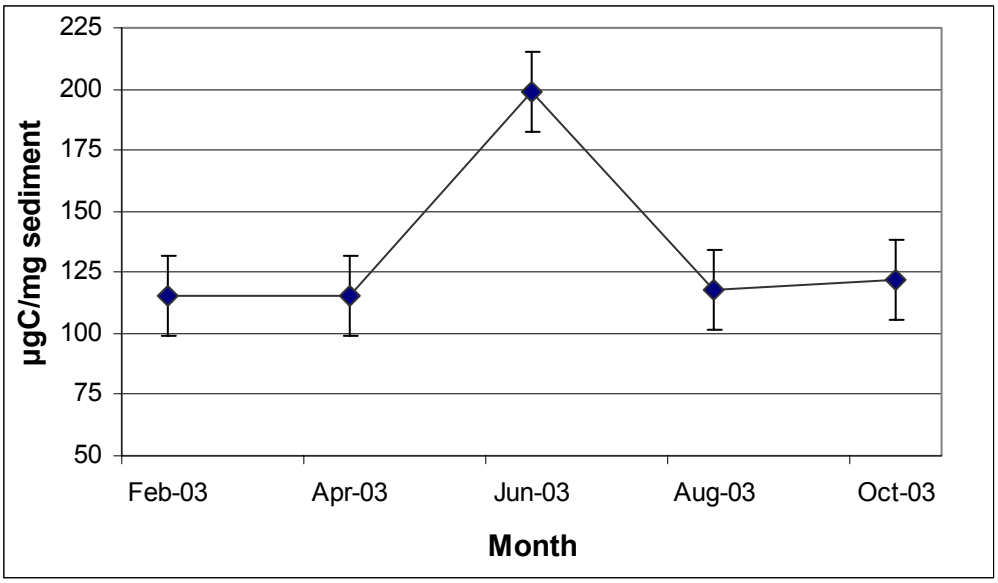


Figure 22.Temporal variation of sediment total carbon.

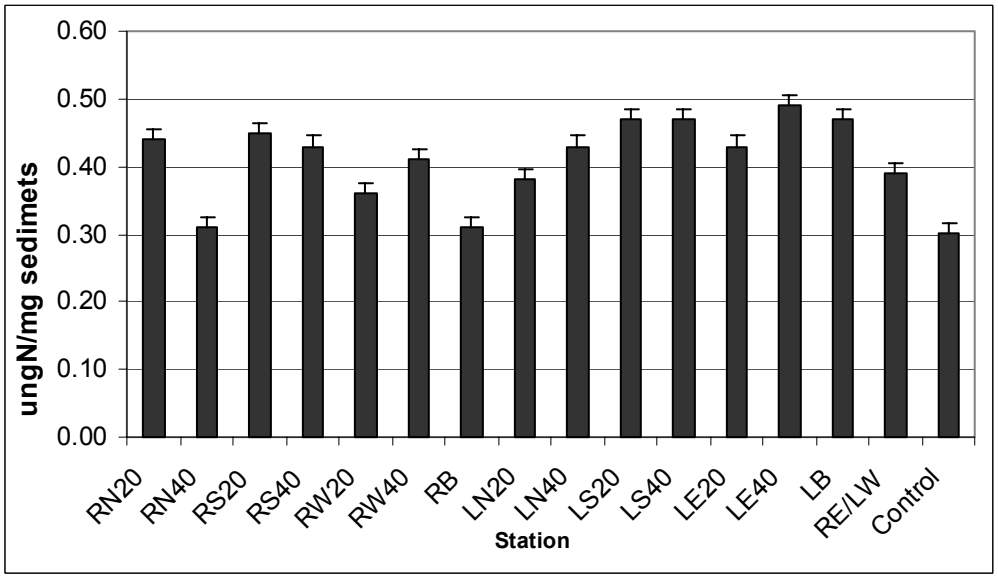


Figure 23. Mean sediment organic nitrogen for each sampling stations at the cage and control sites.

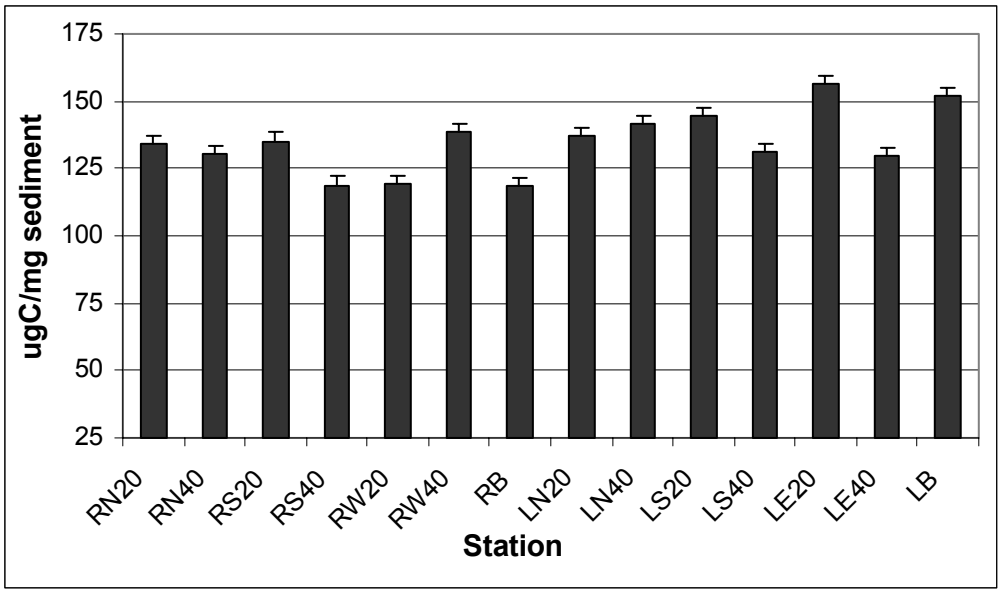


Figure 24. Total carbon for each sampling station at the cage and control site.

Benthic samples: macroinvertebrates

The sediment reflects what occurs in the water column during an aquaculture operation (De la Lanza 1986). The diversity and abundance of benthic organisms is reduced when their habitats are subjected to high levels of organic enrichment derived from fish farming (Brown et al. 1987). Thus, changes reflected in macroinvertebrate communities are indicators of contaminated sediments. In our study, there were significant differences among dates and sampling stations for the macroinvertebrate population near the cages ($p < 0.05$). Contrast analysis indicated less abundance of species during June 2003 than other months, probably due to the high feeding rates just before fish harvest (Fig. 25). Contrast analysis showed that abundance of macroinvertebrates in the sediments at the control site was only significantly higher when compared to stations beneath the cages (RB and LB), especially at the snapper cage (LB) (Fig. 26). Other sampling stations did not show differences in macroinvertebrate abundance when compared to the control site. This indicates effects on the macroinvertebrates population are localized beneath each cage. At a distance of 40 m from the center of each cage, macroinvertebrate abundance was similar to the control site. Karakassis (2000a) found that impacts on benthos are highly localized, not exceeding a distance of 25 m from the edge of the cages. Utilizing Pearson correlation analysis, no correlations were found between macroinvertebrate abundance and organic matter, organic nitrogen, or total carbon. Contrast analysis indicated a higher concentration of benthic macroinvertebrates at upstream stations than at downstream stations.

There were no differences for the Shannon diversity index (Fig. 26), species evenness index (Fig. 27), or species richness index (Fig. 28) at the cage site versus the control site. The Shannon-Wiener species index and species evenness index for the benthic macroinvertebrates did not change over time (Fig. 25). However, there was a significant reduction in the species richness index during June 2003 (when there was more feed input into the system just before the harvesting process started). The species richness index returned to normal values by August 2003 (two months later), probably because a significant biomass was harvested from the cages, and consequently less feed was fed to the fish. This suggests the environment may return to normal conditions soon after some impact. Recovery processes may vary considerably depending on the type and magnitude of the stressor and the spatial and temporal scale of the disturbance. Complete recovery of the area could last one month to several years. However, there is no universal criterion for determining when a site has recovered (Karakassis et al. 1999). Part of the problem is that most environmental studies have been made in areas already impacted by human activities.

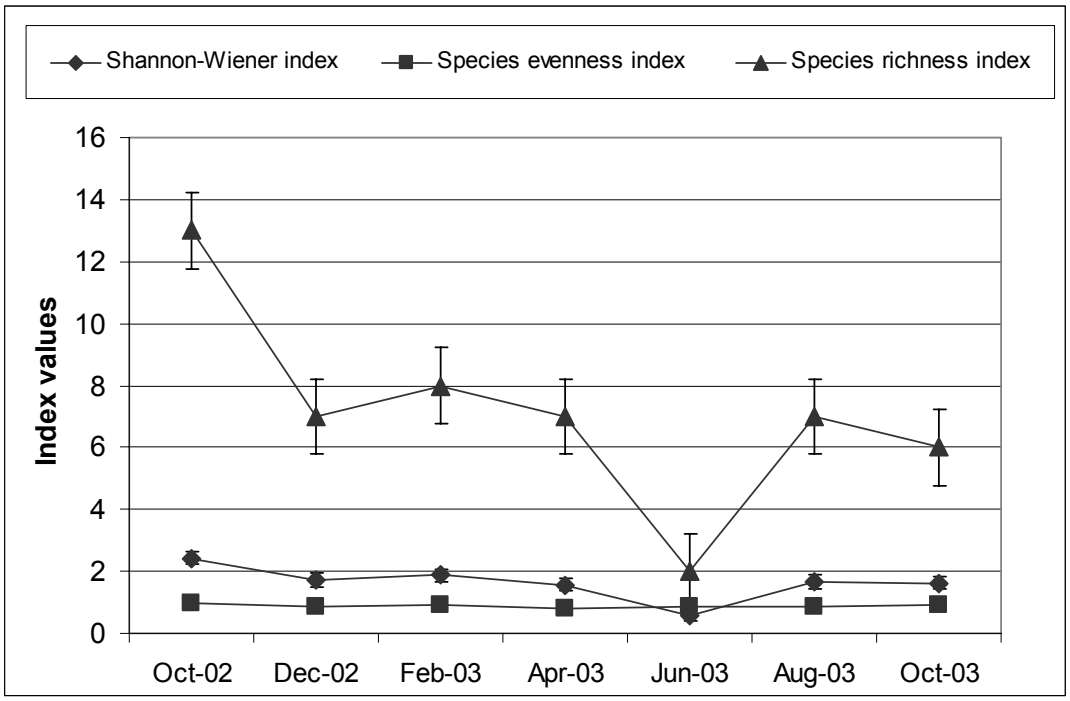


Figure 25. Temporal variation of benthic macroinvertebrates.

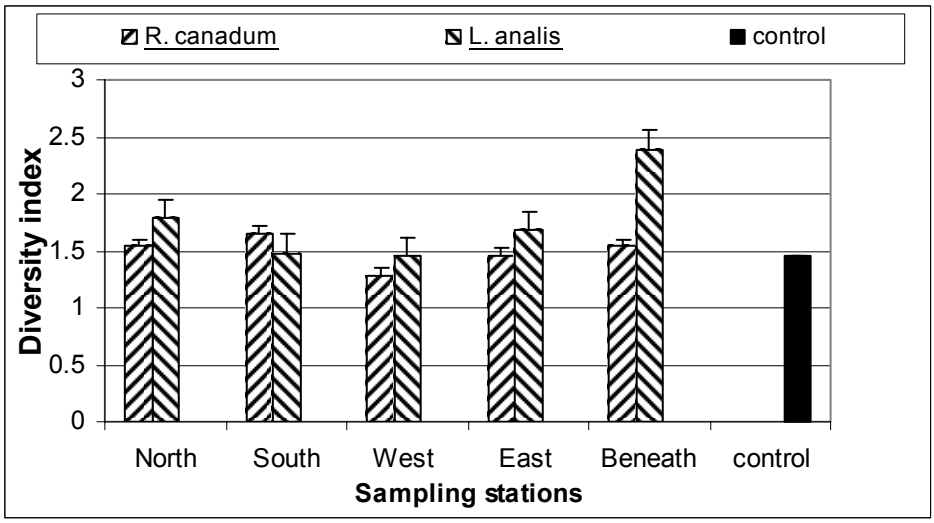


Figure 26. Shannon-Wiener diversity index for the benthic macroinvertebrates.

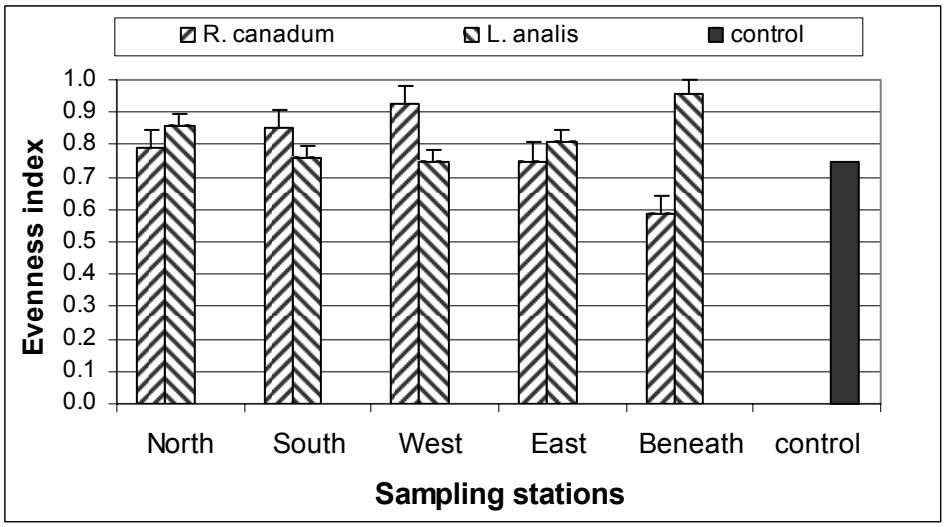


Figure 27. Evenness species index for the benthic macroinvertebrates.

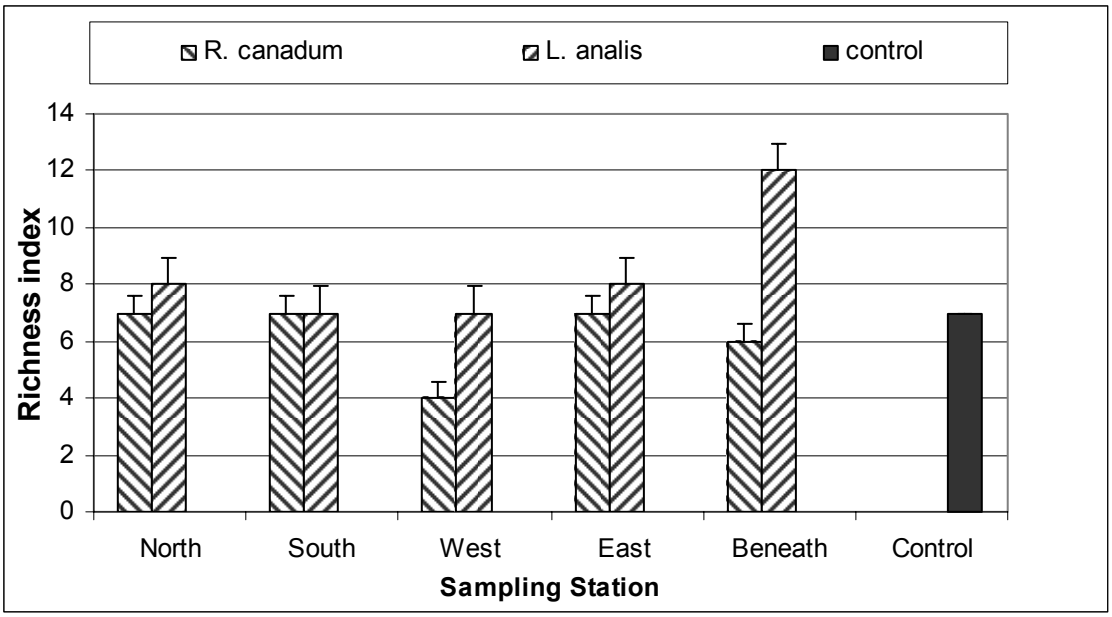


Figure 28. Species richness index for the benthic macroinvertebrates.

Macroinvertebrate communities reflect present and past disturbances with some organisms serving as indicators of organic contamination. The macroinvertebrate predominant groups were Polychaeta, followed by Mollusks and Crustacea. The polychaete families Capitellidae, Spionidae, Cirratulidae are indicators of environmental perturbation. These groups are utilized to characterize species richness and species abundance in relation to concentrations of organic enrichment (Tsutsumi 1987; Méndez 2002; Bybee and Bailey-Brock 2003). The species Capitella capitata has been considered as a universal indicator of contamination due to its proliferation in sediment with a high content of organic matter (Tsutsumi et al. 1990). However, this species was not detected in significant abundance in our study, suggesting conditions were favorable for a variety of benthic macroinvertebrates. Apparently, nutrients enrichment did not promote high numbers of C. capitata in the area near the cages. A total of 66 invertebrate families, one Cephalochordate family, and two orders of Crustacea at the cage and control sites were identified during the study. Tanaidaceaos was the most abundant group (44% of the total organisms identified), which belong to the Phylum Crustacea, followed by the family Tellinidae (18.3%) (Phylum Mollusca), Ostracoda (9.9%), Capitellidae (8.2%) (Phylum Polychaeta), Nereidae (7.7%), Glyceridae (7.4%), and Spionidae (4.5%). The remaining identified families had abundances lower than 4% of the total population.

Most investigations of benthic communities with soft bottoms have been made in temperate areas, and to a lesser degree, in northern, tropical, and subtropical latitudes. Moreover, few studies have been made in the tropics concerning open-ocean aquaculture in submerged cages in the Americas. One study located 2 km off of Ewa Beach in Hawaii (Bybee and Bailey-Brock 2003) indicated significant

changes in abundance over time with the polychaetes Ophryotrocha adherens (Dorvilleidae) and Capitella capitata (Capitellidae) beneath submerged aquaculture cages. However, after the study, the populations of these two species recovered to their normal levels. The second study was made 10 km from Portsmouth, New Hampshire (Grizzle et al. 2003). After 4 years (1997-2000), Polychaetes constituted the dominant group with four families (Spionidae, Paraonidae, Thyasiridae, and Maldanidae), followed by Molluscs (bivalves) and Crustacea.

Water column: inorganic nitrogen

Water analyses in the water column of both cages indicated similar ammonia-N, nitrite-N, and nitrate-N concentrations at the cage site compared to the control site (Fig. 29), suggesting differences could be seasonal. Low ammonia concentrations are normal for Puerto Rican waters, frequently less than 0.007 mg/L. Contrast analysis indicated mean ammonia concentrations near the R. canadum cage were lower (0.0024 mg/L) than the L. analis cage (0.0029 mg/L). October 2002 and February 2003 data indicated the highest concentrations (Fig. 30). There was a significant increase of ammonia concentration with depth with the highest values (0.0037, 0.0024, 0.0019 mg/L) found in the bottom-depth samples (Fig. 31). Mean values of the samplings stations at the cage site for ammonia concentration were similar to those of the control site (Fig. 32).

Mean nitrite and nitrate concentrations in our study were low for each month (usually less than 0.004 mg/L), with August 2002 indicating the highest values for each variable (Fig. 30). Surface samples had the lowest mean values for nitrite and nitrate (Fig. 31). Mean values of the samplings stations at the cage site for nitrite and nitrate were similar to those of the control site (Figs. 33 and 34, respectively). Contrast analysis indicated mean nitrite concentrations upstream (0.0053 mg/L were lower than downstream (0.0072 mg/L), while the nitrate concentration were lower upstream, with the lowest value downstream (0.0074 and 0.0044 mg/L, respectively). Contrast analysis indicated no differences in mean nitrite and nitrate concentrations at RB and LB at the cage site compared to those of the control site. Karakassis (2000a) reported that impacts in the water column are relatively low even in conditions with lack of significant tidal currents. Caribbean waters are oligotrophic and nitrogen is a limiting nutrient (Corredor 1999). Pitta et al. (1999) found that ammonia concentration increased significantly at two farms in the Mediterranean Sea, compared with background nutrient concentrations.

Water column: phosphate

The cage site had mean phosphate concentrations similar to the control site, suggesting changes were seasonal (Fig. 29). No differences were found among months. Phosphate concentrations were low, usually less than 0.003 mg/L. Phosphate concentrations oscillated throughout the sampling dates with October

2003 (the last month monitored) indicating the highest value (0.0037 mg/L) (Fig. 30). Phosphate concentrations at mid-depth were significantly lower than the top and bottom-depths (Fig. 31). Phosphates at the cage site were similar to those of the control site (Fig. 35). No differences in phosphate concentrations were noted between upstream and downstream stations.

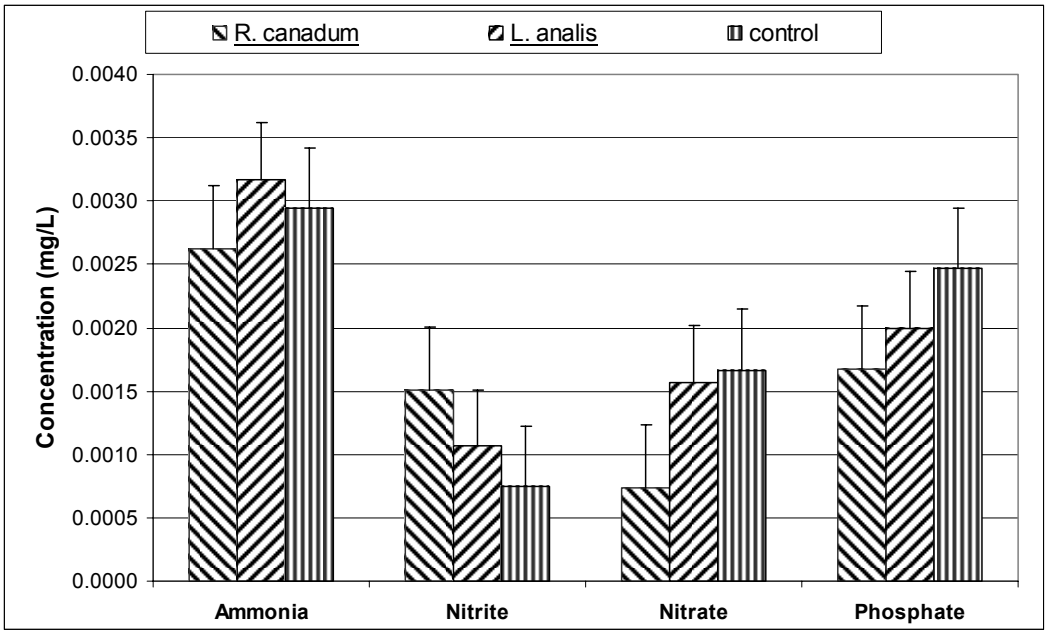


Figure 29. Dissolved nutrients in the water column.

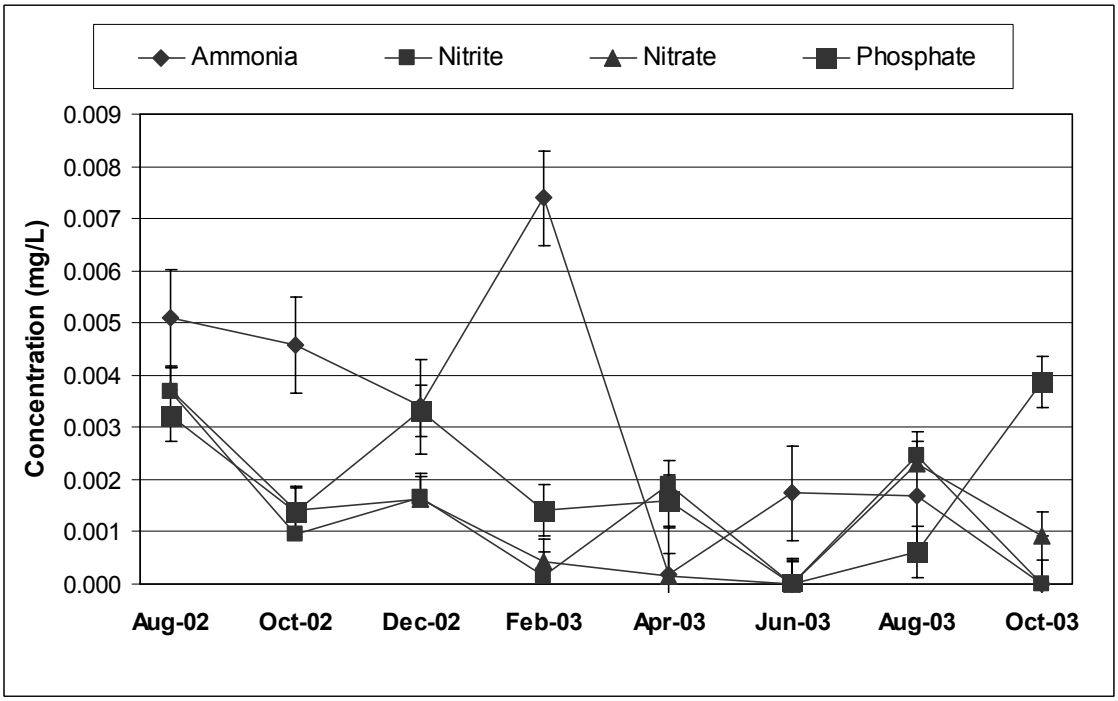


Figure 30. Temporal variation of dissolved nutrients in the water column.

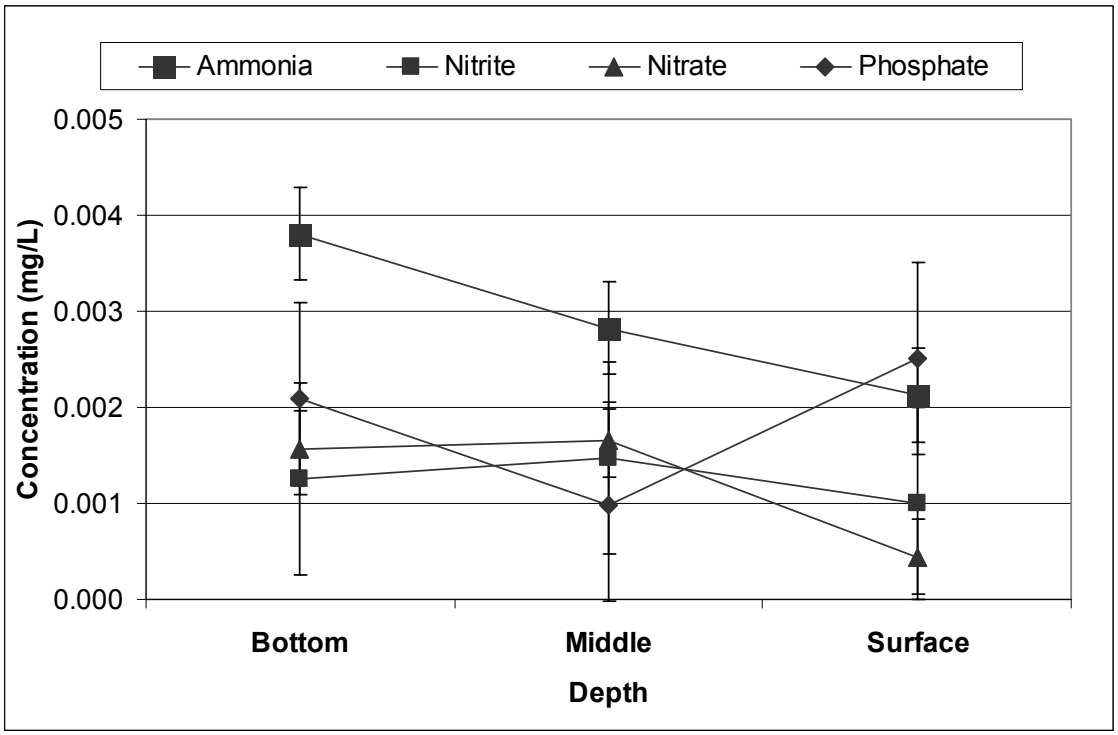


Figure 31. Vertical variation of dissolved nutrients in the water column.

A significant increase in concentrations of phosphate and ammonium was detected within the cages of Mediterranean fish farms, compared with a control site (Pitta et al. 1999). Most of these farms are inshore and are not directly comparable with the open-ocean environment.

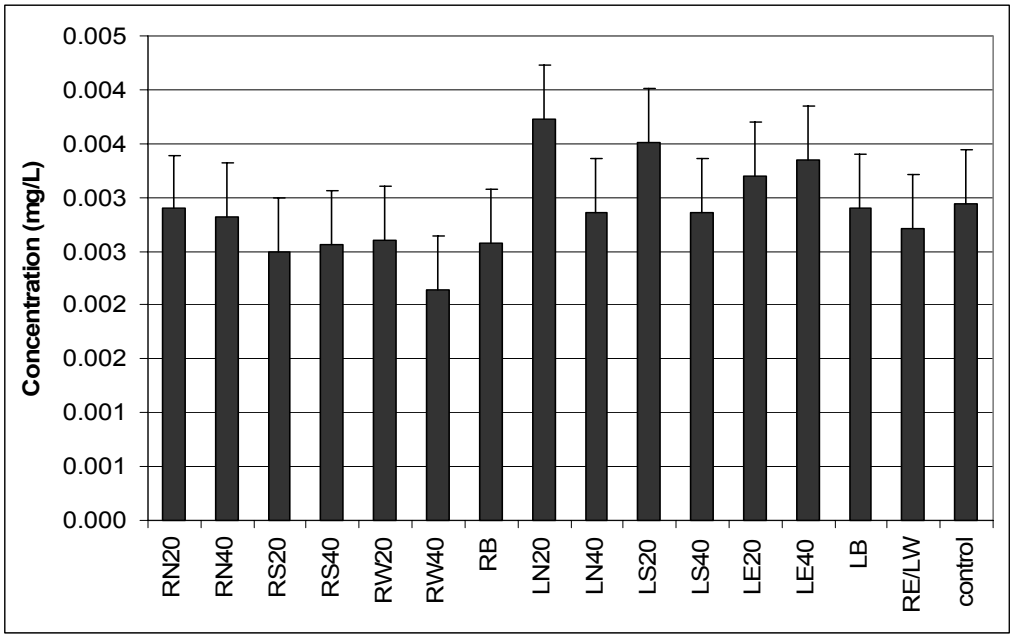


Figure 32. Dissolved ammonia in the water column for stations at the cage and control sites.

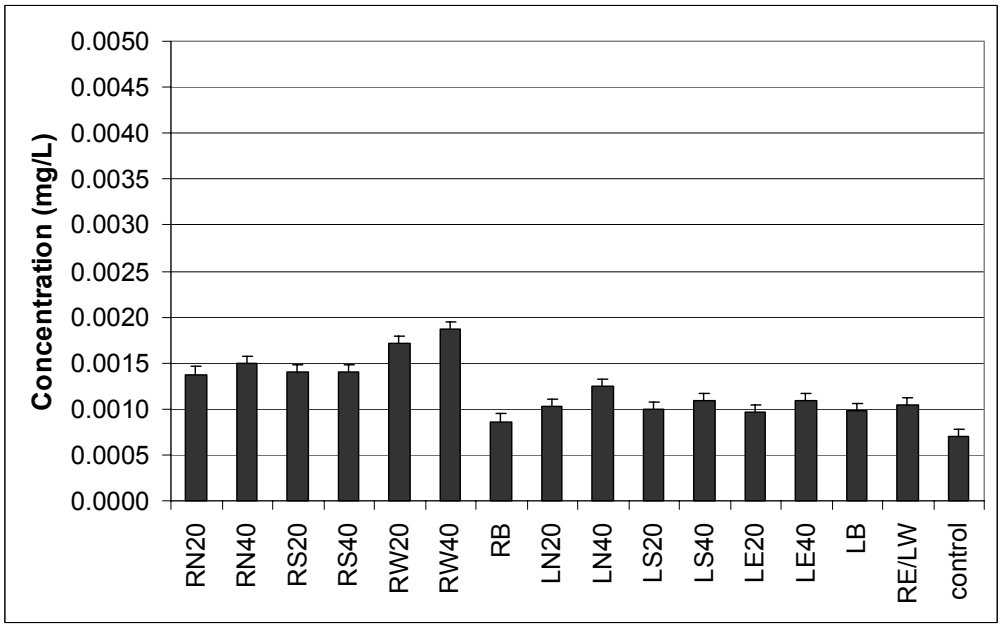


Figure 33. Dissolved nitrite in the water column for stations at the cage and control sites.

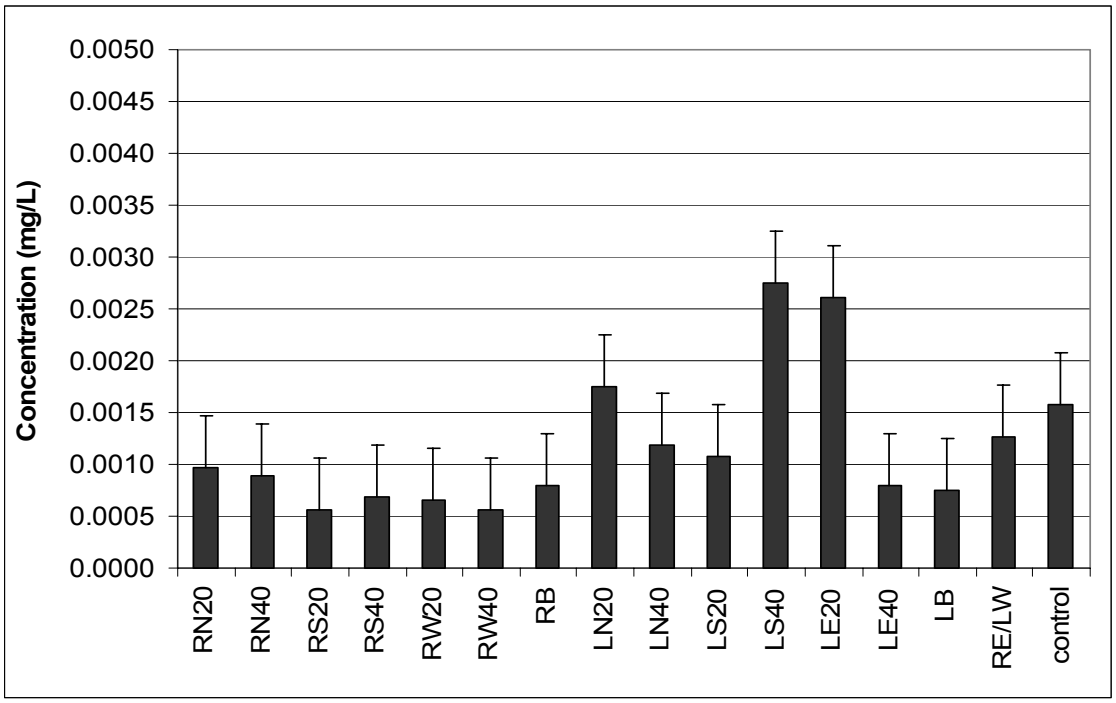


Figure 34. Dissolved nitrate in the water column for stations at the cage and control sites.

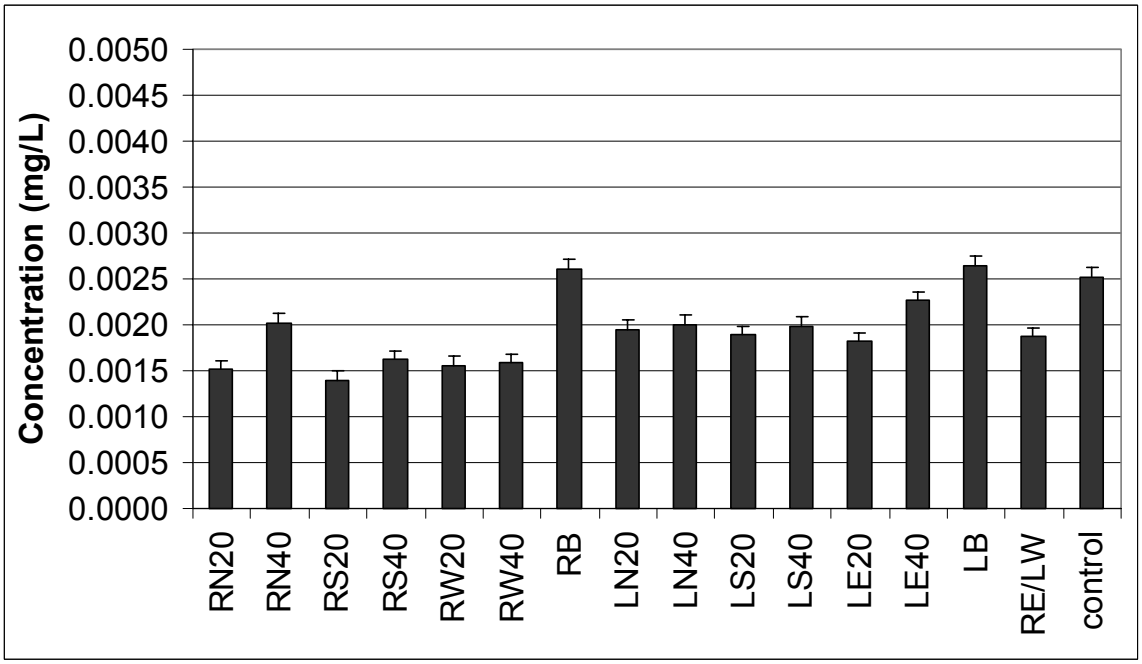


Figure 35. Dissolved phosphate in the water column for stations at the cage and control sites.

Water column: dissolved oxygen, temperature, chlorophyll-a, turbidity and salinity

No significant differences were detected for dissolved oxygen concentrations for the cage site compared to the control site. Dissolved oxygen concentrations generally remained above 5.0 mg/L during the sampling period (Fig. 36). The mean dissolved oxygen saturation in the area was about 92.3% with mean concentrations of 5.3 mg/L. These oxygen levels are optimal for appropriate growth of the organisms cultured. Strong currents, waves, and winds of the area maintained the water well aerated.

The water temperature was recorded for 450 days (December 2002 to March 2004) and no difference was found between the cages and the control site (Fig. 37). Maximum and minimum water temperatures in the area were 29.9 and 26.0 C, respectively, with an overall mean temperature of 27.8 C. The mean water temperatures declined slightly from December 2002 to February 2003 by about 1 C, and then increased to a maximum of 29.8 C by October 2003 (Fig. 37). Changes throughout the year were less than 3.0 C (from 26.5-29.5 C) with most of the culture period with temperatures above 26.0 C. The coldest months for Puerto Rico are December-February. These are optimal water temperatures for growth of tropical fish such as R. canadum and L. analis. The warm temperatures are excellent for aquaculture, thus accelerating the metabolic processes of the organisms cultured and of the surrounding biota (i.e. bacterial activity near the cages).

There were no differences in chlorophyll-a concentration between the cages and the control site during the experimental period (Fig 38). This suggests that nutrient input from the cages had no effect on the concentration of chlorophyll-a at the cage site. Similar finding has been reported by several researchers (Pitta et al. 1999; Wu et al. 1994). Concentrations of chlorophyll-a oscillated throughout the months analyzed (from December 2003 to April 2004) and usually remained below 1.0 µg/L. These concentrations are typical of this region because of the oligotrophic characteristics of the Caribbean waters. These concentrations are lower than those recommended to avoid eutrophication effects. For instance, for the northern European waters, the maximum value of 10 µg chlorophyll *a*/L has been recommended (CSTT 1994) as an environmental quality standard to avoid eutrophication. The response of chlorophyll-a will take time to develop within algae in response to increased concentrations of nutrients. It would take 1 to 2 days for an algal cell to divide, so even if all of its photosynthetic needs are met, it would takes 8-16 days (8-9 cell generations) to develop an algal bloom (Brooks 2000). A phytoplankton community could travel about 14 km from the location during that time. Thus it is difficult to conclude that the nutrient additions from the farm, generally undetectable at 30 m downstream, would have any effect at all on primary production even if the water body is nutrient limited (Brooks 2000).

There is little information on the effects of fish cages on plankton (Stirling 1990; and Person 1991), especially in tropical regions. Some researchers have reported no changes in chlorophyll-a concentration in fish cages culture, including those located in inshore areas (Pitta et al. 1999; Wu et al. 1994); however they were located in temperate regions. From our study, low levels of nutrients measured from the cages apparently are not detrimental to the immediate area. Increased primary productivity in nutrient impoverished areas may actually support the food chain in the area, leading ultimately to increased fisheries. Again, this indicates the importance of continuous monitoring to determine beneficial levels and ascertain upper levels deleterious to the food chain and to sustainable yield. These should be developed into best management practices (BMPs) for open-ocean cage culture in tropical regions.

No difference in the water turbidity between the cages and the control site were detected from December 2003 to March 2003 (Fig 39). This suggests nutrient input from the cages had no effect on the concentration of suspended particles in the water. Water turbidity oscillated during the months analyzed (from December 2003 to March 2003) and was generally less than 1 NTU. These levels are normal in open-ocean areas around Puerto Rico. Nutrients from uneaten feed and wastes from the cages may be partially taken up or eaten by biofouling or fauna, respectively.

No difference in salinity between the cages and the control site were anticipated, nor were differences detected (Fig 40). Salinity remained homogenous throughout the experimental period with a mean of 34.6 ppt and a range from 33.8-35.5 ppt. Because there are no sources of freshwater in the area, drastic salinity changes were not expected.

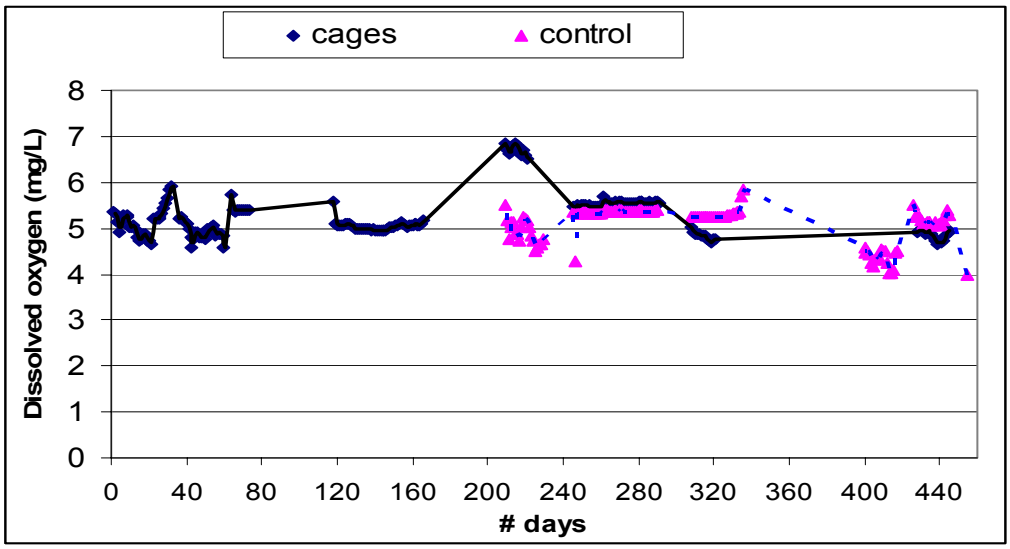


Figure 36. Dissolved oxygen at the cage and control sites from December 2002 - March 2004.

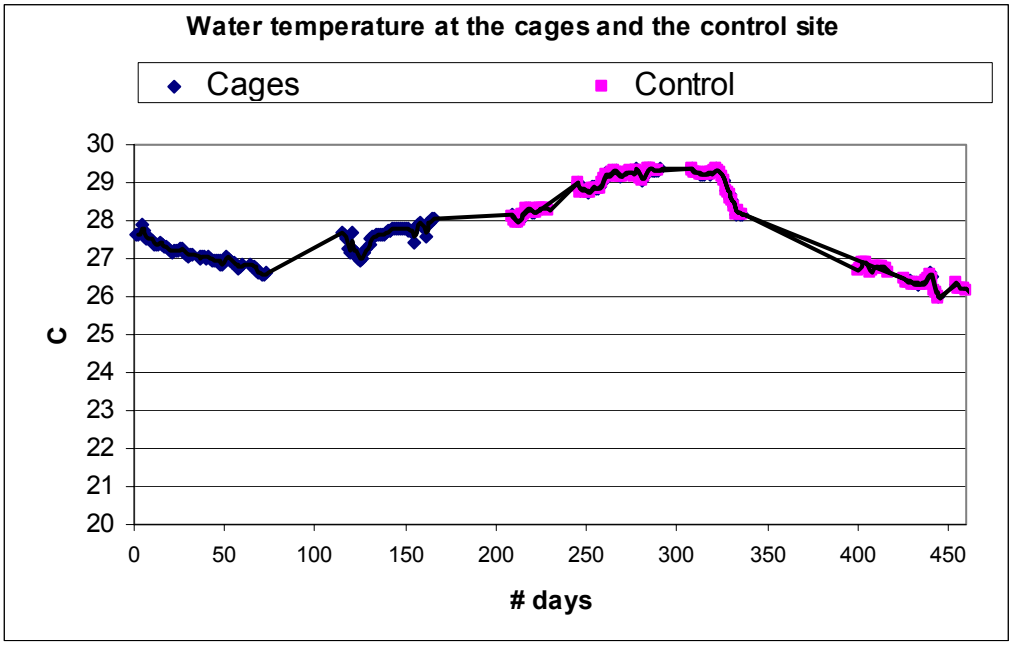


Figure 37. Water temperature at the cage and control sites from Dec 2002 - March 2004.

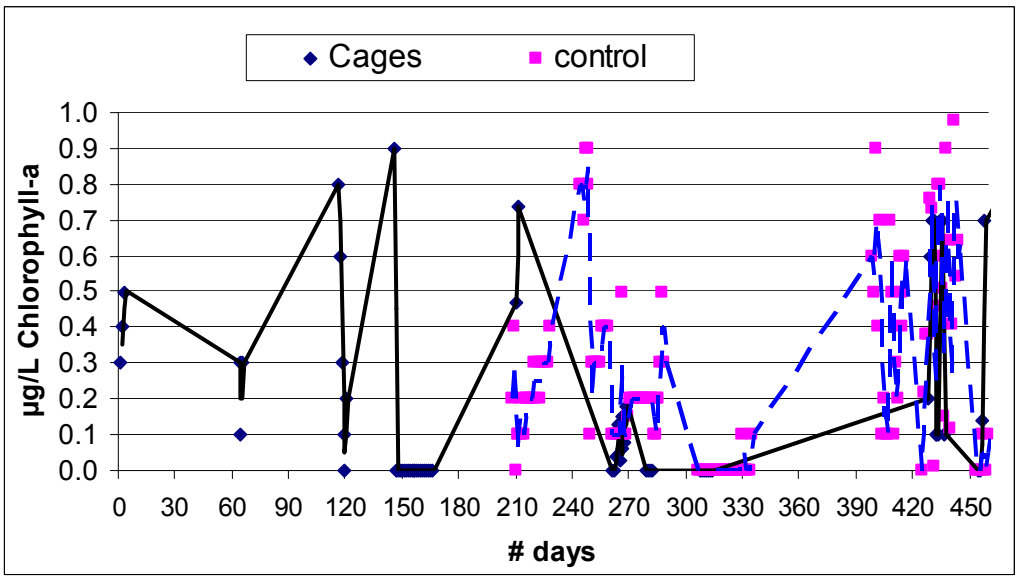


Figure 38. Chlorophyll-*a* concentration at the cage and control sites from December 2002- May 2003.

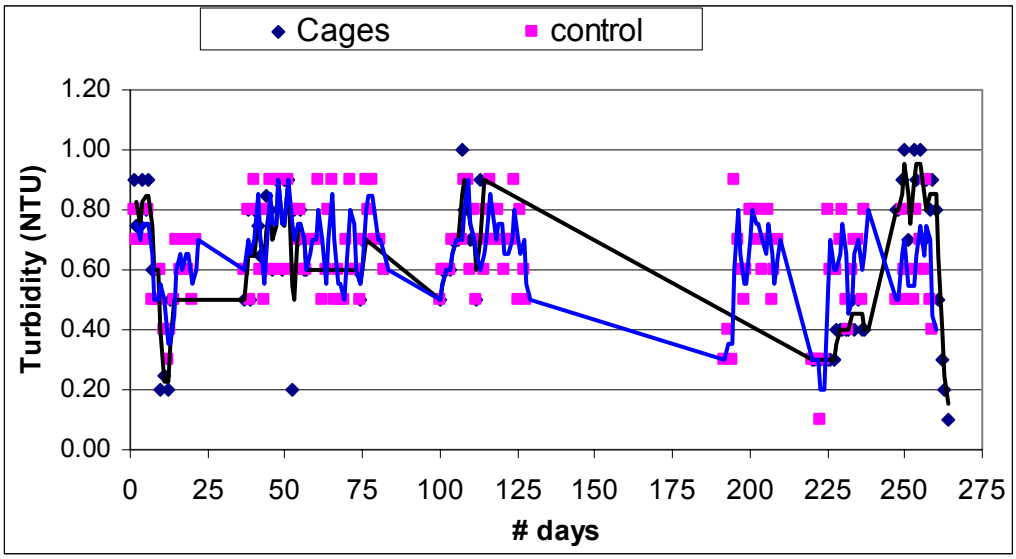


Figure 39. Turbidity at the cage and control sites from December 2002-May 2003.

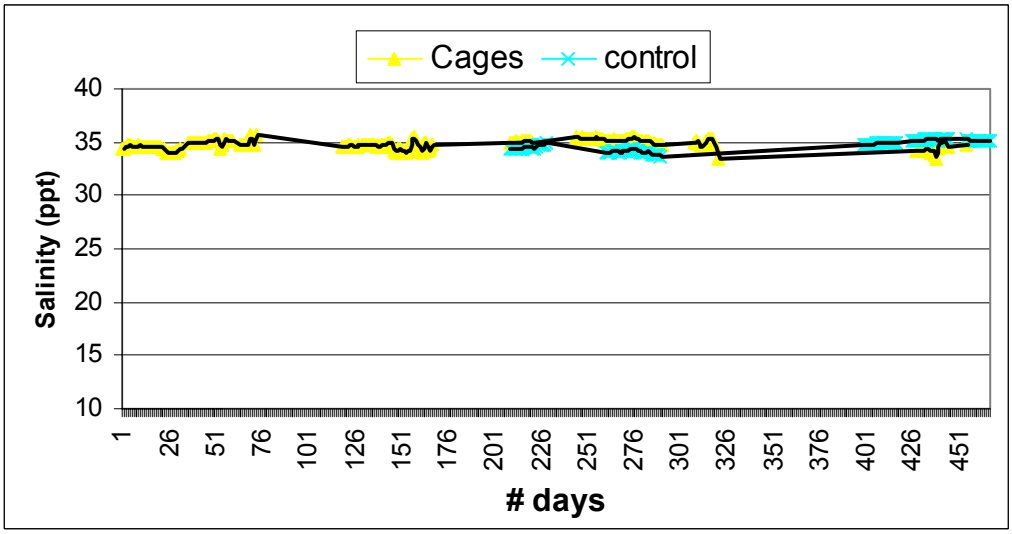


Figure 40. Water salinity at the cage and control sites from Dec 2002 – March 2004.

Water column: wild fish fauna

One caveat for the fish census is that it is impossible to determine if fish censused from one period to the next were the same individuals or different wild fish. This factor is further complicated by fluctuations in fish populations observed each month (see below). In one case, one large barracuda (*Sphyraena barracuda*) was probably the same individual during much of the study.

Videos taken before the cages were installed indicated only few small fish in the water column. However, during the second sampling in August, a large assemblage of about 10-20 cm long fish were attracted to the cage site. Videos taken from June 2002 to April 2004 suggest significant increases in fish abundance at the cage site. A total of 15,636 wild fish were recorded around the cages during 18 censuses performed from August 2002 – April 2004. These fish belonged to 6 orders, 23 families, and 40 species (Table 6). Almost all individuals (99%) belonged to nine species (Fig. 41).

The submerged cages apparently served as s (fish aggregating devices) throughout the year. Visual censuses and videos comparing fish abundance and species richness at the cage and control sites corroborated this concentrating effect, as well as the videos taken before cage deployment. It is difficult to make direct comparisons with similar habitats because of the lack of detailed studies of fish populations near submerged cages. However, compared to other fish aggregating device (FAD) studies, richness values obtained in our study were high at the cage site with 40 species belonging to 23 families. Significant differences in the species richness and fish abundance were found between the cage and control sites, and between the cage sites before cage deployment with the cage site after cage deployment. Thus, there were many more fish after cage deployment. Mean species richness at the cage site was 2.6 times higher than at the control site. Mean fish abundance recorded at the cage site was approximately 40 times higher (average of 1,050 fish) than the fish mean abundance at the control site (26 fish) (Table 7). Note that at the control site, the only structure was a current meter while the cages represented a much greater structure.

The species richness index, the species cumulative abundance, and fish abundance near the cages varied throughout the months analyzed, but no defined pattern was noted (Figs. 42 and 43). However, the mean species richness near the cages were always high (13 species) compared to mean values obtained at the control site (5 species) or in the area before the cages were deployed (3 species). The accumulation of numbers of species recorded near the cages increased over time (Fig. 42). However, months with the greatest increase in cumulated species (i.e., new species attracted to the cages) were months 1-5 (October – December 2002), and 11-12 (June – July 2003).

Most of the species traveled in schools; Depending on the species, some traveled in large schools, while others moved in less dense schools, Carangidae was the most abundant family recorded, with 8 species representing 92% of total fish censused (Fig. 44). Predominant carangids observed were Decapterus sp., Caranx crysos, and Caranx ruber. The families Haemulidae, Acanthuridae, and Labridae were also present in significant abundance (Fig. 44). The clear dominance of carangids (in species richness and individuals abundance) may be explained by the tendency of Caranx and Decapterus to swim in schools and to associate near floating objects (Hunter et al. 1967; Beets 1989). Carangids are

considered open water fish (Koslow 1988) with a clear tendency of forming large schools (Humann 1994). Decapterus sp. was the predominant species in this study and was characterized by compact schools with many individuals. Deudero et al. (1999) affirmed the size of a school is variable depending of the species ecology and on its propensity to be preyed upon. They reported carangid species using the schooling tendency either as defense against predators or as a mechanism for an enhanced foraging activity designed to overwhelm predators. *Caranx* was the genus with more species richness (6 species) and each of the species tends to aggregate in schools.

Other species exhibited a solitary behavior such as Sphyraena barracuda, Scomberomorus cavalla, Scomberomorus regalis, Ginglymostoma cirratum, Dasyatis americana, Aetobatus narinari, and Lutjanus jocu. Many were seen several times by the divers, usually moving away if closely approached.

There were no differences among months for the Shannon-Wiener diversity index, nor for the species evenness index (Fig. 45). Species richness increased significantly during December 2002 and June 2003 (Fig. 42). Feeding rates for the cultured fish, and therefore their wastes, were at a maximum during June 2003 when Snapperfarm began the harvest operation.

Further research is needed to determine if the increased feed and wastes attracts wild fish to the cages or if the cage site is simply a structure serving as a FAD. Other suggested possible explanations for the attraction effect to floating materials include schooling companions, a substitute substrate provided for species undergoing a change to another mode of existence (Hunter and Mitchell1967), and an increase in media complexity (Deudero et al. 1999). Since these fish are opportunistic feeders (Koslow et al. 1988; Humann 1994), their presence around the cages could also be attributable to food acquisition. Therefore, we need to determine if the wild fish assemblage is benefiting directly or indirectly from additional nutrients from the aquaculture activity or if the cage structures naturally accumulate organisms and are simply serving as a substrate.

Thirty-one of the species found near the cages have commercial importance in Puerto Rico, representing 43% (6,683 fish) of the total fish censused. Of these, 94% are used for human consumption (10 pelagic species and 8 reef species) (Table 8) and 6% for the aquarium trade (Table 9). Carangidae and Haemulidae were the most important families recorded used for human consumption, while Labridae and Acanthuridae were the most abundant families used in the aquarium trade (Figs. 46 and 47, respectively). The vast majority of the fishes for human consumption (82.5% or 5,513 fish) attracted to the cages were pelagic fish swimming in large and numerous schools.

Most subsistence fishermen in Puerto Rico focus their efforts in inshore areas that are dependent on reef species. This causes a high pressure on coral reef species (Weiler and Suarez-Caabro 1980). Hence, FADs to attract pelagic fishes

are integrated into management strategies to enhance local fisheries. Open-ocean cages may enhance tropical fisheries by attracting both reef and pelagic fish. Pelagic fish species are not frequently captured by artisanal fishermen because of the increased difficulty, effort, and expense needed to locate and capture these fishes. The presence and aggregation of numerous pelagic fish near cage sites may improve fishing success for pelagic resources by artisanal fishermen who normally have access only to reef or mangrove species. Thus, the opportunity to increase their catch by including pelagic fish may represent economical alternative, thereby augmenting available resources.

Aquarium species attracted to submerged cages could play an important role by enhancing the stock of these species because the open-ocean cages act as artificial habitats where they can increase their survival rate. Tropical fish collectors employ artificial habitats in many countries to attract and catch reef fish (Johannes 1997). Collectors in many countries contribute to reef devastation by fishing with explosives and poisons. Progressive, responsible collectors using sustainable techniques become active stewards to protect reef areas, guarding against destructive techniques.

Although the cage site was located in open-ocean conditions, approximately 1.0 km from the nearest reef, 23 reef species, and 17 pelagic species aggregated at the site. Nevertheless, pelagic fish were the mst numerous fish, representing 92% of the individuals recorded (Table 10). Because fish occasionally make exploratory movements outside areas of normal activity (Kramer and Chapman 1999), they make temporary or permanent migrations over large areas, looking for better habitats. Thus, it is not surprising that 23 of the 40 species recorded were reef fish species. Strong zonal currents help species to navigate across discontinuities within their home range (Appeldoorn et al. 1997).

Many reef fish use a variety of habitats during ontogeny, often showing distinct spatial separation in settlement areas, nursery areas, juvenile, and adult feeding areas. The costs and benefits associated with different locations are related to physical and chemical conditions, food supply, density of predators and parasites, abundance of shelter and breeding sites, and abundance of competitors or cooperators (Kramer and Chapman 1999). After locating an appropriate habitat with improved qualities, there may be little incentive to leave it. Fish encountering a suitable habitat may be become reluctant to return to their original habitat, presumably because of high risk of predation (Kramer and Chapman 1999). Offshore migrations among tropical reef fish are believed to be common in many important groups in which several processes can create situations where alternative locations are better than the one currently occupied by a fish (Kramer and Chapman 1999). Appeldoorn et al. (1997) argue that habitat is important in controlling coral reef fish distribution, as well as the timing, rate, pathway, and distance of fish migrations.

Although the cage site was located in open-ocean conditions approximately 1 km from the nearest reef, 23 reef species, and 17 pelagic species were observed aggregating near the cages (Table 8). Juvenile organisms of twelve fish species were recorded near the cage systems. In almost all samplings juveniles of Aulostomus maculates, Cephalopholis cruentata, Lutjanus mahogany, Holacanthus ciliaris, Acanthurus coeruleus and Acanthurus chirurgus were consistently observed. The genera *Acanthurus* was present only in juvenile stages and its distribution was usually limited to the top of the cages. In addition, *Thalassoma bifasciatum* was limited to the top of the cage. No other species exhibited a depth preference. Some juveniles individuals can be forced out of the preferred habitat as the mean size of the individuals in a cohort increases. This may be a source of post-settlement juveniles immigrating to newly available habitat such as artificial reefs (Russell et al. 1974) or to the cage site. Of the 32 juvenile species recorded, 12 belonged to reef species, almost half of the entire reef species associated with the submerged cages. Studies of artificial habitats indicate juveniles use them for shelter. Therefore, juvenile individuals representing one-third of the recorded species at the cage site is similar to juvenile counts recorded near floating objects. Beets and Hixon (1994) indicated that artificial habitats not only concentrated juvenile groupers, but also promoted increased survival rates by serving as shelter. Submerged culture cages could act as additional habitat, providing suitable conditions for the existence and survival of juvenile fish.

Referring to possible cultured fish that could possibly have escaped, several Lutjanus analis and two Rachycentron canadum were observed near the cages. However, they were larger than the cultured fish, so they probably represent individuals from the native wild population. During the study, no fish escapes were seen during the sampling period. The primary source of escapes would probably occur from a rip or tear in the netting. However, no tears in the netting were observed during the sampling period. Another source of fish escapes could result from fingerling animals passing through the nursery netting, especially if they were emaciated before arrival. R. canadum are very thin as juveniles, rapidly increasing their length; they do not “fill out” until they are larger. When transferring juvenile fish to the nursery net, samples must be taken to determine the minimum “head-size” to assure no fish escapes from the juvenile net. R. canadum is typically an open-water fish; although it is native to Puerto Rico, few fishermen have caught significant numbers. Most Puerto Rico fishermen focus on catches near the coast.

The foremost concern among negative environmental impacts of Atlantic salmon farming on the West Coast of the United States and Canada is the fear of biological pollution in the form of escaping salmon (Schatzberg 2002). Fear is growing that escaped fish could harm wild runs of Pacific salmon by competing for space and resources, interbreeding, and spreading parasites and disease. While cages will have some “leakage” of some farmed salmon, large-scale releases from storms, human error, vandalism, and marine mammal damage

have allowed greater numbers of fish to escape. In Washington, USA, single-incident escapes were reported at 107,000, 369,000, and 115,000 fish in 1996, 1997, and 1999, respectively (Schatzberg 2002). Escaped Atlantic salmon could breed with native populations of Pacific salmon, thus altering the genetic makeup of wild stocks and weakening local adaptations. Scientists are considering culturing sterile Atlantic salmon on the west coast.

Results reported here suggest the aggregation effect of the cages is significantly strong for the wild fish community. Future research should study the possibilities of the cage site serving as sources for fish recruitment to area reefs, especially those damaged from anthropomorphic activities. Other tropical studies need to relate the positive or negative contribution of aquaculture cages to fish enhancement, their value to protected adjacent reserves, to coastal zones, and to depleted offshore reefs.

More research is needed to determine if the wild fish assemblage is benefiting directly or indirectly from additional nutrients from the increased feed and wastes from the aquaculture activity or if the cage structures naturally accumulate organisms and are simply serving as a substrate serving as a FAD. If fish benefit from the additional nutrients, this may represent a positive response by the environment (in terms of native fish) to incorporate allochthonous wastes (from outside the system) into wild fish flesh, thereby reducing the potential impact of the wastes released into the environment.

Table 6. Taxonomic list of fish identified at the cage site during 18 months of culture period. Classification is based on Eschmeyer (1989) and Nelson (1994).

CLASS ELASMOBRANCHII
- I. ORDER ORECTOLOBIFORMES
  - 1. Family Ginglymostomatidae
    - Ginglymostoma cirratum Muller & Henle, 1837
- II. ORDER RAJIFORMES
  - 2. Family Dasyatidae
    - Dasyatis americana Hildebrand & Schroeder 1928
  - 3. Family Myliobatidae
    - Aetobatus narinari (Euphrasen, 1790)

CLASS ACTINOPTERYGII
- III.. ORDER AULOPIFORMES
  - 4. Family Synodontidae
    - Synodus intermedius (Spix & Agassiz, 1829)
- IV. ORDER BERYCIFORMES
  - 5. Family Holocentridae
    - Holocentrus adscensionis (Osbeck, 1765)
- V. ORDER PERCIFORMES
  - 6. Family Aulostomidae
    - Aulostomus maculatus (Valenciennes, 1837)
  - 7. Family Sphyraenidae
    - Sphyraena barracuda (Walbaum, 1762)
  - 8. Family Serranidae
    - Cephalopholis cruentata (Lacep'ede, 1802)
    - Serranus tigrinus (Bloch, 1790)
    - Serranus tabacarius (Cuvier, 1829)
  - 9. Family Malacanthidae
    - Malacanthus plumieri (Bloch, 1786)
  - 10. Family Rachycentridae
    - Rachycentron canadum (Linnaeus, 1758)
  - 11. Family Echeneidae
    - Echeneis naucrates Linnaeus, 1758
    - Echeneis neucratoides Zouiev, 1786
  - 12. Family Carangidae
    - Caranx bartholomaei Cuvier, 1833
    - Caranx crysos (Mitchill, 1815)
    - Caranx hippos (Linnaeus, 1766)
    - Caranx latus Aggassiz, 1831
    - Caranx lugubris Poey, 1860
    - Caranx ruber (Bloch, 1793)
    - Decapterus sp.

Elagatis bipinnulata (Quoy & Gaimard, 1825)

13. Family Scombridae

Scomberomorus cavalla (Cuvier, 1829)

Scomberomorus regalis (Bloch, 1793)

14. Family Lutjanidae

Lutjanus analis (Cuvier, 1828)

Lutjanus jocu (Bloch & Schneider, 1801)

Ocyurus chrysurus (Bloch, 1791)

15. Family Haemulidae

Haemulon aurolineatum Cuvier, 1830

Haemulon melanurum (Linnaeus, 1758)

Haemulon sciurus (Shaw, 1803)

16. Family Chaetodontidae

Chaetodon striatus Linnaeus, 1758

17. Family Pomacanthidae

Holacanthus ciliaris (Linnaeus, 1758)

18. Family Pomacentridae

Stegastes partitus (Poey, 1868)

19. Family Labridae

Thalassoma bifasciatum (Bloch, 1791)

20. Family Acanthuridae

Acanthurus bahianus Castelnau, 1855

Acanthurus chirurgus (Bloch, 1787)

Acanthurus coeruleus Bloch & Schneider, 1801

21. Family Sparidae

Calamus penna (Valenciennes, 1830)

VI. ORDER TETRAODONTIFORMES

22. Family Monacanthidae

Aluterus scriptus (Osbeck, 1765)

23. Family Tetrodontidae

Sphoeroides spengleri (Bloch, 1785)

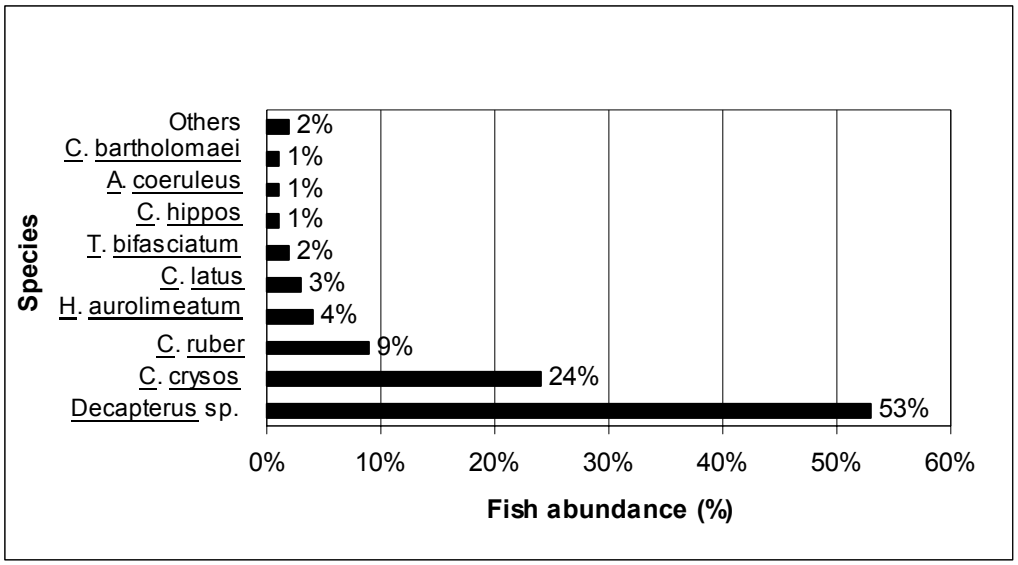


Figure 41. Most abundant fish species found at the cage site.

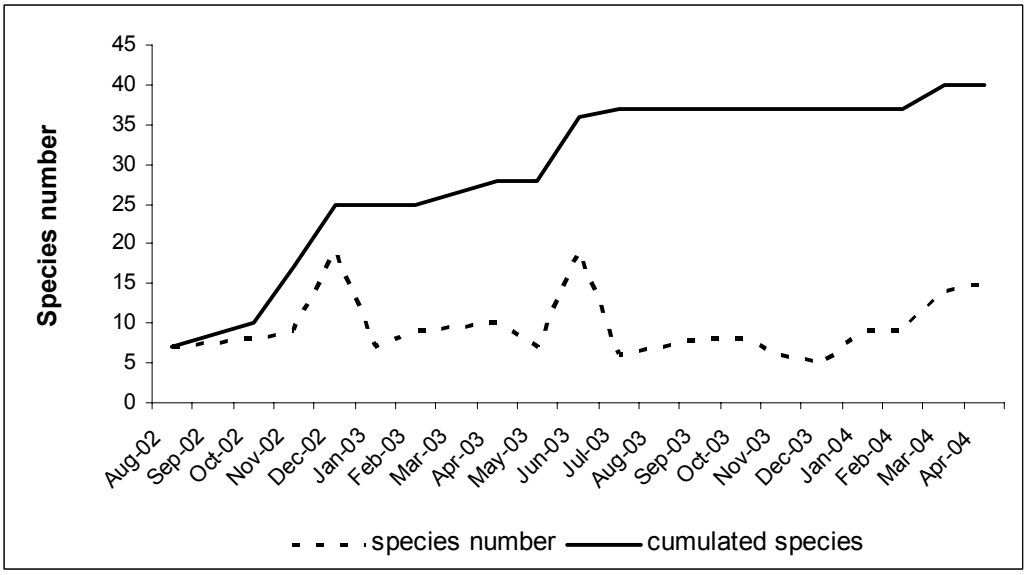


Figure 42. Species richness index and cumulated species of wild fish at the cage site.

Table 7. Species with commercial importance found at the cage site.

Human consumption		Aquarium trade	
Species	Relative abundance (%)	Species	Relative abundance (%)
C. crysos	58.79	T. bifasciatum	48.4
C. ruber	23.40	A. coeruleus	43.3
H. aurolineatum	11.02	H. ciliaris	3.8
C. hippos	3.51	A. bahianus	1.0
C. bartholomaei	1.63	A. chirurgus	0.8
O. chrysurus	0.40	A. maculatus	0.8
C. cruentata	0.30	S. tabacarius	0.5
S. barracuda	0.30	S. spengleri	0.3
D. americana	0.16	S. intermedius	0.3
H. melanurum	0.10	S. partitus	0.3
L. jocu	0.08	S. tigrinus	0.3
S. regalis	0.06	C. striatus	0.3
H. adscensionis	0.06	A. scriptus	0.3
L. analis	0.05		
E. bipinnulata	0.05		
H. sciurus	0.03		
R. canadum	0.03		
S. cavalla	0.02		
TOTAL	100.00	**TOTAL**	100.0

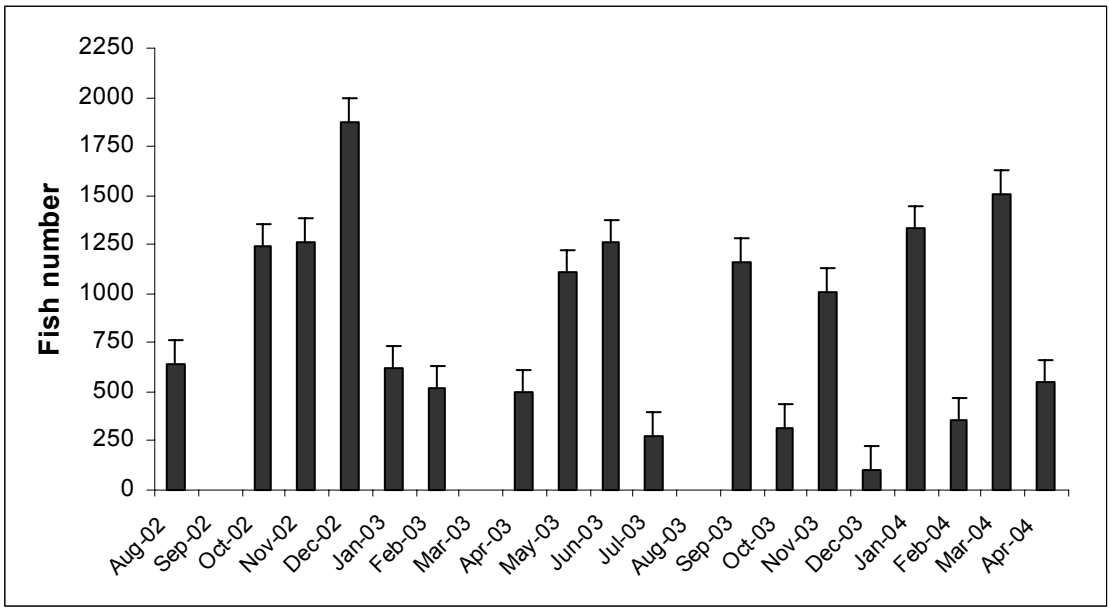


Figure 43. Temporal variation of fish abundance at the cage site.

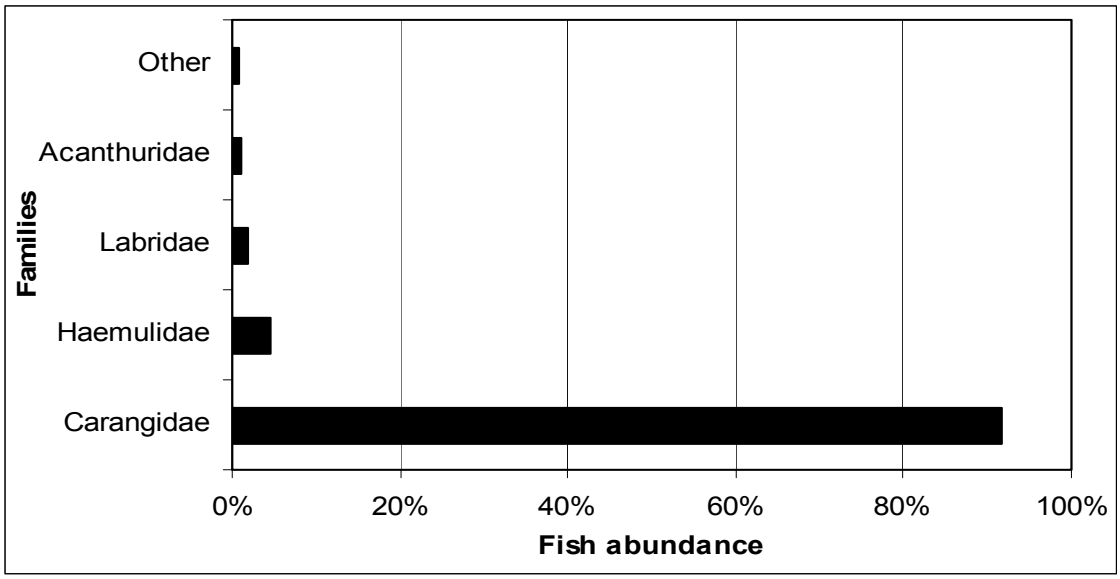


Figure 44. Fish families' abundance at the cage site.

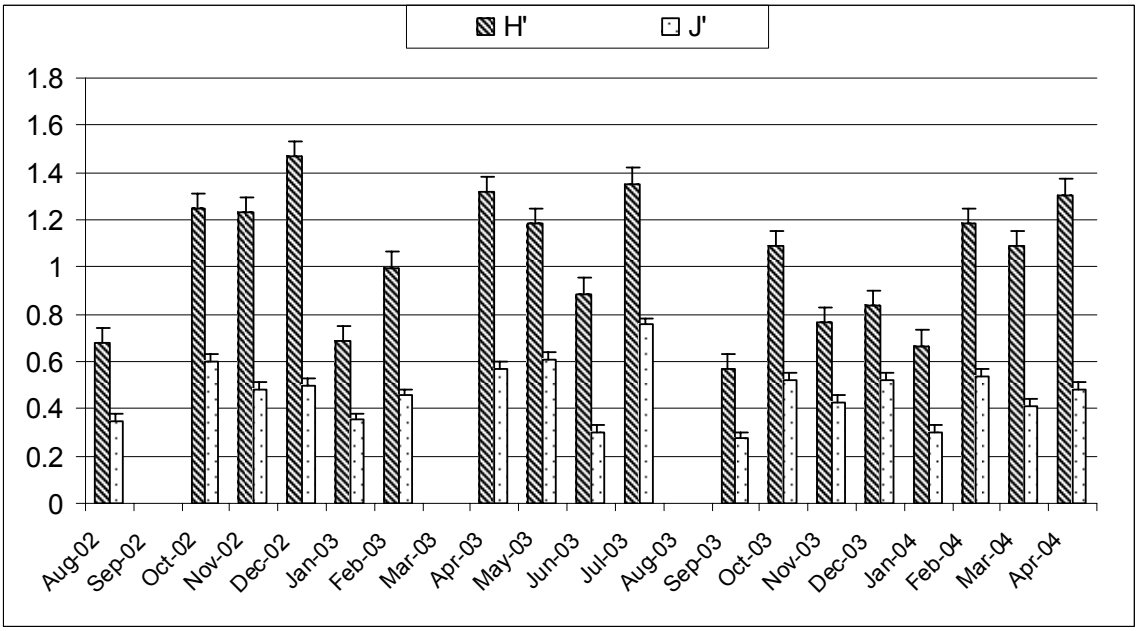


Figure 45. Shannon-Weaver Diversity Index (H') and Species Evenness index.

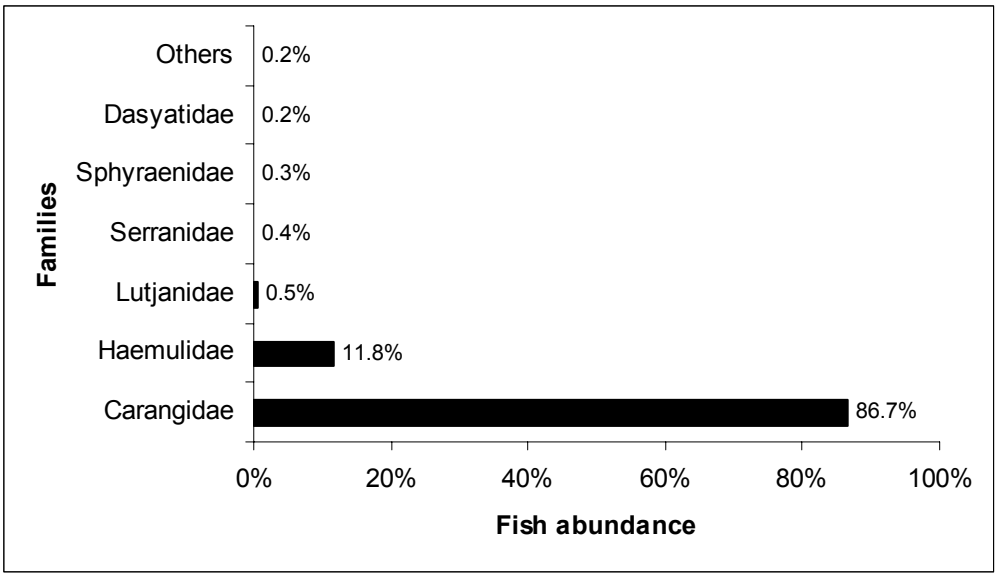


Figure 46. Families of wild fish that are utilized for human consumption.

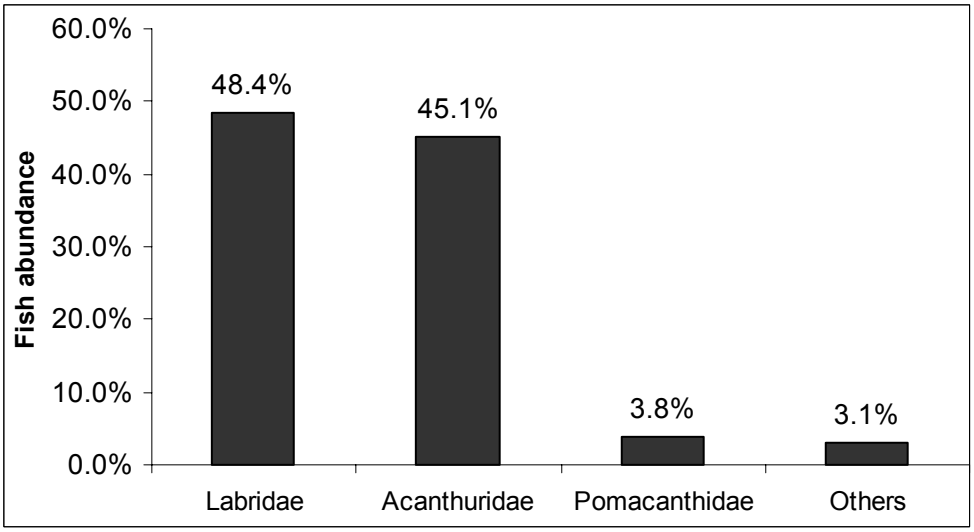


Figure 47. Families of wild fish utilized in the aquarium trade.

Table 8. Commercially valuable fish (for human consumption) found at the cage site. (P: pelagic fish; R: reef fish).

Specie	Total abundance (Nº Ind)	Relative frequency (%)	Habitat
C. crysos	3685	58.79	P
C. ruber	1467	23.40	P
H. aurolineatum	691	11.02	A
C. hippos	220	3.51	P
C. bartholomaei	102	1.63	P
O. chrysurus	25	0.40	A
C. cruentata	19	0.30	A
S. barracuda	19	0.30	P
D. americana	10	0.16	P
H. melanurum	6	0.10	A
L. jocu	5	0.08	**A**
S. regalis	4	0.06	**P**
H. adscensionis	4	0.06	**A**
L. analis	3	0.05	**A**
E. bipinnulata	3	0.05	**P**
H. sciurus	2	0.03	**A**
R. canadum	2	0.03	**P**
S. cavalla	1	0.02	**P**
TOTAL	**6268**	**100.0**	

Table 9. Aquarium fish species attracted to the cage site.

Specie	Total abundance (Nº Ind)	Relative frequency (%)
T. bifasciatum	302	48.4
A. coeruleus	172	43.3
H. ciliaris	16	3.8
A. bahianus	4	1.0
A. chirurgus	3	0.8
A. maculatus	3	0.8
S. tabacarius	2	0.5
S. spengleri	1	0.3
S. intermedius	1	0.3
S. partitus	1	0.3
S. tigrinus	1	0.3
Ch. Striatus	1	0.3
A. scriptus	1	0.3
TOTAL	**508**	**100**

Table 10. Fish abundance around the cages according the predominant habitats.

Reef species			Pelagic species		
	Total abundance (No ind.)	Abundance (%)		Total abundance (No ind.)	Abundance (%)
H. aurolineatum	691	4.6	*Decapterus sp*	8175	54.2
T. bifasciatum	292	1.9	*C. crysos*	3385	22.4
A. coeruleus	172	1.1	*C. ruber*	1447	9.6
O. chrysurus	25	0.2	*C. latus*	453	3
C. cruentata	16	0.1	*C. hippos*	220	1.5
H. ciliaris	15	0.1	*C. bartholomaei*	102	0.7
H. melanurum	6	0.0	*C. lugubris*	20	0.1
A. bahianus	4	0.0	*S. barracuda*	17	0.1
L. jocu	4	0.0	*D. americana*	9	0.1
A. chirurgus	3	0.0	*S. regalis*	4	0
L. analis	3	0.0	*G. cirratum*	2	0
A. maculatus	3	0.0	*E. neucratoides*	2	0
H. adscensionis	3	0.0	*E. bipinnulata*	1	0
H. sciurus	2	0.0	*A. narinari*	1	0
S. tabacarius	2	0.0	*S. cavalla*	1	0
C. penna	2	0.0	*E. naucrates*	1	0
S. tigrinus	1	0.0	*R. canadum*	1	0
Ch. striatus	1	0.0			
M. plumieri	1	0.0			
S. partitus	1	0.0			
S. intermedius	1	0.0			
A. scriptus	1	0.0			
S. spengleri	1	0.0			
Total	1250	8.3		13841	91.7

Water column: biofouling

Biofouling has been identified as one of the main problems in marine aquaculture activities because it may increase the cage's drag, the cages weight, the structures corrosion, reduce the water flow passing through the cages systems, reduce the light availability for the cultivated organisms and should be considered a risk factor for diseases. Fish farm and many other researchers have reported that biofouling growth on cage netting may cause unexpected problems and found that after cleaning the cage's netting by underwater scrubbing of netting surfaces, the fouling communities may grow faster, becoming a highly labor intensive procedure. The biofouling organisms are attached in a specific order, with algae settling on the sludge followed by barnacles or corals. Sludge refers to microbiota colonizing hard surfaces that creates a coating of materials that succeeding organisms colonize. Crustaceans, such as crabs, often preyed upon these organisms. The cage culture industry has developed several mechanical techniques to remove biofouling from submerged cages, there are still many problems concerning the biofouling growth on aquaculture cages.

In our study, the determination of biofouling coverage of each organism on the nets was quite complicated to analyze because many organisms were overlapped on the sessile organisms. Abarzua & Jakubowski (1995) affirmed that a clear separation of biofouling organisms could be impossible. The percent coverage of biofouling for each cage at Culebra was statistically similar (Fig. 48), with a mean coverage above 50%. The fact that both cages showed similar biofouling coverage in spite of the difference in feed input and fish cultures may suggest that biofouling formation is defined by external factor instead of the cages effect. Although the biofouling attached to the cages could play an important role removing part of the nutrients released to the environment from the culture system, external factors such as water currents and water temperature could affect similarly both cages. Dubost et al. (1996) found that most of biofouling formation is dictates for physics and chemistry characteristics of the water such as water temperature, nutrients contents, and current velocity.

No differences were found for percentage coverage of downstream versus upstream samples; no differences were found for top-placed samples (above the cages rim) versus underneath placed samples (below the cages rim) (Fig. 49). However, the type of organisms attached above and below of each cage varied. Although the netting place above and below the rims were only separated for 2 m approximately, the cage's shape produced a shadow for the nettings below the rim. Consequently, the netting placed above the rim received a significant higher amount of sunlight, which could explain the higher algal growth in this position. Several researchers have reported that zoospores of common fouling algae react to light intensity and have shown preference for lighter conditions (Hodson et al. 2000). Although depth is a factor that affect the biofouling formation (Venugopalan and Wagh 1990; Dubost et al. 1996) it could not have any influence in the biofouling formation since the above and below position were

only separated by 2 m. Accumulation of biofouling (coverage) was highest during summer (June), with the least biofouling occurring in February 2003 (Fig. 50). However, the company probably affected the biofouling coverage during February due to accidental cleaning during routine cleaning procedures. The cleaning process suspends a great deal of material into the water column, thus affecting the normal vision of the divers. Thus, the biofouling nets were probably cleaned accidentally. Subsequently, growth of biofouling could occur due to the survival of macroalgae remnants in crevices, which enable rapid recolonization and regrowth of fouling. Two months later, (April), the biofouling coverage in the cages increased up 61% in average. Because biofouling was problematic, Snapperfarm changed their cleaning schedule from monthly to biweekly.

The cages net attained 49% of biofouling coverage after two months of cages deployment and were significantly lower (49%) than months 4, 8, and 10 (61%, 61% and 71% respectively). This suggests the biofouling continued accumulating after the two first months, although it was in a slower rate.

The biofouling groups changed during the study. At first, two main groups dominated the biofouling coverage (macroalgae and hydroids); however, by the end of the study (one year after cage installation), the nets were mainly colonized by small mollusk, rug (alga-hydroids) and ascidians (Ascidea) (Fig. 51). Mollusk and crustaceans were also present on the cages as associated fauna and in lower abundance. These organisms are motile and could escape when approaching during sampling. The organisms found such as hydroids, sponges, ascidians, bryozoans, mollusk and crustaceans are typical organisms attached to aquaculture nets (Relini et al 1994, Abarzua & Jakubowski 1995 and Dubost et al. 1996). Zongguo et al. (1999) said that true fouler are referred to as those sedentary organism that remain attached for most of their life to a submerged substratum. The other organisms are associated fauna, which search for either food or shelter among the growth of the major foulers. Zongguo et al. (1999) also reported that the associated fauna are unlikely to cause problems (Decapods) of either net blockage or an increase in weight because of their mobility and generally small size. It is well known that most of the true biofouler are filter-feeding invertebrates, which takes the particulate organic matter and in some cases may takes metals or some toxic substances from the water. Thus, the biofouling could play an important role removing a significant amount of the wastes released from the culture systems.

Algae and rug were the dominant group for samples above the rim on each cage (64% and 31% respectively). The netting above the rim had higher algal growth (64%) than below the rim (12%) due to the light influence of the former, which could stimulate the algal growth. It is named “rug” the complex layer between algae and hydroids, in which the determination of biofouling coverage individually was impossible.

Generally, the biofouling nets underneath the rim of each cage had more organism diversity, with dominant groups of “rug” (46%), hydroids (20%), ascidians (13), and algae (12%) (Fig. 52). Other organisms such as sponges (5%) and bryozoans (4%) were also present. The morphotype up current and down current (South and North, respectively) were similar (Fig. 53).

Because a major advantage of open-ocean aquaculture is the interchange of high quality water, any obstruction to water flow could result in less production. This is especially true near the time of harvest since feeding rates and carrying capacity are at a maximum. Each submerged cage has been designed within certain design specifications, so additional weight can affect cage flotation. . In tropical regions, marine cages with potentially heavier concentration of biofouling may have higher risk of damage from currents, especially during hurricane season. Aquaculturists are especially interested in clean biofouling from cage nets during hurricane season to decrease drag. Puerto Rico is located in a hurricane zone, so additional drag is of particular concern during the hurricane season.

Because less light reaches the bottom of each cage, we expected more biofouling coverage on the upper surface. However, we observed no differences between the upper and lower the cage surface.

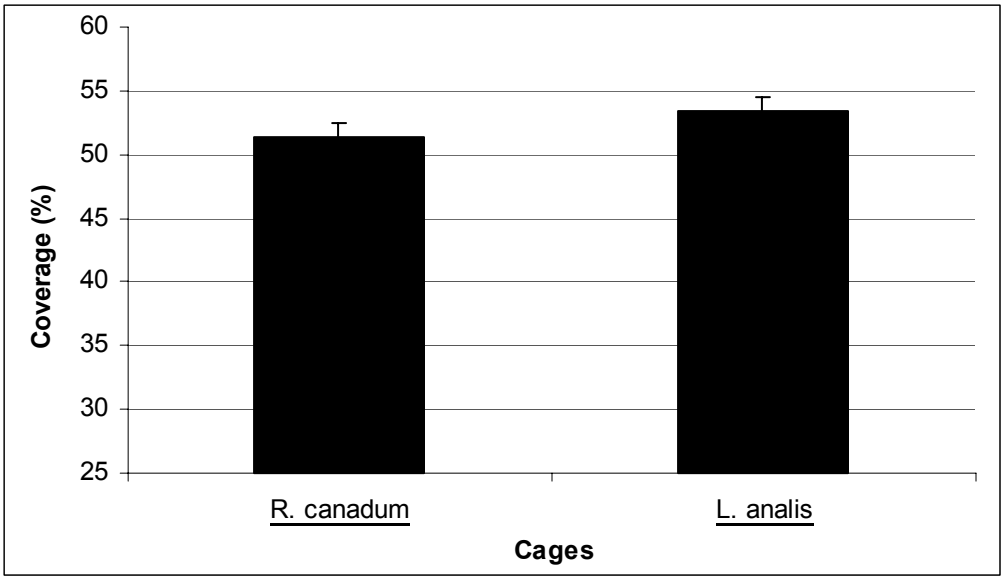


Figure 48. Biofouling coverage for each cage.

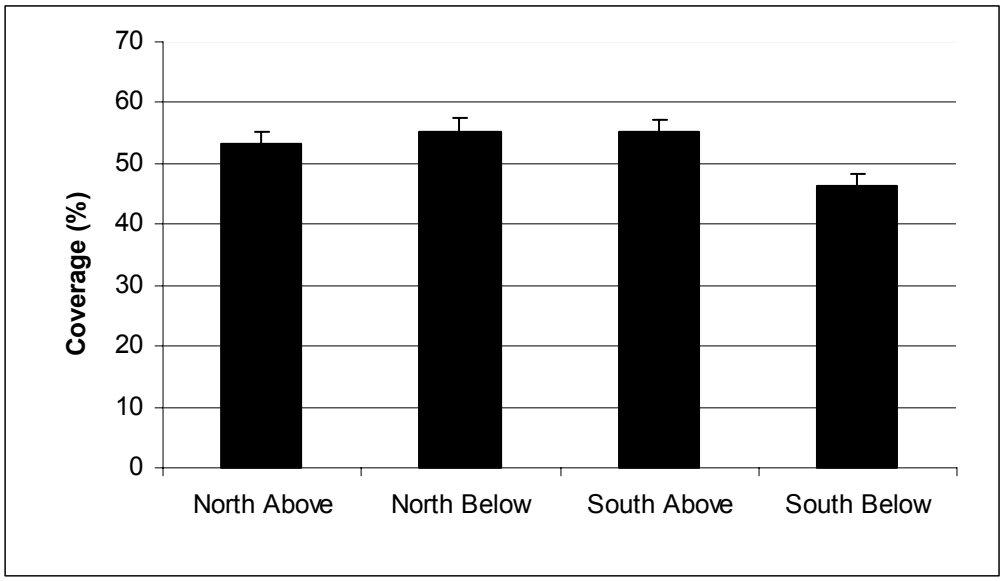


Figure 49. Biofouling coverage for each sampling station.

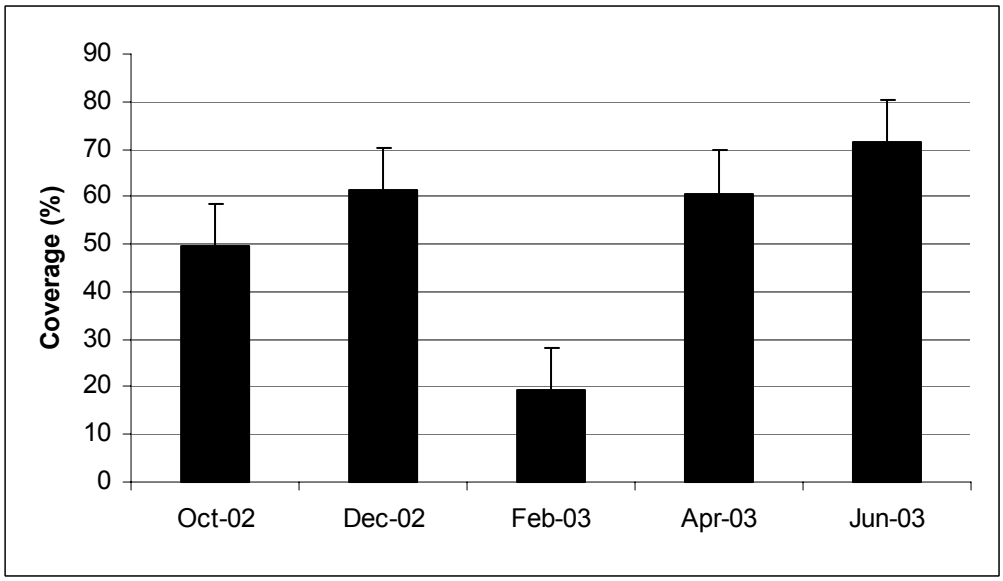


Figure 50. Biofouling accumulation in the cages from October 2002 - Jun 2003.

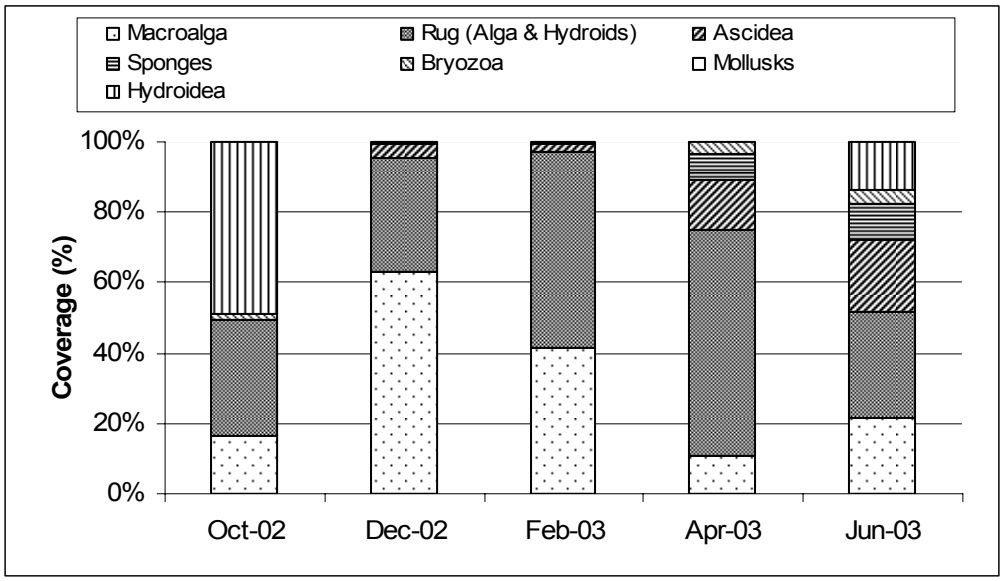


Figure 51. Predominant biofouling morphotype during one-year of cage culture from October 2002 - Jun 2003.

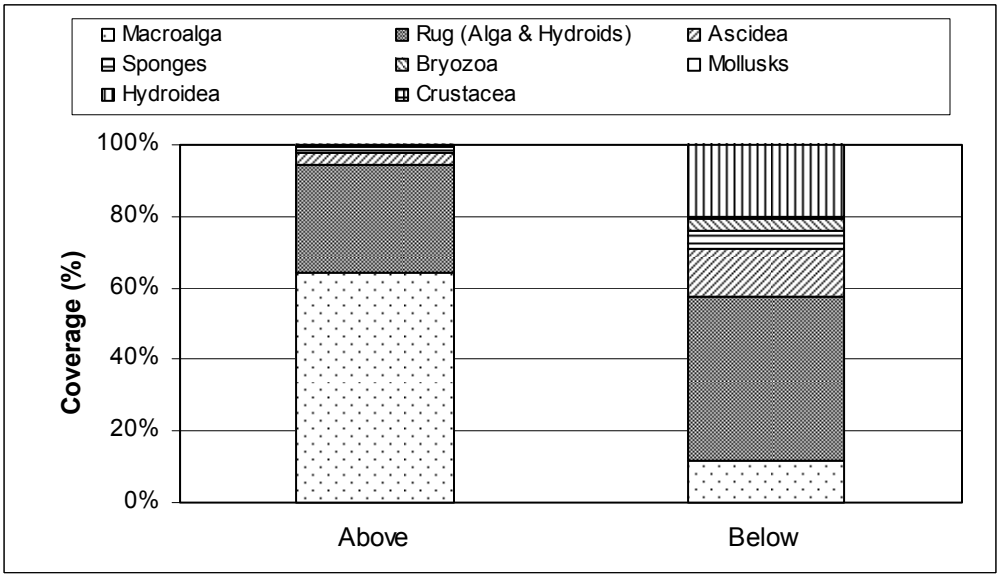


Figure 52. Predominant biofouling morphotype above (un-shaded) and below (shaded) during one-year of cage culture from October 2002 - Jun 2003.

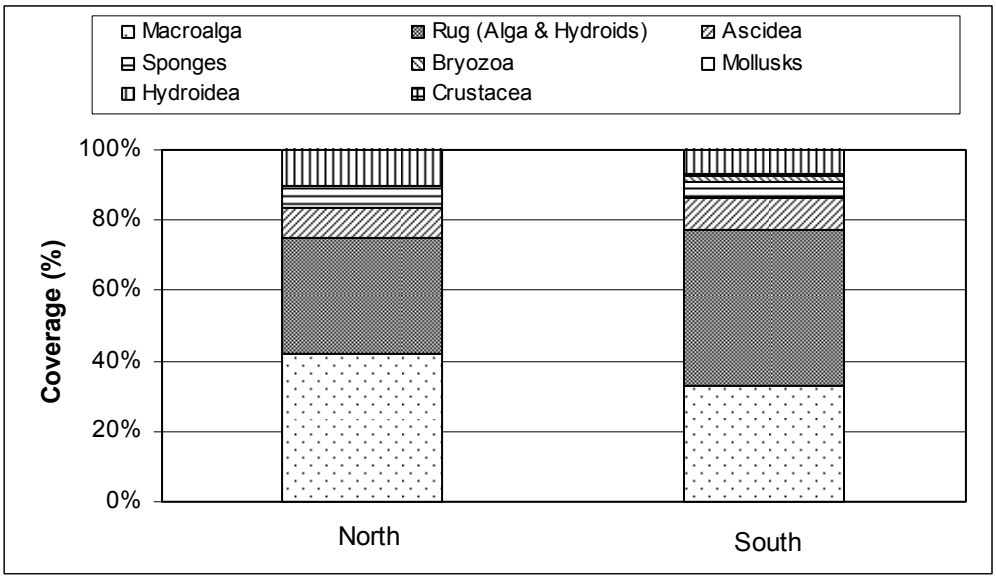


Figure 53. Predominant biofouling morphotype north and south during one-year of cage culture from October 2002 - Jun 2003.

Water column: tidal and influence from weather

The mean monthly tidal current at Culebra passage was usually less than 0.4 m/sec, with a mean of maximum ebb and flood tide of -0.41 and 0.37 m/sec, respectively (Fig. 54). Please refer (below) to more details relating to the current patterns in the “Flow Regime” section.

Air temperature, heat index, and dew points followed similar patterns (Fig. 55). Air temperature fluctuations were similar fluctuations of water temperature, with a mean of 27.6 C from June 2002 to April 2004. The coldest and warmest months were January (mean of 25.2 C) and August (mean of 29.7 C), respectively. Mean heat index and dew point were 30.7 and 23.2 C, respectively.

The mean wind velocity from June 2002 until April 2004 were 16.1 km/h. Wind oscillated from month to month with October and November with the least wind speeds, while June, February, and March had the strongest winds (Fig. 56). The constant water movement caused contributed to year-round high concentrations of dissolved oxygen in the water column, which is essential for any viable aquaculture operation. However, year-round wind speeds were not so robust as to thwart essential routine work such as feeding, net maintenance, or harvesting procedures.

Relative humidity of the air was generally above 70%, with a mean of 76% (Fig. 57). The mean pressure from June to October was 29.9 in Hg. September 2002 had the highest pressure while October 2003 had the lowest (Fig. 58).

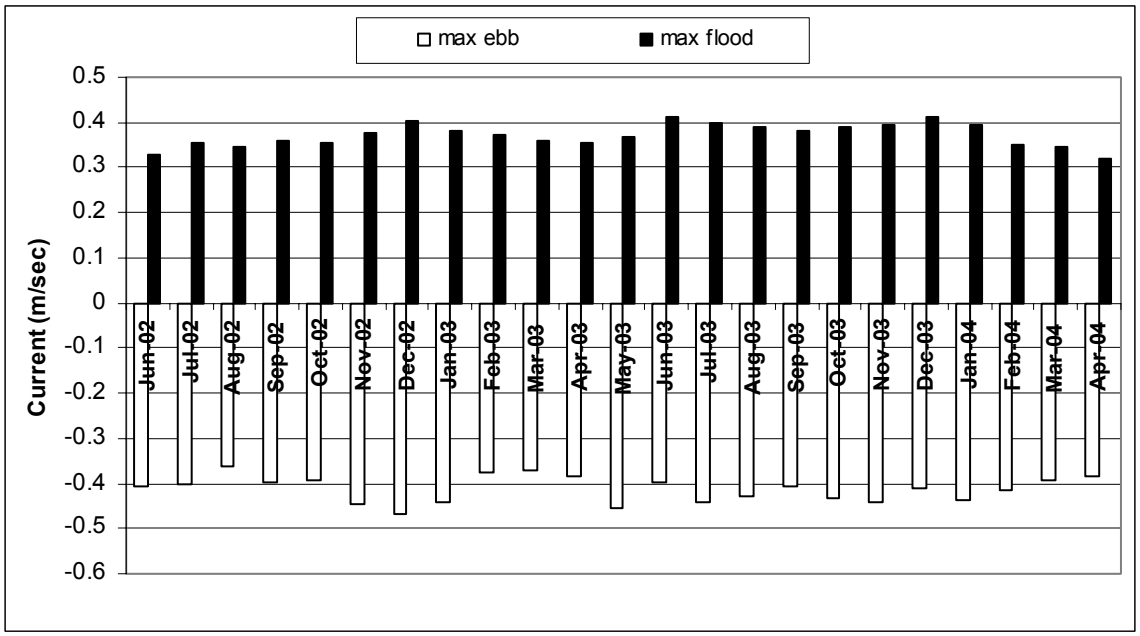


Figure 54. Average monthly tidal currents fluctuation for the Culebra/Vieques Passage.

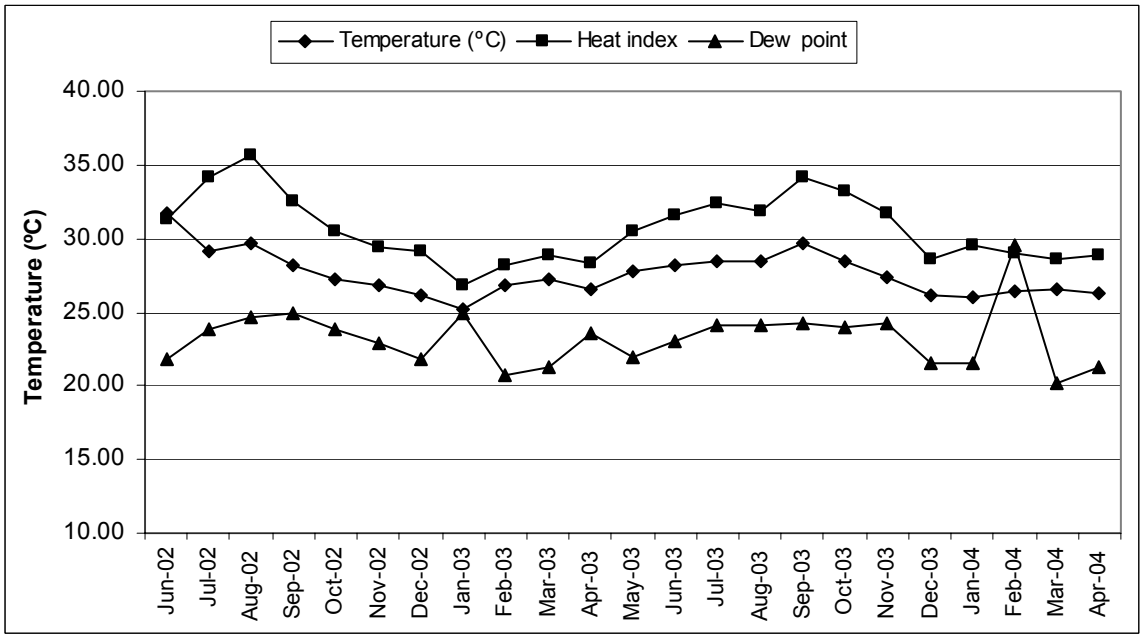


Figure 55. Average monthly air temperature, heat index, and dew point for the Culebra/Vieques Passage.

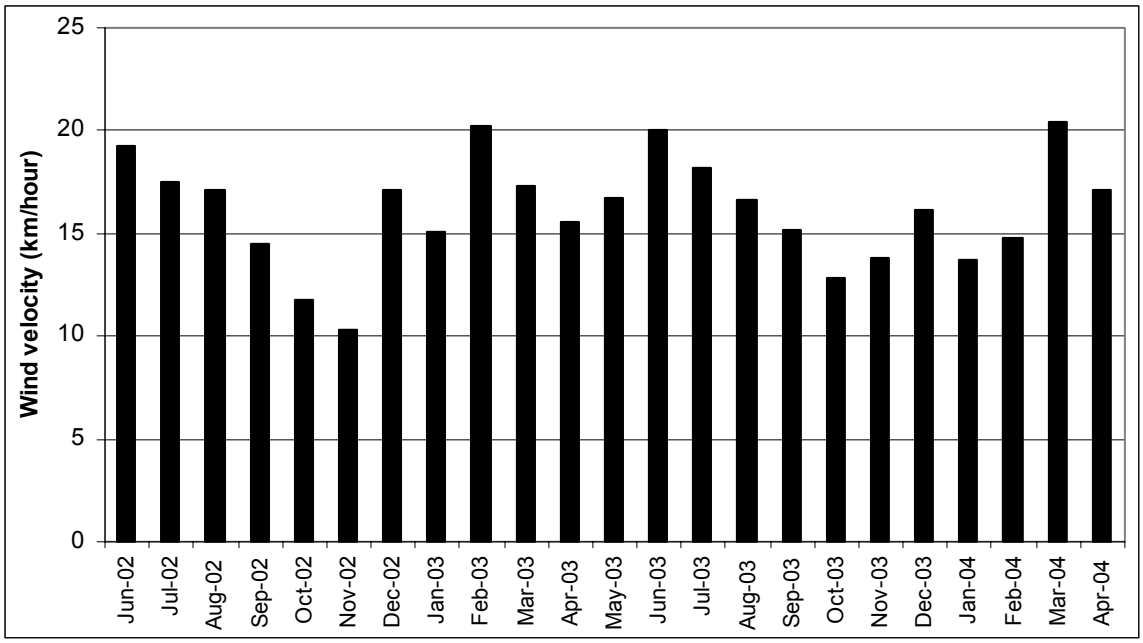


Figure 56. Mean monthly wind velocity for the Culebra/Vieques Passage.

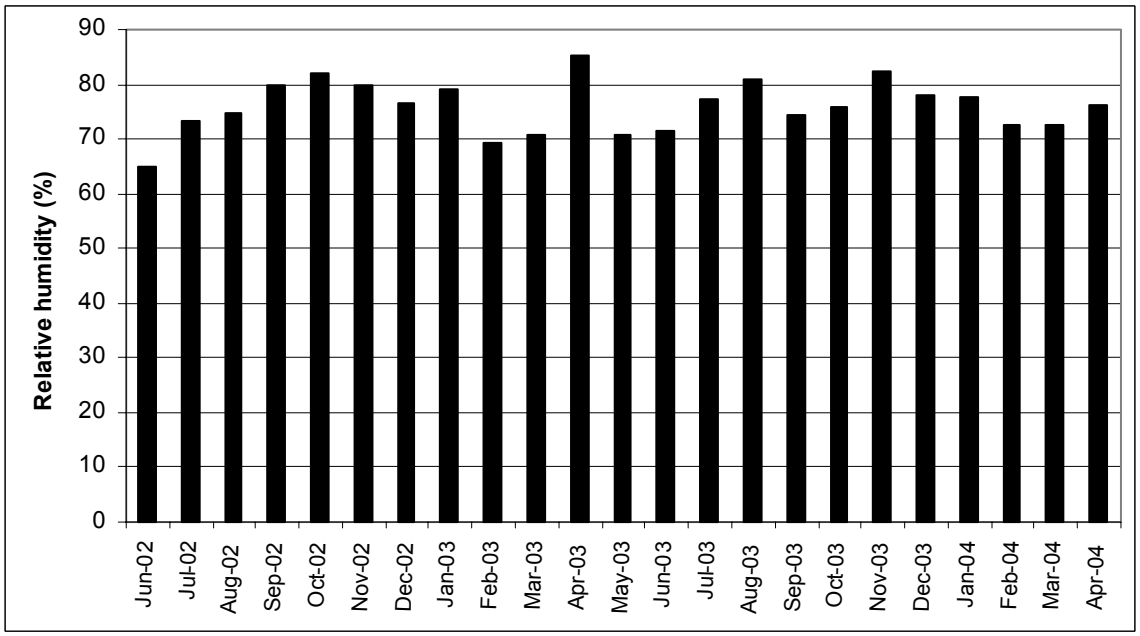


Figure 57. Average monthly relative humidity for the Culebra/Vieques Passage.

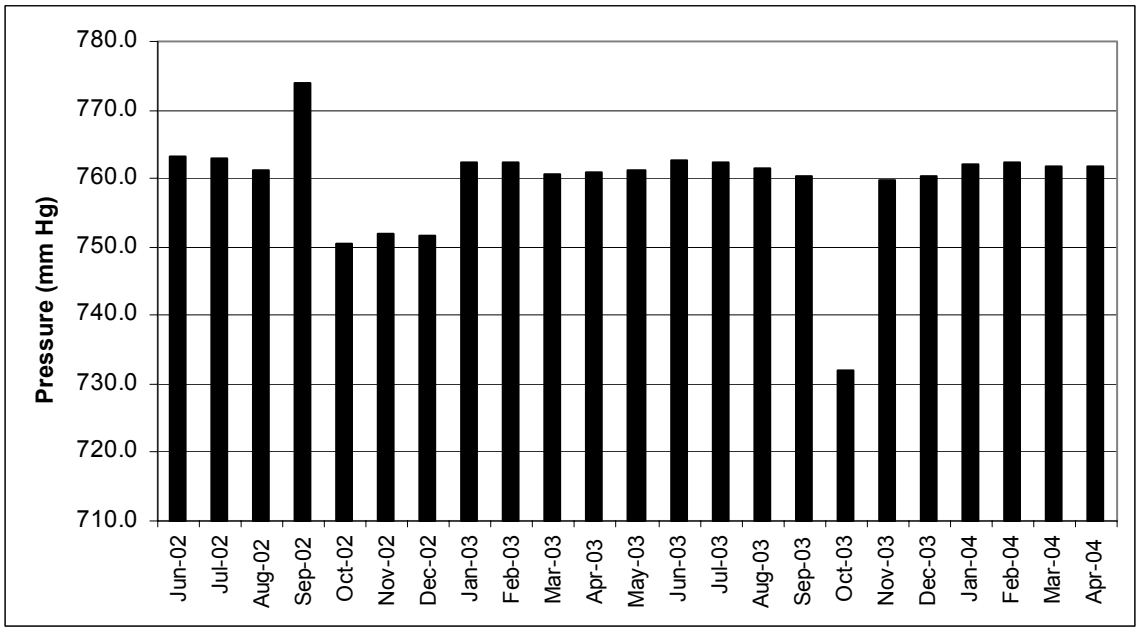


Figure 58. Average monthly pressure for the Culebra/Vieques Passage.

Water column: flow regime

The reader may want to read an introductory publication entitled "Oceanographic and meteorological considerations for open ocean aquaculture in the Puerto Rico-USVI platform" (Appendix 1).The flow regime observed during the C05 monitoring period did not differ much from that observed during the three previous deployments; the mean, or resultant, flow direction remained steady towards the northwest while the degree of flow variability, as represented by the R/S ratios (Resultant/Scalar) in Table 11, showed a similar stability. However, the resultant, mean and percentile current speeds indicated significant variability at seasonal time scales; the mean speed during C04 being ~32% higher than during C02 while the resultant vector was 23% stronger.

Summary statistics for each deployment (~season), and for the total data set, are presented in Table 11 and Figs. 59 and 60. Average quantities shown in bold in the *Avg 2-5* row have been normalized by record length, the corresponding *R/S* average was calculated from the average *Scalar* and Res quantities while the *Max* value of *59.9 cm/sec (1.2 knots)* is the maximum recorded speed. These long term averages are also plotted in Figs. 59 and 60 and must not be confused as forming part of the C02-C05 time series. The trend is for a slight weakening and northward turning of the flow (clockwise when viewed from above) during Winter and Spring. The mean magnitude of the flow is represented by the scalar mean speed, average of 17.0 cm/sec, and by the 50th percentile speed, 15.6 cm/sec (Table 11).

Table 11. Mean statistics and percentiles. Depth in meters and speeds in cm/sec.

	Scalar	Res	Dir	R/S	*u-rot*	*v-rot*	10	50	90	Max
C01	14.5	3.0	141	0.2	0.1	-3.0	2.8	12.7	31.0	45.1
C02	15.2	8.4	300	0.6	0.0	8.4	3.2	13.0	30.4	47.0
C03	17.6	11.1	295	0.6	-1.0	11.1	4.6	15.5	33.6	56.1
C04	20.1	10.3	294	0.5	-1.0	10.2	6.5	19.4	36.7	59.6
C05	16.9	6.5	306	0.4	0.7	6.5	4.2	15.9	31.0	59.9
Avg 2-5	**17.0**	**8.4**	**301**	0.5	**0.0**	**8.4**	**4.3**	**15.6**	**32.1**	59.9

The full progressive vector pseudo-trajectories for C02-C05 are plotted in Fig. 61a. The persistence of northwestward flow along bottom contours at the cage site is clearly observed by comparing Figs. 9 and 61a. A blow up of these progressive vector plots has been included as Figure 61b to highlight the effect of tidal oscillations on the mean flow; note that these small-scale features are mostly obscured in Fig. 61a. The C01 vectors have been also included in Fig. 61b. Periods of sustained mean (sub tidal) flow towards the southeast are of short duration and are characterized by weaker speeds.

The directional distribution of transport per unit area during C05 is presented in Fig. 62. Similar plots for C01-C04 are found in the corresponding reports. The principal flow axis and mean northwestward flow are indicated in these figures.

Fig. 63 shows the full C02-C05 temperature time series at the S4 position. The minimum-recorded temperature was 25.8°C during early morning hours on March 6, 2004. The maximum temperature of 29.70°C was recorded during the late afternoon on September 26 and October 6 of 2003.

The full velocity data time series for events C01-C04 are presented in the corresponding reports in the form of current direction and speed time series and as *u* (cross-isobath or southwest-northeast) and *v* (along-isobath or northwest-southeast) component time series in the corresponding reports (Appendix 2). The *u* and *v* components were rotated by 60°, so they are aligned (*v-rot*) and perpendicular (*u-rot*) to bottom contours (C01 is the exception as geographic coordinates were used in that first report). Due to the large number of velocity data points these figures are confusing; however, several important features are most easily seen in this way. The closely spaced oscillations (wiggles) correspond to the dominant semidiurnal oscillations of the velocity vectors.

For C05, it was chosen to plot in Fig. 64 the tidal envelope of the *rotated-v* component. This envelope time series is constructed by connecting the points of high tide (upper curve) and low tide (lower curve) throughout the full time series. This results in a much cleaner plot and allows us to clearly observe the effect of winter cold fronts (mid-latitude low-pressure systems arriving from the north) on the velocity field. Plates 1-3 show satellite infrared images and wind field vectors

over our region during the approach of three cold fronts in the winter of 2003-2004; these satellite images are dated December 2, December 28, and March 1. These dates are associated with flow variability at weekly time scales in Fig. 64, specifically those three occasions when the low tide curve significantly breaks above the zero line. The initial response to the approaching cold front is for intensification of the southeastward flow, followed by a rebound towards the northwest. The maximum observed flow speed during the entire monitoring period occurred during the rebound phase of the early December 2003 event.

Please refer to the previous reports for discussions on the relationship between tidal currents at the S4 site and NOAA software-predicted tide at Ensenada Honda, the NOAA tide station closest to the Snapperfarm cage site (Appendix 2). The C05 record does not add new information in this regard.

Flow speed and direction plots for those periods during which UPRM water quality monitoring events were conducted are included as Figs. 65a-e. The corresponding speed and direction time series are included with this report. Data include two days prior to the actual field sampling.

Multi-Taper-Method (MTM) flow speed spectra for C02-C05 are presented in Figures 66-69. The full spectrum for each speed time series is presented in part (a) of each figure while part (b) is a blow-up of the low frequency part of the spectrum (≤0.5 cycles per hour). Of the various available spectral estimators, the SSA Toolkit MTM was chosen because it "is designed for harmonic analyses or estimation of sharp spectral peaks" and provides useful significance tests, very useful properties when dealing with time series full of tidal and inertial harmonics. The semidiurnal peak (frequency of ~0.08 cy/h) is dominant in all spectra, usually followed by other tidal harmonics such as the diurnal (~0.04 cy/h) and 6-hour (~0.16 cy/h) peaks. However, these spectra are rich with other significant peaks (above the 99% confidence interval) in the low and high frequency range. The low frequency (sub inertial) spectra is especially interesting because it shows significant peaks towards the low end that are probably associated with the approach of tropical storms or hurricanes from the east during the summer and fall and to cold fronts during winter and spring. The high frequency range should be relevant for structural cage dynamics.

The future application of spectral time-domain techniques should prove useful in the analysis of the frequency response evolution of the velocity field to the passage of intense weather features.

Water flow summary

The flow regime observed during the monitoring period is characterized by:

- Predominantly along-isobath flow along the axis 300° ↔ 120° true; Northwestward flow (towards 300°-320° true) occurs during the flooding

tide (as the sea surface elevation is increasing) whereas the ebbing tide coincides with southeastward flow (120°-140° true).

- strong semidiurnal (two cycles per day), and weaker diurnal (one cycle per day), tidal components with maximum amplitudes of 20-30 cm/sec;
- diurnal inequality of the tidal currents that is much weaker than the surface tide;
- mean, or low-frequency, northwestward flow with a year-long mean towards 301° true at 8.4 cm/sec;
- northwestward flow (towards 300°-320° true) during the flooding tide (as the sea surface elevation is increasing) whereas the ebbing tide coincides with southeastward flow (120°-140° true);
- peak flow that lags the tidal peak by about three hours (approximately a quarter of a semidiurnal cycle);
- tidal ellipses elongated along bottom contours to the point of nearly a straight line so that changes in direction occur very quickly; there is very little transport towards land and the velocity vectors are observed to swing back and forth across the offshore hemisphere;
- quasi-periodic 4-day to weekly components in the low-frequency signal;
- the strongest, largest amplitude, low-frequency flow variability appear related to the approach of tropical storms or hurricanes from the east during the summer and fall and to cold fronts during winter and spring

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The monitoring period from April to June 2003 marked the transition from spring to summer weather patterns in the Western Tropical Atlantic. During mid April the area was under the influence of a swell-generating low-pressure system off the Atlantic coast of the United States. These are typical winter and spring conditions in our region, with the low-pressure systems moving eastward across the Atlantic while creating a fairly predictable sequence of meteorological conditions in Puerto Rico and the US Virgin Islands. Two more similar weather systems influenced local conditions in late April and mid-May, bringing closure to the spring season. Starting in June, local weather conditions switched to a mode where low-latitude low-pressure waves start arriving periodically from the east creating a pattern of oscillation in the strength of the Easterly Trade Winds. The weather patterns affecting the local region are quasi-periodic in time with approximate periods of one to two weeks.

The tropical cyclone season during 2003 in the North Atlantic was above average in the number of storms and their intensity. Luckily, none of these cyclones made

a direct hit over the cage site; however, several tropical storms and hurricanes passed in the vicinity. The S4 monitoring period from June-October 2003 covered the bulk of the tropical cyclone season.

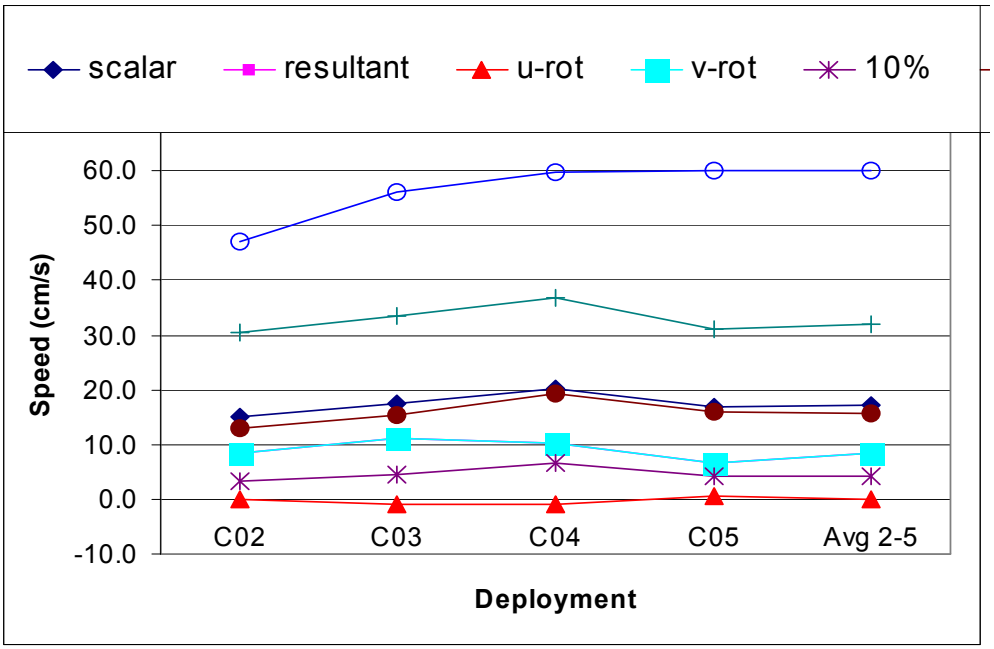

Figure 59. Culebra record-mean speed time series and year-long averages.

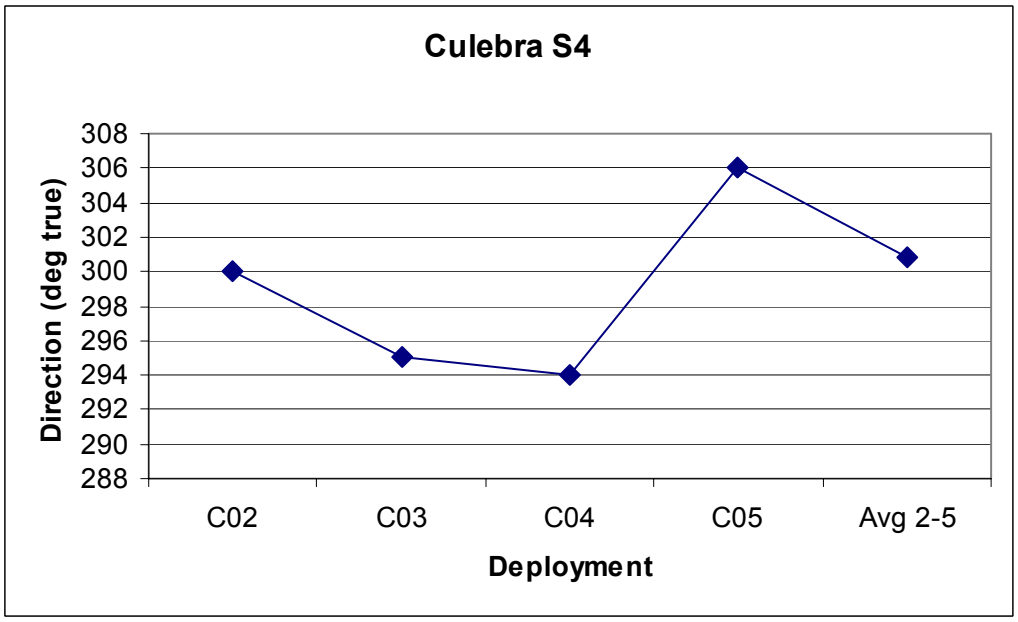

Figure 60. Culebra record-mean direction time series and year-long average.

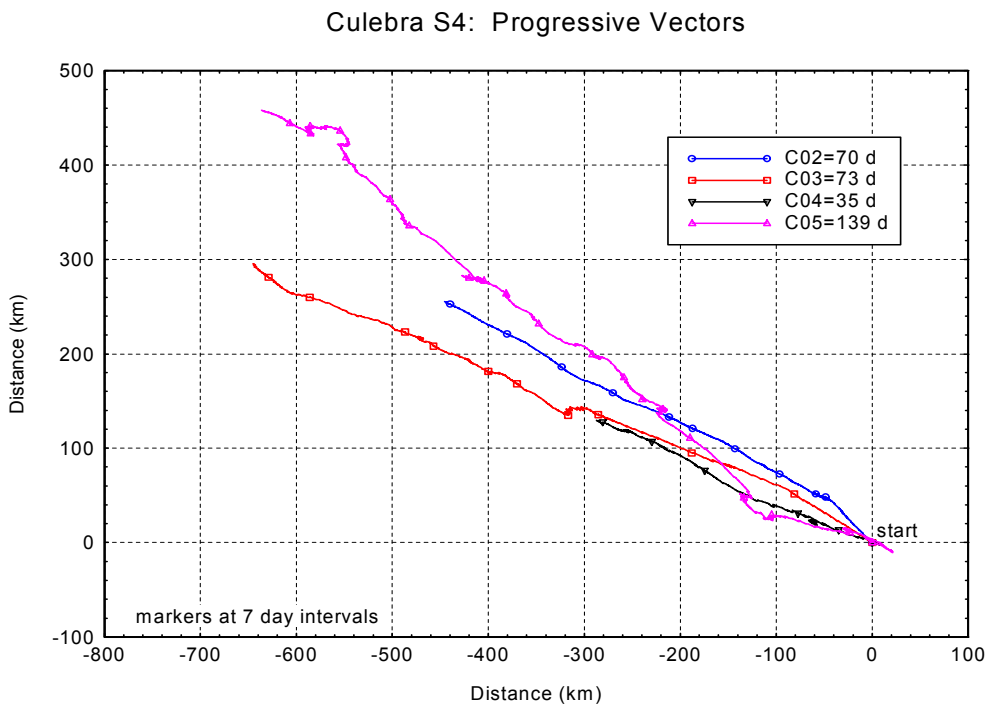

Figure 61a. Culebra progressive vector pseudo-trajectories: full C02-C05 records with markers spaced on a weekly basis.

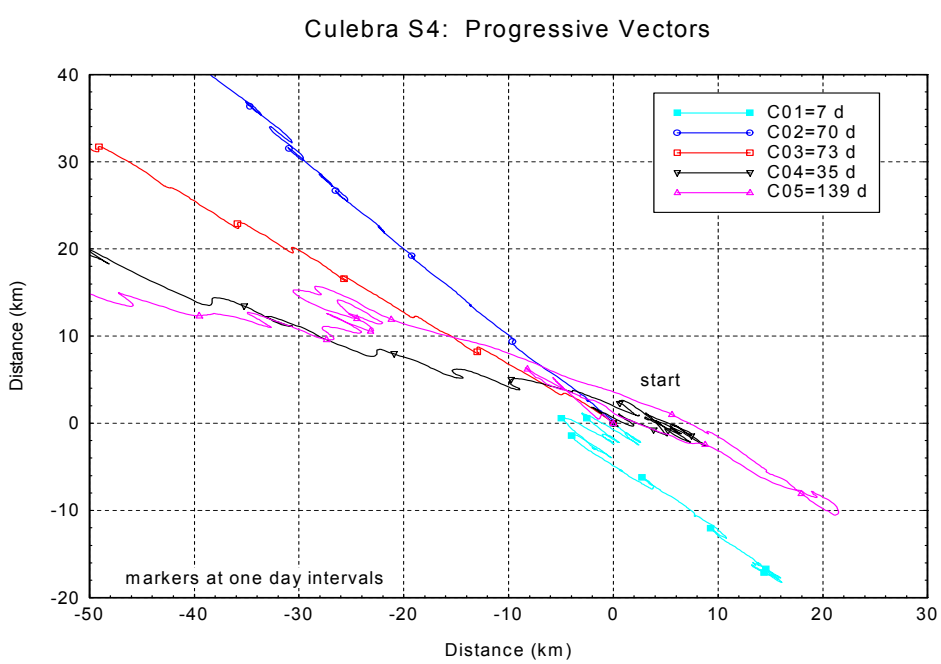

Figure 61b. Culebra progressive vector pseudo-trajectories: near field blow-up plus C01 with markers spaced on a daily basis.

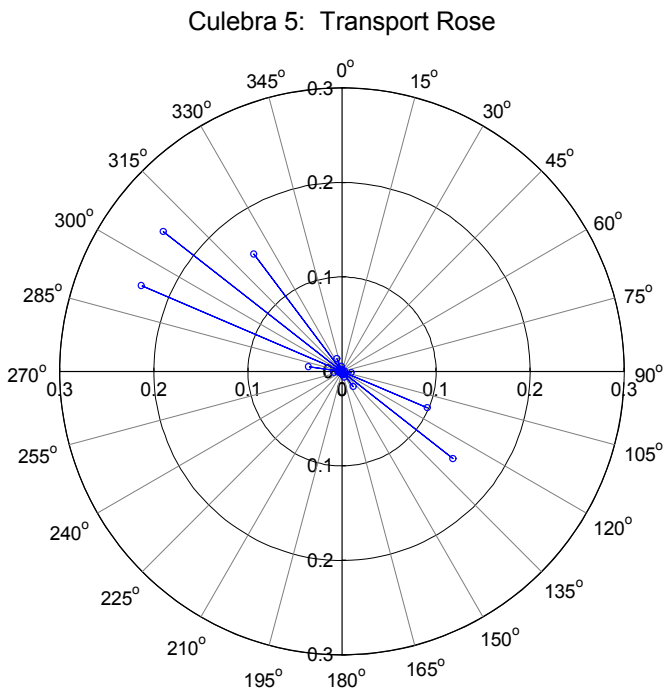

Figure 62. Culebra C05 current transport rose. The length of each vector represents the percentage of the total transport that lies in any given 15° bin. Each radial division indicates 10% of the total transport.

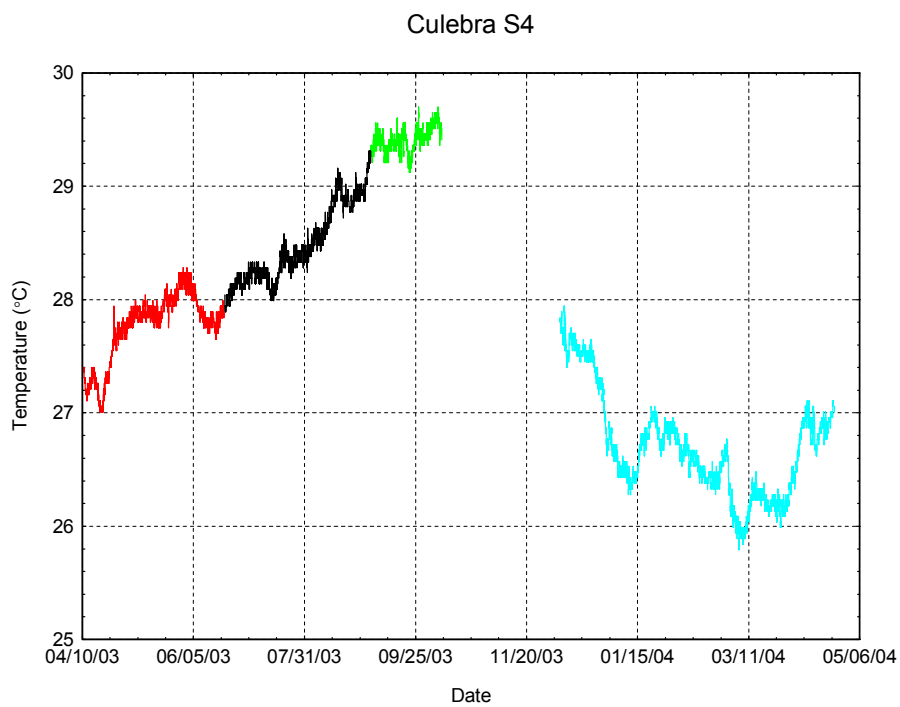

Figure 63. Culebra full temperature time series from the S4.

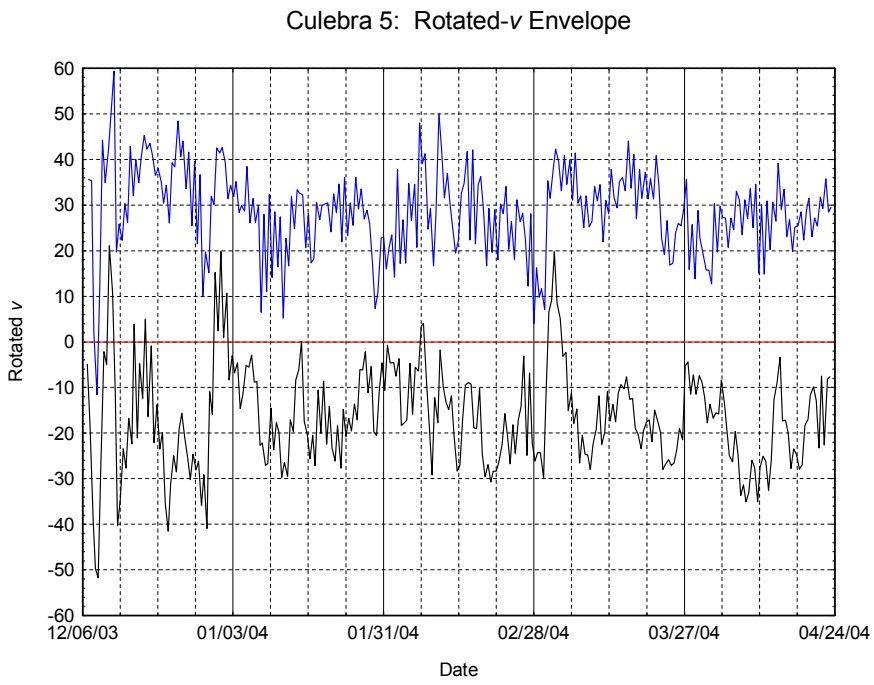

Figure 64. Culebra C05 rotated *v* envelope time series. North-south axes rotated by 60° so positive/negative *v* points towards 300°/120° true.

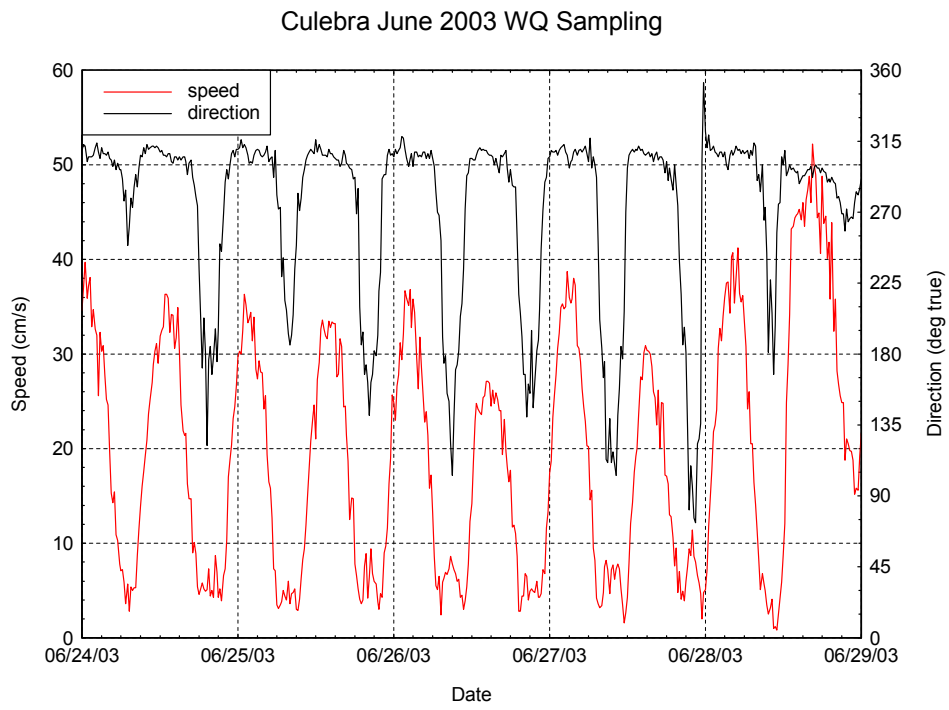

Figure 65a. Culebra speed and direction time series corresponding to water quality sampling at June 2003.

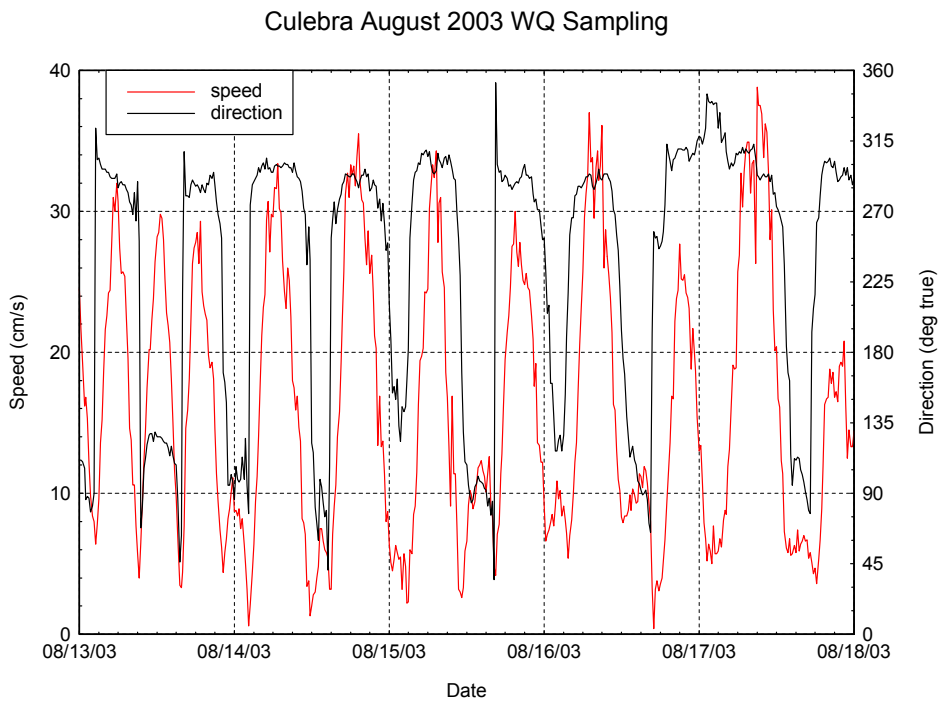

Figure 65b. Culebra speed and direction time series corresponding to water quality sampling at August 2003.

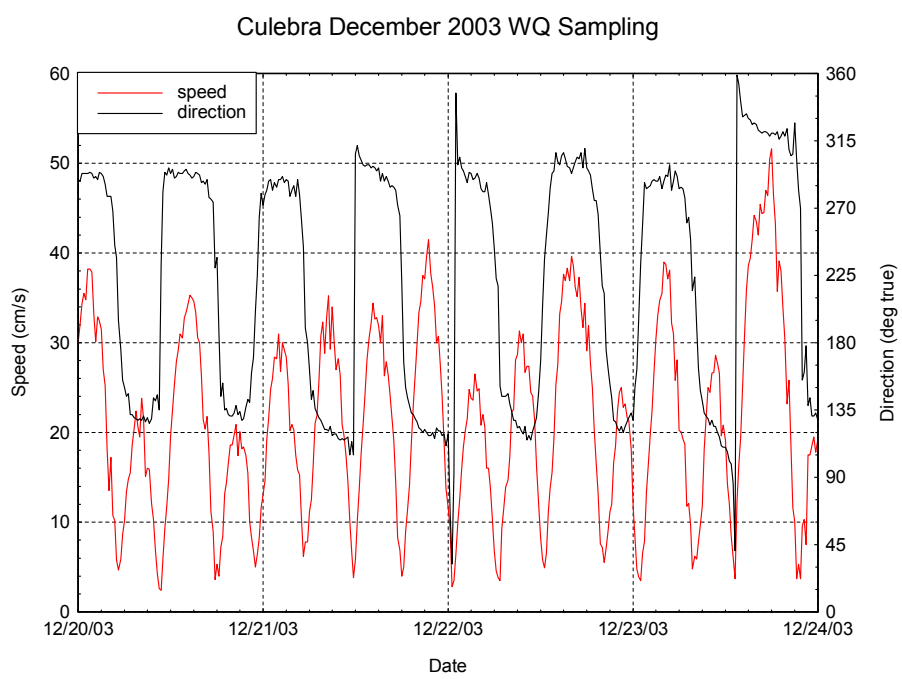

Figure 65c. Culebra speed and direction time series corresponding to water quality sampling at December 2003.

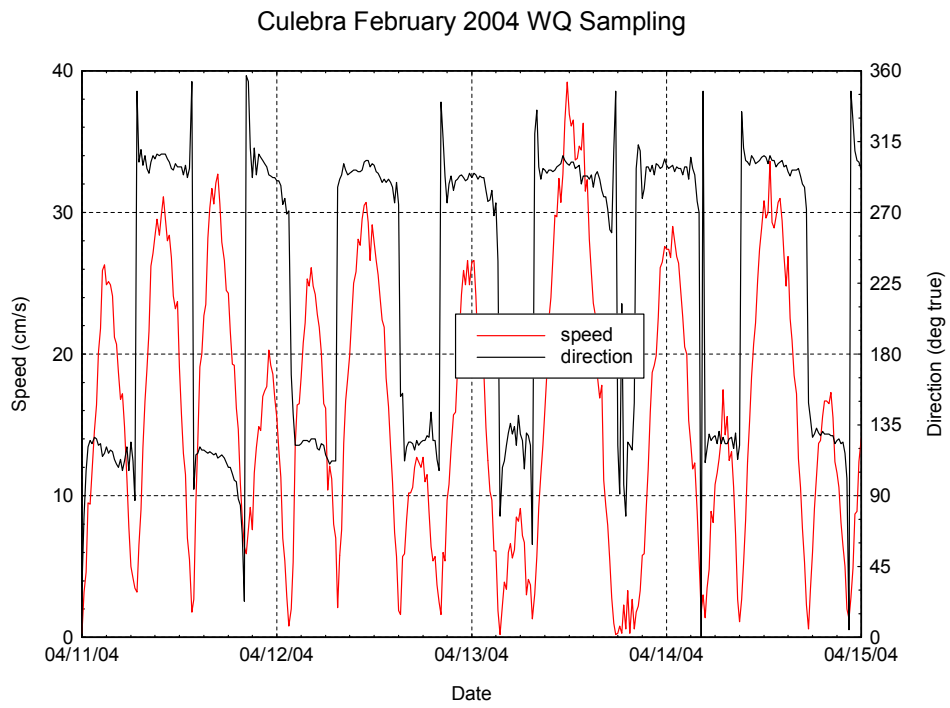

Figure 65d. Culebra speed and direction time series corresponding to water quality sampling at February 2004.

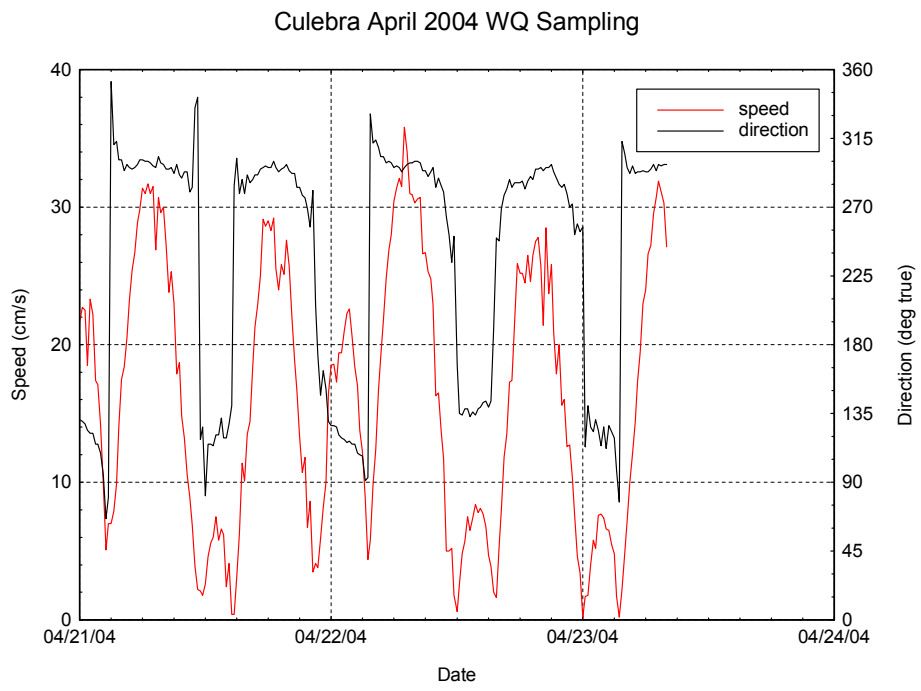

Figure 65e. Culebra speed and direction time series corresponding to water quality sampling April 2004.

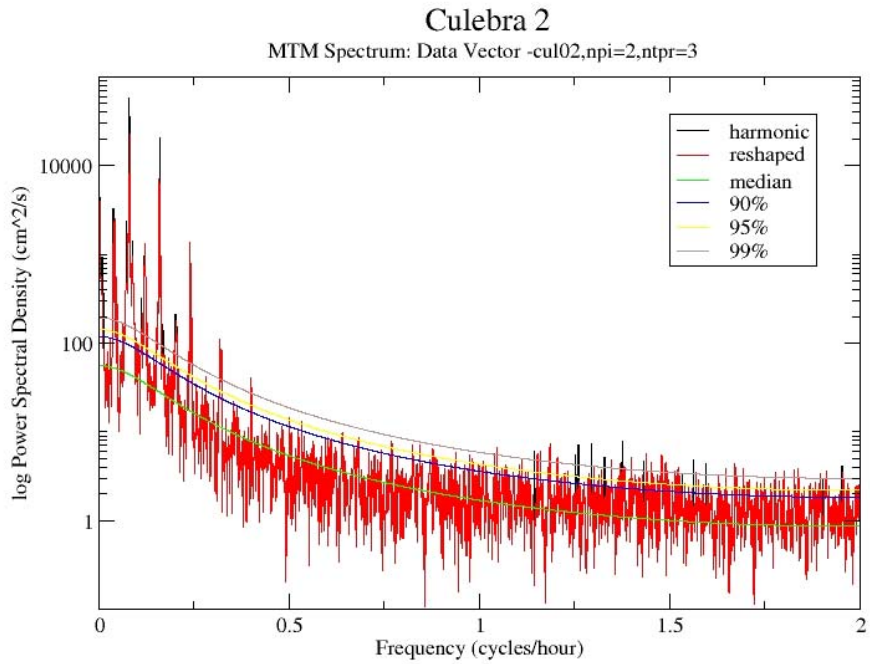

Figure 66a. Culebra C02 MTM spectra: full spectrum.

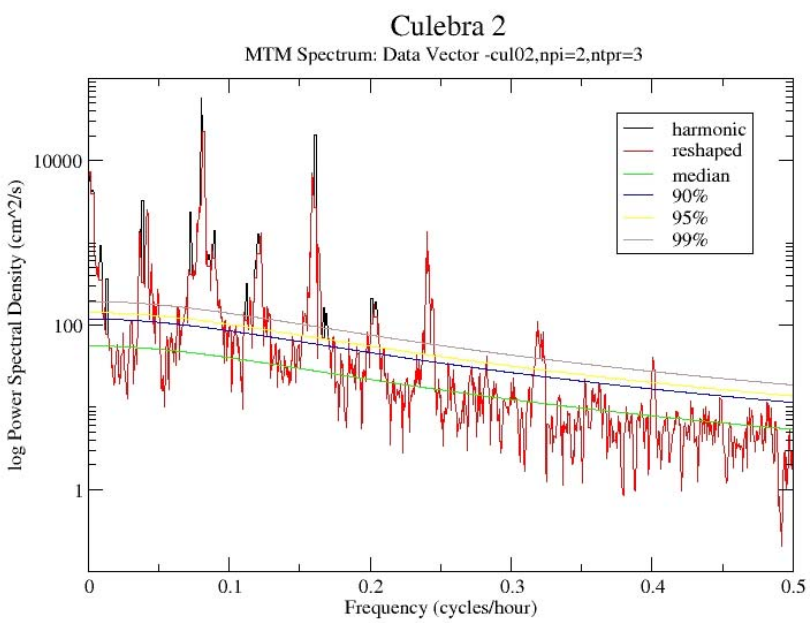

Figure 66b. Culebra C02 MTM spectra: blow-up of the low frequency part of the spectrum (≤0.5 cycles per hour).

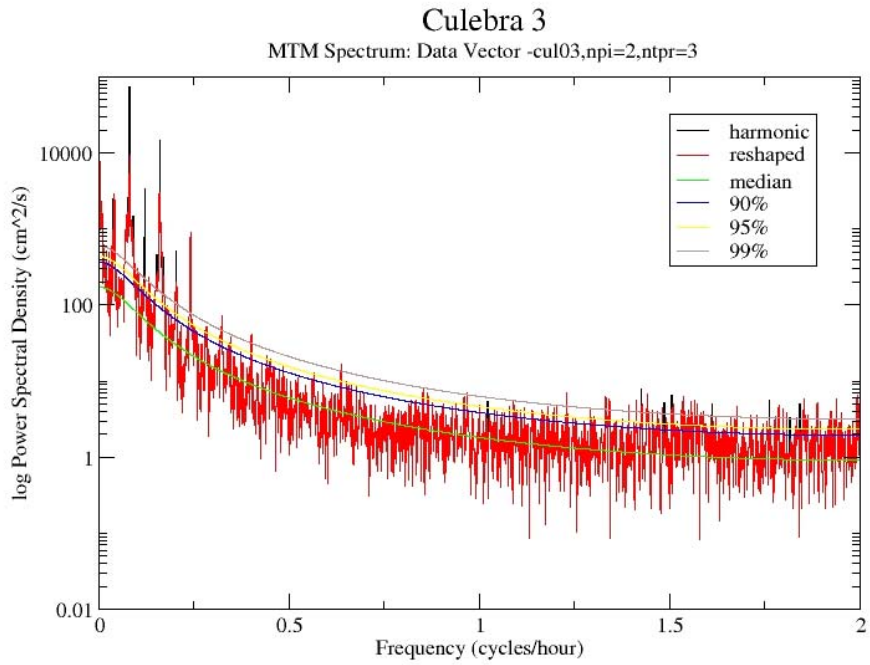

Figure 67a. Culebra C03 MTM spectra: full spectrum.

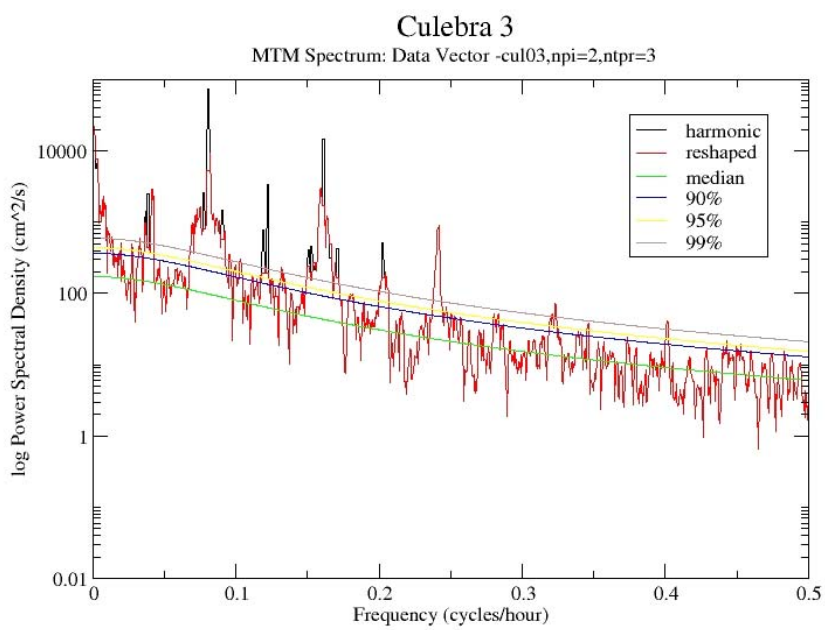

Figure 67b. Culebra C03 MTM spectra: blow-up of the low frequency part of the spectrum (≤0.5 cycles per hour).

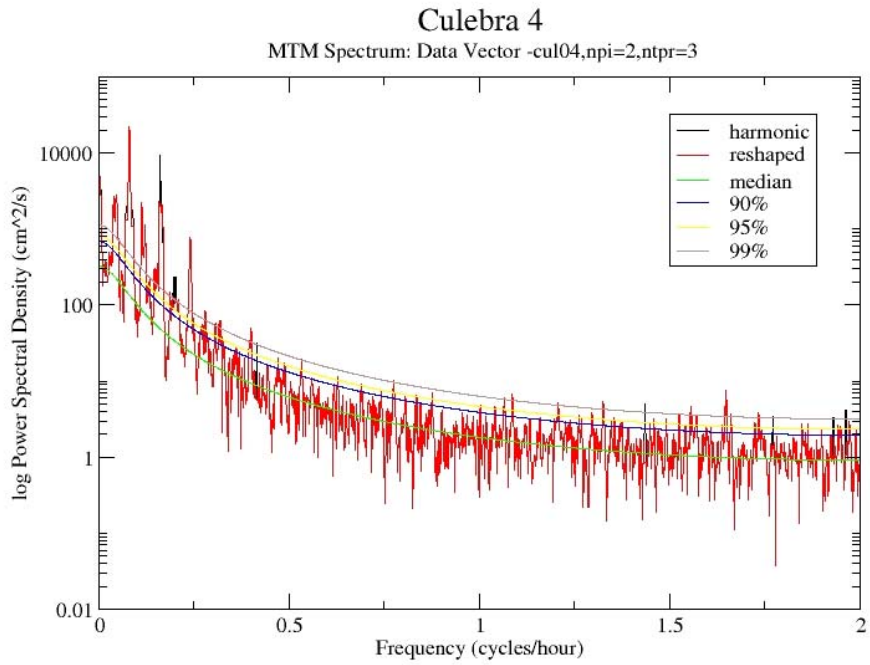

Figure 68a. Culebra C04 MTM spectra: full spectrum.

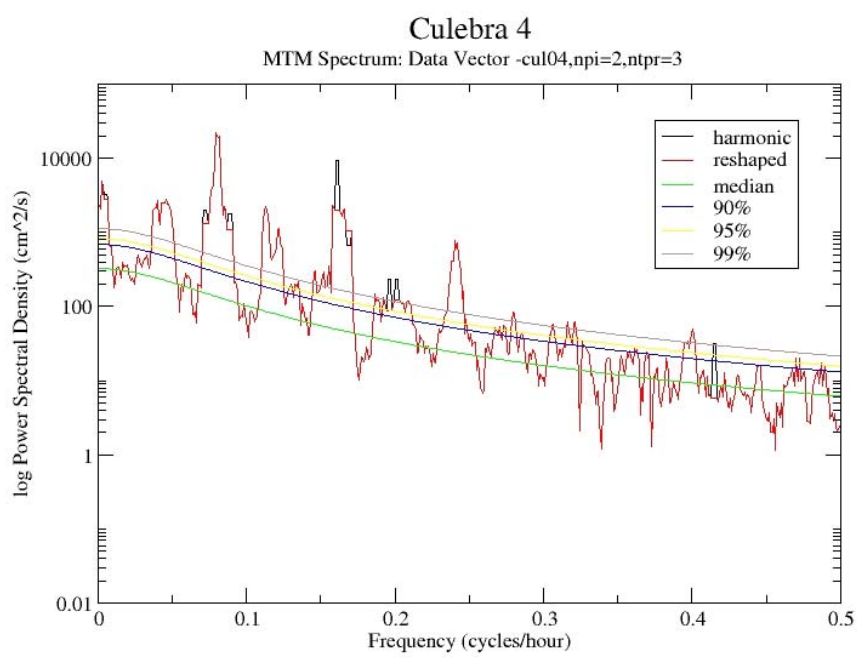

Figure 68b. Culebra C04 MTM spectra: blow-up of the low frequency part of the spectrum (≤0.5 cycles per hour).

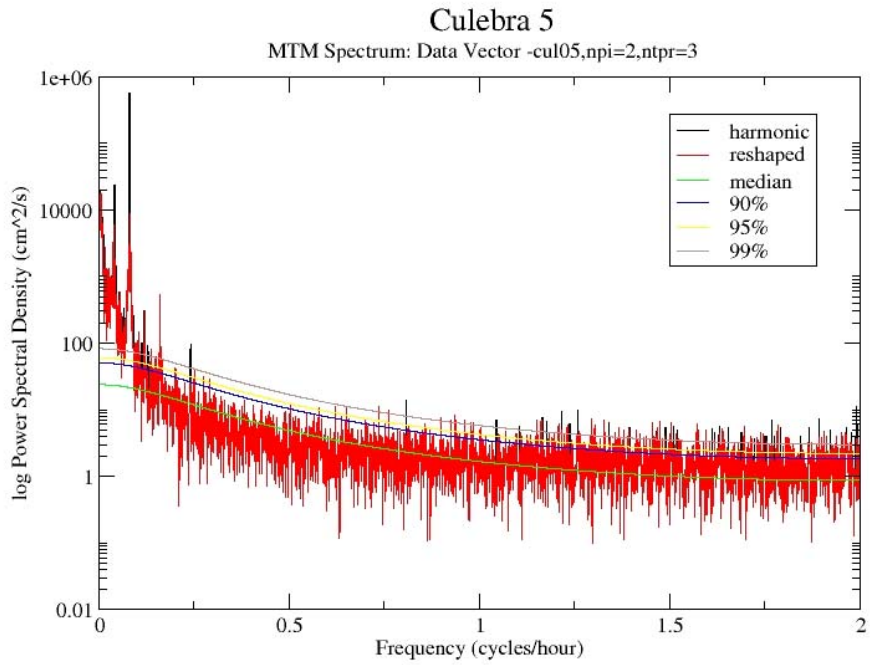

Figure 69a. Culebra C05 MTM spectra: full spectrum.

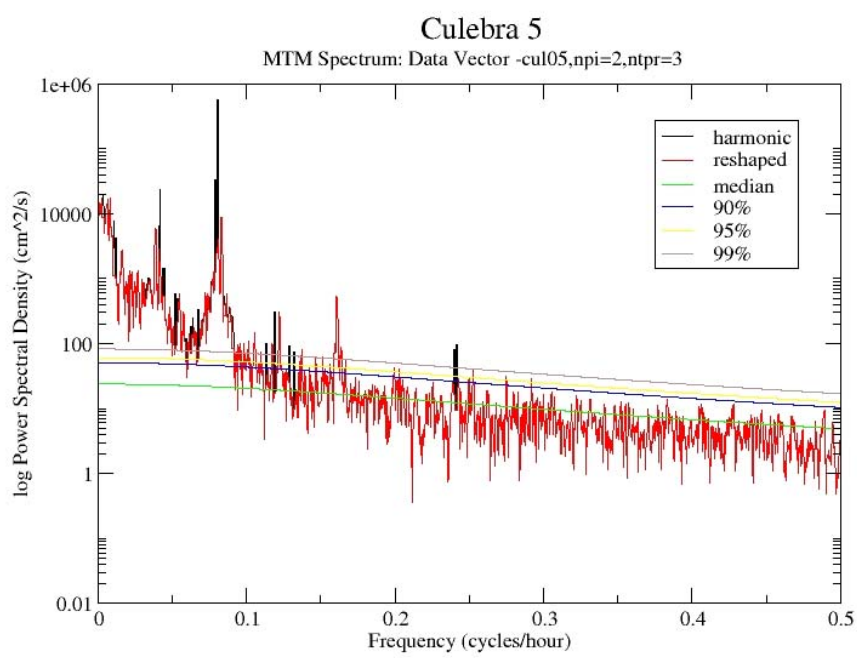

Figure 69b. Culebra C05 MTM spectra: blow-up of the low frequency part of the spectrum (≤0.5 cycles per hour).

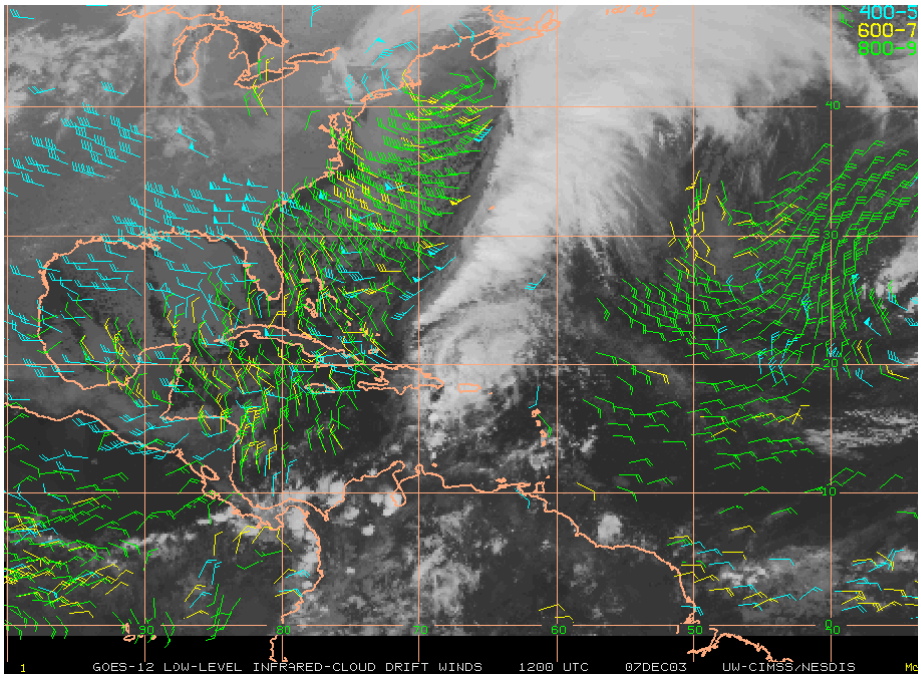

Plate 1. Satellite infrared image of the Eastern Caribbean with superimposed wind vectors for December 2, 2003.

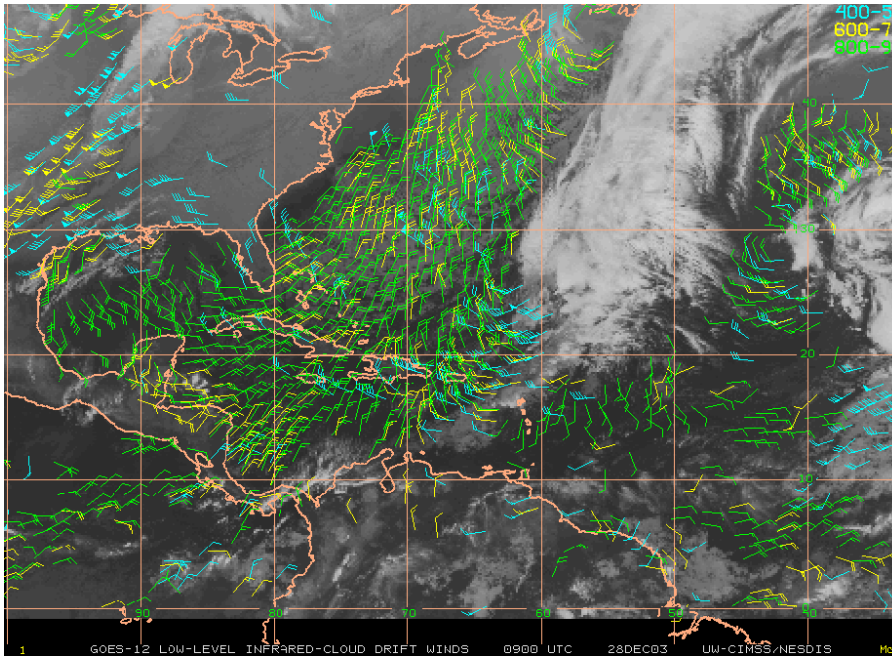

Plate 2. Satellite infrared image of the Eastern Caribbean with superimposed wind vectors for December 28, 2003.

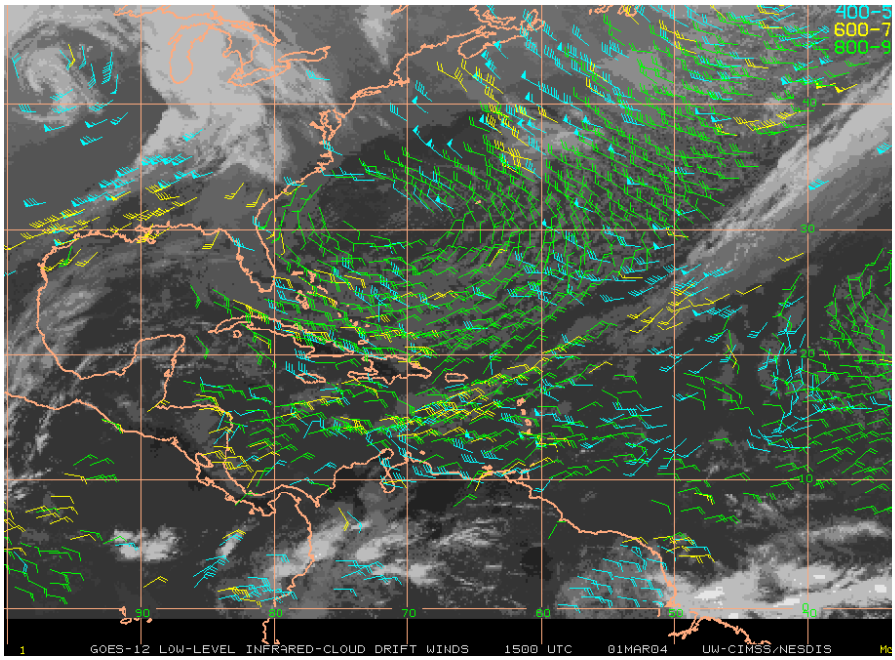

Plate 3. Satellite infrared image of the Eastern Caribbean with superimposed wind vectors for March 1, 2004.

Bathymetry and seafloor features

A NOAA bathymetry chart was corroborated with a previous study conducted from Vieques to Culebra for the Puerto Rico Electric Power Authority (Weil et al. 2000). For this study, the bathymetry data was performed using a FURUNO GP-1810 unit operating at 200 kHz. Data and was not corrected for tidal variations. Bathymetric charts were produced using the SURFER (Golden Software) software package generating matrices of 240 x 250 and 480 x 500 nodes. Latitude and longitude in the charts was expressed in degrees and decimal fractions of degrees to the nearest thousandth.

A bathymetric chart and a three dimensional depiction of the seafloor is provided in Fig. 70; sea floor relief between Culebra and Vieques is minimal. The seafloor exhibits a gentle deepening slope from the Vieques shore to the vicinity of the Culebra shore where it rises abruptly (Fig. 71). Depths from Culebra to the cages sites increase from 22 m (12 fathoms on the chart) near the Culebra shore to 28 m (15 fathoms) at the cages site. Depths on the chart immediately around the cage site are 27.4 m (370 m, magnetic bearing 12 ^{o}, north of the site), 27.7 m (241 m, 60 ^{o}, northeast of the site), 28.6 m (354 m, 132 ^{o}, southeast of the site), and 28.0 m (210 m, 297 ^{o}, west north-west of the site). Thus the bathymetry surrounding the site is uniform with sandy bottom (see grain analyses). Unexploded ordinance is reported 1.4 km (24°, north north-east of the cage site), 1.6 km (89 ^{o}, east of the site), 1.9 km (337 ^{o}, northeast of the site), and 2.0 km (344 ^{o}, northeast of the site). The closest point of land is Cayo Luis Peña off Culebra Island, is located 2.6 km north of the cage site (17 ^{o}, north of the site).

The port of Dewey, Culebra Island, is located 4.6 km (55 °, northeast of the site); the Culebra Fishermen's Association is located in Dewey and serves as the base for the Snapperfarm operation.

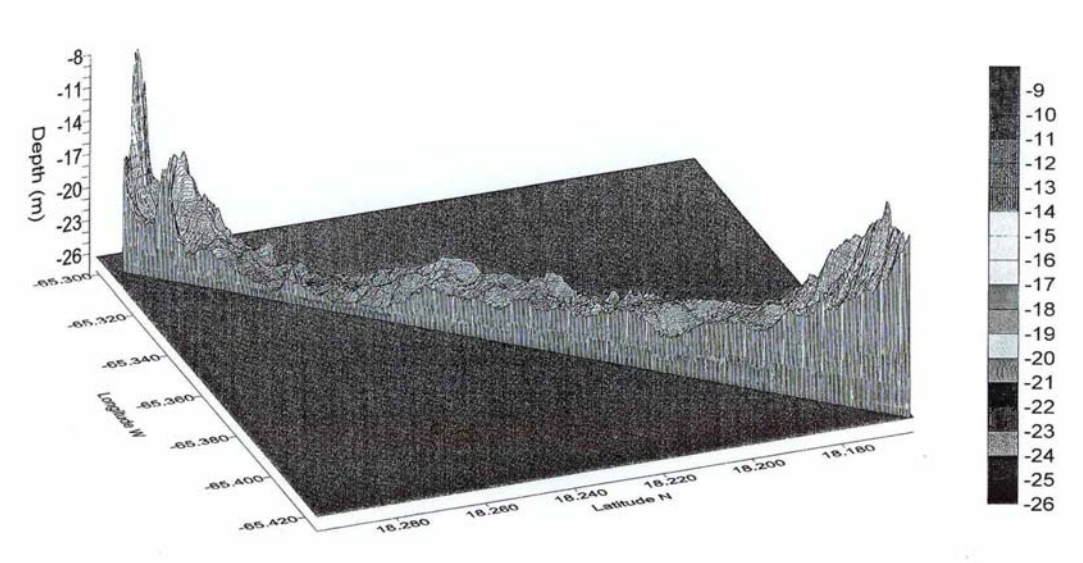

Figure 70. Seafloor relieve along the Vieques – Culebra transect (Weil et al. 2000)

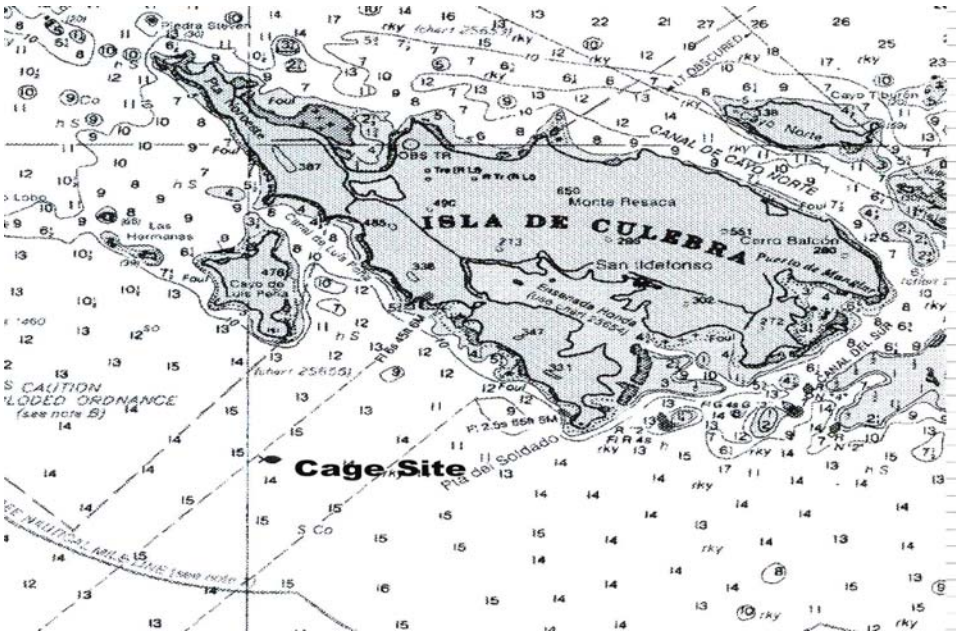

Figure 71. Bathymetric map from Culebra Island and the cages site.

Fetch

Fetch, the unobstructed distance of open water over which the wind blows, was apparent during the entire year when the unobstructed wind (over distances of more than 20 km) was primarily east to west or southeast to northwest (Fig. 72). During winter, long rolling swells (reaching 2 m) were from the north. Deep swells affected the cages more than summer waves.

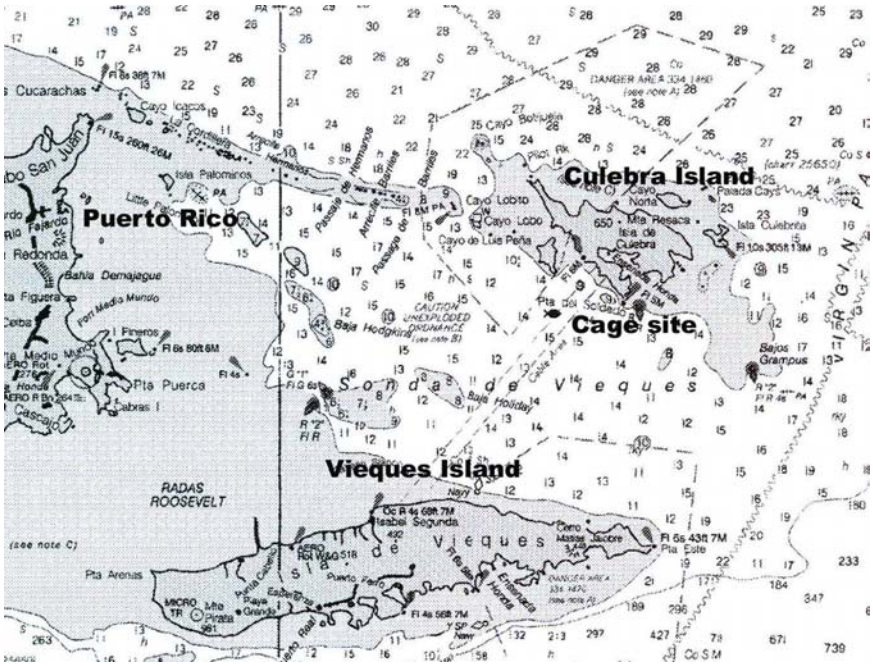

Figure 72. The cage site is exposed on the northwest, southeast, and southwest quadrants. However, winds are primarily from the east to west and southeast to northwest.

Nitrogen budget for an open-ocean cage at Culebra, Puerto Rico

The nitrogen budget for R. canadum was prepared by using a mass balance approach. Theoretically, the nitrogen budget equation can be estimated from the following variables: feed fed to the fish (feed input); percentage nitrogen input in feed (%N-feed input); percentage nitrogen retained in the fish crop (%N-fish retained in crop) as a difference in percentage nitrogen at its final weight at harvest (%N-fish final) minus the percentage nitrogen at its start of the culture period (%N-fish start); the percentage nitrogen retained in the fish crop (%N-fish retained in crop); percentage nitrogen loss due to fish mortality (%N-fish mortality); percentage nitrogen excreted primarily as ammonia (%N-fish excretion); and percentage nitrogen loss due to feces and feed waste (%N-feces-feed waste). Any variable in the equation which is difficult to measure can be

calculated by difference, provided the values of all other budget variables are known. The nitrogen budget was constructed for a one-year culture cycle of R. canadum and utilized the following equation:

%N-feed input = %N-fish retained in crop + %N-fish mortality + %N-fish excretion + %N-feces-feed waste (1)

The percentage nitrogen input in feed was calculated by obtaining values from the feeding table and the percentage of nitrogen in the feed which was determined in the laboratory.

feed input = total feed input during one year x percentage of nitrogen in feed (2)

The percentage nitrogen retained in the fish crop was estimated by the total biomass harvested multiplied by the percentage nitrogen retained in the fish after one year of culture. The percentage nitrogen retained in the fish carcass (%N-fish carcass) was determined at the start and end of the one-year culture cycle. Thus, this component was calculated as:

*%N-fish retained in crop = total biomass harvested after one year * %N-fish carcass* (3)

%N-fish carcass = %N-fish final – %N-fish start (4)

Monthly percentage nitrogen loss due to fish mortality was estimated from the records of fish mortality, fish size, and percentage nitrogen retained in fish carcass. Fish size for each month was estimated by a growth rate equation reported by Benetti et al. (2004) for R. canadum growth in the Culebra cage. The percentage nitrogen loss due to fish mortality (%N-fish mortality) was estimated by distributing the net nitrogen retained during the one-year culture cycle for each month. Total nitrogen loss of fish biomass due to mortality was estimated by summation the monthly nitrogen mortality.

*%N-fish mortality = fish mortality each month * mean fish size for each* (5)

*month * %N-fish carcass*

The total loss of nitrogen due to ammonia excretion after feeding was estimated by the equation of Leung et al. (1999) which calculates the daily nitrogen excretion rate in mg N/kg body weight/day. Total nitrogen loss through ammonia excretion over the one-year culture period was then calculated by integrating daily ammonia excretion rates over the one-year period. Based on Leung et al. (1999), the excretion ammonia loss after feeding was:

$$\%N\text{-fish excretion} = (22.81 * \text{temperature in } ^{o}C) + (28.78 * Rt) - 378.18 \qquad (6)$$

Where Rt is the feed ratio size at day t (in % body weight/day). Rt for each day was calculated by using the amount of feed and the estimated biomass present at day t. Daily water temperature was taken from our records and incorporated into the equation.

Because the determination of fish feces and feed wastes is impractical in open-ocean conditions, their contribution in the nitrogen budget was estimated by difference using equation (1). We assumed that the accountable nitrogen was primarily distributed as N-feces and feed wastes.

$$\%N\text{-feces-feed waste} = \%N\text{-feed input-}(\%N\text{-fish retained in crop} + \%N\text{-fish mortality} + \%N\text{-fish excretion}) \qquad (7)$$

The cumulative mortality of the cultured fish was 15% over the one year culture period. The annual nitrogen budget for open-ocean cages at Culebra derived from the summation of the monthly budget and is presented in Fig. 73. From the total nitrogen input (3,900 kg) during a one-year culture period, 18% nitrogen was retained in the fish crop, 3% nitrogen loss due to fish mortality, and 66% nitrogen excreted primarily as ammonia. The remaining percentage nitrogen could not be estimated directly, so using equation (7), the percentage nitrogen loss due to feces and feed waste was calculated as 13%. The nitrogen budget variables in order of importance are listed in the following decreasing order: %N-fish excretion (66%) > %N-fish retained in crop (18%) > %N-feces/feed-waste (13%) > %N-mortality (3%).

The most important budget variable was ammonia excretion, which composes 2/3 of the nitrogen input (66%). Similar percentage of ammonia have been reported in nitrogen budget of fish cages culture (66.1%-Leung et al. (1999) for Epinephelus aerolatus (areolate grouper); 78.0%-Gowen and Bradbury (1987) for Oncorhynchus mykiss (rainbow trout); 73%-Porter et al. (1987) Sparus aurata

(gilthead seabream); 60.0%-Hakanson et al. (1987) for Oncorhynchus mykiss); and 54.6%- Suresh and Lin (1992) for Sarotherodon sp. (tilapia). Although ammonia excretion represented the higher budget variable, no significant levels of ammonia compared with background levels could be detected, probably because of the strong current and the high volume of water passing continuously through the cages. No significant impact was detected for nitrite and nitrate in the area since they are also dispersed in the water column. Because ammonia dissolves in the water, this implies most of nitrogen released from the fish cages will be lost to the water column instead of the sediment. Biofouling attached to the net could also absorb a significant amount of nitrogen released as ammonia, so the real fate of this nitrogen is unknown. Because biofouling is cleaned from the surface of the net each two or three weeks, rapid growth of the biofouling represents a “biofilter” to remove ammonia from the water column with biofouling organisms incorporating ammonia into their biomass (thus transforming ammonia into organic nitrogen).

Several authors have reported that 19-28% of the nitrogen feed input can be harvested as fish production on trout farms (Penczak et al. 1982, Gowen et al. 1985, Phillips et al. 1985.Enell 1987, Foy and Rosell 1991, and Hall et al. 1992). Our percentage recovered in fish biomass was similar (18%).

The unaccountable nitrogen assumed to be released to the environment mainly as solid material (fish feces and feed wastes) was about 13% which may have settled to the bottom. In situ measurements of fecal and feed waste are considered to be impractical. Some authors suggest the excretion of urea and dissolved organic nitrogen (DON) may be part of this unaccountable nitrogen. Some of these nitrogenous products are probably consumed by the wild fish fauna. The low percentage of the feces and feed waste in the nitrogen budget may be attributed to adjusted feeding rates after visual observations by divers who verified fish consumed the feed.

No nitrogen enrichment (measured as organic nitrogen in the sediment) was detected at the cage site. Nitrogen loss as solid material to the environment may also be consumed by wild fish near the cages. Wild fish tended to congregate beneath the cages, so they probably consumed material falling from the cages. Fish nitrogen loss due to mortality was only 3%. A significant mortality occurred only once, approximately two months before harvesting.

Table 12. Summary statistics of the biomass gained, initial and final fish protein as dry and wet weigh and the total feed nitrogen input and the nitrogen retained during a one-year culture period of R. canadum at the Culebra open-ocean site.

Item	**Quantity**
Biomass gained (wet weight)	23,621 kg

Initial fish protein content (dry weight)	58%
Final fish protein content (wet weight)	15%
Total feed nitrogen input	3800 kg
Nitrogen retained in the fish crop	708 kg

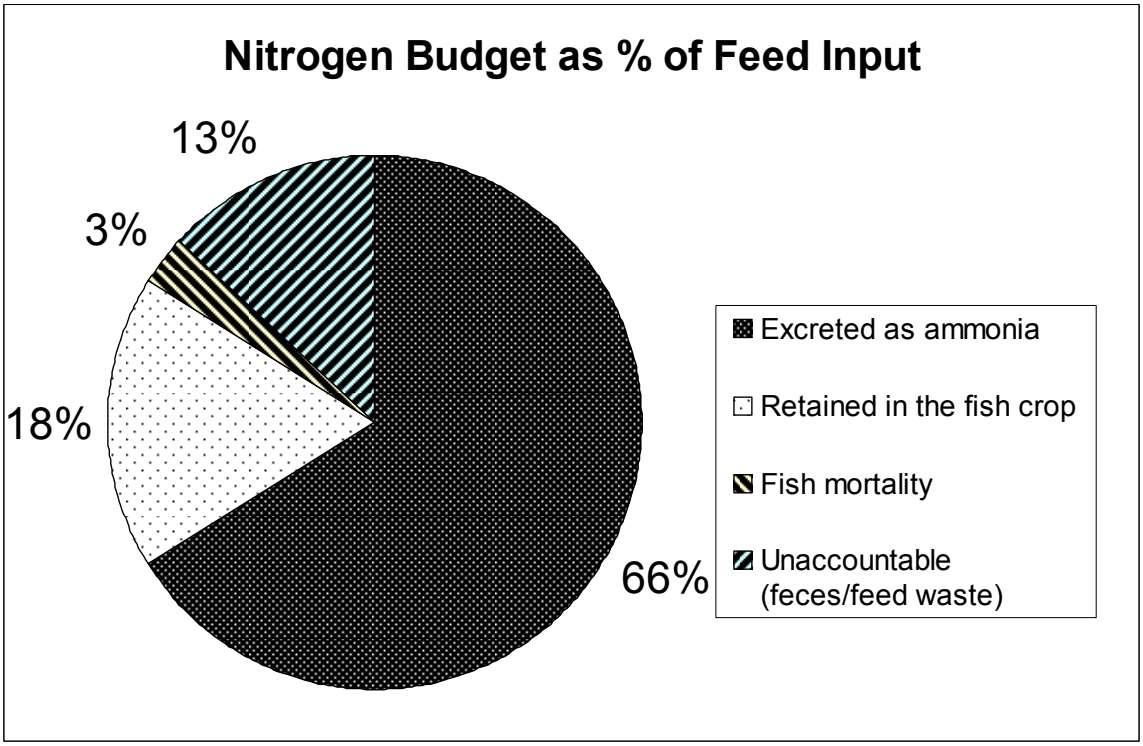

Figure 73. Annual nitrogen budget of R. canadum in open-ocean cages.

Fish disease

The highest mortality occurred only once, approximately two months before harvesting, probably from some nutritional deficiency in the feed. No parasites or diseases were attributed to mortalities reported during the two-year operation at the cage site; consequently, no results are presented. Similar results were found at the Hawaiian operation, with no fish parasites or diseases attributed to significant mortalities.

Social Component Report: Culebra Political Ecology Fieldwork

Our participation in this interesting project with brief allotted fieldwork aims to produce bare bone lines for future full investigation to be carried out by UPR. To verify this report's "facts" and understanding of the various interest groups' perceptions, there needs to be more in-depth life and work histories, the core field method of political ecology/cultural anthropology utilized in Culebra.

Demographics/Employment

In 2000 a census indicated that Culebra's population was 1,868, of whom 1,626 were Puerto Rican. Illegal foreigners are not covered but locals estimate an additional 1,000 Dominicans. Add to this figure off-islanders, mainly Americans and Europeans owning 800 houses.

Off-island migration is the norm, especially to Puerto Rico (PR), the Virgin Islands, and New York. In general, people on Culebra are encouraged even forced to go off-island for advanced medical care and education. The goal (federal/island level political directives) is to keep the population fairly low. Unemployed, ambitious or professionals tend to leave Culebra.

A twenty-something turtle watch employee for Coralations says 85% of his peers no longer live on Culebra, but on St. Thomas, the "Big Island" (local name for mainland Puerto Rico), and in the States. A number of students go on to Fajardo for University. Of his peers who did stay, most are divided between drug money, construction jobs ($9-15/hr.), some sweet medical factory positions, and then the highly desired government office jobs.

The majority of people on Culebra do work for the government (e.g. "palas"). The most gifted and trained tend to hold office type jobs, especially for the federal, island, municipal government. Culebra in one way can be seen as left with zero unemployment, since those who remain jobless turn down menial offers.

Construction companies (e.g. to build a sewage plant) often contract their labor from the Dominican Republic. Perhaps a 1,000 Dominican men live here, crowded into little houses. Another source of menial labor comes from Vieques, as will be discussed.
Some few can earn money, extra money, or get free rent is to be the caretaker/housesitter for one of the 800 houses owned by off-islanders.

The three largest employers on Culebra are the Municipality, DNER, and RD Medical (a medical tubing factory). RD Medical is employing young menial laborers from Vieques because Culebrenses don't like working the assembly line for $9/ hr.

This overall situation has implications for Snapperfarm as a future employer. Who will they be able to hire given who they will need to hire in the capital-intensive high-tech side of their industry? And, who will be willing to work for them as menial labor on Culebra?

Perspectives on Menial Work

Parents of Culebra youth on island without fulltime jobs sometimes perceive their children as being full of laziness and having a lack of shame for going on the dole. The parents attribute this to a lack of drive, discipline and the influence of drugs. Ironically, a common perception held by Americans (including Euros) is that Culebrense labor in general will quit, preferring to subsist on foodstamps, government housing and land that continues to be parceled out through the traditional *parcela* system.[1] The roots of the US dole and the federal underlying agenda to hold the islands in a relatively undeveloped, low population state need to be examined and addressed before social change is possible.

Meanwhile, in the wider context of constrained local infrastructure where youth have been highly discouraged from remaining on island, Snapperfarm's future unskilled job offers might actually encourage more day labor to come over. This is likely despite their good intentions of encouraging local youth to stay. Thus, Snapperfarm's best possible contribution to the community might be in terms of environmental education at local schools and informal education programs, as well as those in Vieques. It is important that the culture of conservation permeates the next generation no matter where they live, and those who stay closer to nature on islands will understand the critical role of human/environmental interactions.

For the new MPAs to function in the sea, this education is essential, along with the top regulatory level's ability to incorporate visual and economically sensitive management regimes designed with locals to generate local adoption and compliance. Otherwise, the MPAs inevitably stay at the level of paper tigers. Brut enforcement has never worked.

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[1] Note that the distribution of *parcelas* is highly political in terms of what lot one can get. An American qualifies for a *parcela* if they meet the resident requirements required of everyone (and to live on the land and build a house. Most land surrounding the Airport is *Parcela* land. The poorest, including the Dominicans, are settled on the hill by the airport. They get by with latrines for toilets. Thus, it is conceivable that Vieques people and other outsider workers could settle in as a marginalized labor force, and have cheap places to live, if Culebra developed in a way that provided these jobs. Perhaps the current commuting ferry service recently implemented between Vieques and Culebra specifically to bring over the medical factory workers is an attempt to block this scenario and keep others from settling in Culebra.

Politics

Three levels of government operate on Culebra: US federal, PR island, and Culebra municipal. The majority of the island is "Red" (status quo, i.e. *Partido Popular*... instead of "Blue" for statehood or outright independence). These political affiliations are taken seriously, splitting extended families so that they avoid socializing even on holidays. Snapperfarm, though not political, indirectly must support those in power and operates business under the majority position of status quo.

During April 2003's fieldwork, we participated in a one day event put on by the key three interest groups presenting themselves in alliance to U.S. Fish & Wildlife for funding. Unfortunately, the request itself has recently been turned down. However, the process of trying to function as an alliance is important for the future, given force in numbers and coordinated environmental education efforts that they can mutually support from different angles. The triangle is:

(1) **Snapperfarm**. Coordinating economically with the Culebra Association of Fishermen, led by one strong local leader, Lourdes (daughter of the beloved longterm former mayor of Culebra who quietly got the Navy ousted and stated discussing environmental objectives for the island). The Culebra Association of Fishermen provides the docking and shore space as well as selling the supplies to Snapperfarm.

(2) **Turtle Project**. Coralations --run by Mary Ann Lucking (8 years PR and 4 years Culebra)—is working with the local US Fish and Wildlife --headed by Theresa (18 years on island) to create this project. The project leads small groups of visitors to the beaches who must stay the whole night and carry out counting. The idea is to invoke as sense of being serious and respectful, countering the days of eating turtles and their eggs.

The project aims (a) to provide youth with environmental training and jobs as guides counting nesting sea turtles, esp. leatherbacks and hawksbills, and (b) to provide ecotourism business for local hotels and restaurants by insisting that anyone going to see the turtles all night with them first must have paid for a hotel. A few youth are already being paid by Coralations for guiding ecotourism to the turtles. Last year the pay was $5/hr., and this year it is $8/hr., depending on the amount and directives of the acquired grants.

The Turtle Project is trying to coordinate efforts with local DNER who control beach permits and science on the turtles. But, their ideas on what constitute effective and safe studies on the nesting turtle's conflict. DNER sometimes has withheld beach permits to the Turtle Project while granting others access. One antithesis to the project granted a recent permit was the PR tourism film crew who came with bright lights at night to increase tourism outside the bounds of the Turtle Project's eco-sensibility.

(3) **Marine Reserve**. The coral biologist from UPR Rio Piedras, Dr. Edwin Hernandez Delgado is funded by DNER and is working with Coralations currently funded by US Fish & Wildlife.

The Authority for the Conservation and Development of Culebra (ACDEC) is a Commonwealth of Puerto Rico agency that works closely with the municipality. ACDEC was formerly under the Department of Natural and areas. Since the change occurred by law, there have been some local questions about the marine area jurisdiction that ACDEC needs to resolve locally with the participation of DNER. NOAA is currently working with DNER and the community of Culebra to provide a setting for a collaborative process to write a management plan for the Luis Peña Channel Reserve. Through the National Fish and Wildlife Foundation (NOAA funds), ACDEC received a grant to write the management plan in conjunction with DNER and the community.

Financing the management of the Reserve is also an area of concern. The community will be exploring many financing options, and among these, the legality of a separate independent trust fund outside the municipality that is managed by a group of stakeholders could be studied. The stakeholders include the coral biologist who is doing studies for the marine reserve and who will coordinate the writing of the plan; DNER, CORALations; ACDEC, municipality representatives; US Fish and Wildlife, Culebra Association of Fishermen, dive shops, the Fund for Culebra's Marine Conservation, other business owners, etc. This group may explore implementing the management plan jointly but this will be decided in the process of writing the management plan as all legal issues are investigated. Nestor, the director of ACDEC, agrees in principle with this independent trust fund group that incorporates the various interest groups (Eileen Alicea, NOAA/NOS International Program Office, D.C.).

Community in the Context of Development

Please see the fine historical study by Claro C. Feliciano's *Apuntes y comentarios de la colonización y liberación de la Isla de Culebra* (2001). Here is a simple outline of Culebra society's interactions within their community hierarchy and with the outside influences. The US Navy came in 1903, when cows, sold to the mainland, were a main industry. In 1985 the last of the cattle died out due to lack of water, lack of workers, dropping beef prices, and perhaps an apocryphal cow stepping on unexploded Navy ordinances. The farms grew over in cactus and sat as rather unused assets until real estate booms.

Relations among the people and the Navy were good; Culebra women would quite often found husbands from the American Navy. Crime was low, despite a fair amount of rum smuggling, and in the 50s and 60s there were still only foot police.

In 1975-76 the Navy left. Reports are mixed on whether the Navy left quietly or if there was a bit of donnybrook. One official version is of a peaceful even befuddled Naval departure over the “mouse that roared”, Culebra with its Harvard-trained lawyer.

When the Navy pulled out there came major social structure change. The 1975 population was 575, and after the Navy left most people moved to NY, St. Croix, and St. Thomas, and the Big Island. Culebra became a more a place of older people, with very few workers. In general, Culebra did not keep up pace with the development speed of the Big Island.

About ten years ago, Hurricane Hugo hit. Houses of cinderblock withstood the winds, yet few wooden houses survived. Fruit trees were expensive; FEMA came but did not help to replant fruit trees after the storm. Only recently some have been replanted. But at this time there were very few ferries or tourists, and scant hotels. There was only one public car/taxi.

In 1996 a new big ferry for cars began operation, greatly increasing access and tourism. Today’s Culebra hosts huge weekend bashes on the beach, especially on holidays. There is more movement than ever among youth, bringing in MTV dreams and expectations. The adults do not appreciate the deluge of day trippers, yet feel helpless. The enterprises at the beachfront benefit; the costs of sanitation and police protection land on the Culebra.

A lot of US people in particular had been investing in land. Around the turn of the millennium, real estate has been developing rapidly. This was a different class of developers than the first rich homebuilders. The current developers have come to build on smaller bits of rezoned land, gambling on apartments and condos, desiring to pump up land speculations. An example is the condominium complex of Costa Bonito, nicknamed *Costa Feita*—Ugly Coast by angry locals. People felt helpless to stop it. It sports 145 apartments on 15 acres, built despite 8 law violations and much community protest. Note that Mary Ann Lucking of Coralations has correctly linked this sort of development with a reduced quality of life and opportunities for Culebra people. She has been extremely active, even facing death threats, in countering such development abuses, using her educational capital to protest in high courts, citing erosion and ecosystem degradation, and educating locals to these dangers and rounding up their support .

It will be important to know how land enters the market and what could motivate people to hold on to what they still have. This relates to the goals of Snapperfarm, Coralations, the Turtle Project, and even the Marine Reserve. There are currently 5 main finca owners: Marque, Nieve, Claro Feliciano, Antonio Lugo, Diversio Gonzalez. There are also smaller farms. Some owners are developing parts of their farms land to rent apartments and to sell. This brings in short-term profit money to those with farms.

The island still has no lawyers, no judges, and no court system. People arrested for bad crimes are taken to Fajardo. Most planned births are still in Fajardo, like the rest of the medical system.

The ferry system is now very busy bringing tourists. Again, most goods and services require a trip to the mainland, but sometimes the ferry is too full to even bring Culebrenses, especially on those weekends, causing frustration among locals. Puerto Rico today forbids private *boats* from taking passengers between Culebra and Fajardo, the mainland port. Drug dogs only recently began coming over on the public ferry on weekends. However, there is no kind of enforcement in terms of private boats that come, so folks bring in drugs in the ferry before the big weekends, and after, and on boats other than the ferry. Local police, since local, don't arrest relatives for drugs, or illegal fishing. Some locals benefit from drug money as in the US.

The Marine Reserve faces the deluge of private boaters at sea, especially on weekends and holidays that are uncontrolled in terms of numbers, their fishing, and anchoring. Some unknowingly casually drop the anchor onto those commonplace unexploded ordinances left behind by the Navy. Only the main tourist beach land has been carefully swept clean of years of bombing practice refuse.

Danger from unexploded ordinances is a largely undiscussed/undisclosed type of pollution on Culebra, certainly ignored by tourism interests. Teresa heading US Fish and Wildlife stays very active in this regard. She, herself, has risked tip toeing as through a mine field to avoid being blow up to study the nesting of the 60,000 sooty terns that vortex into Culebra once a year to reproduce. Vieques and Culebra were subjected to napalm. There are stockpiles of nasty military chemical substances on these islands that are not clearly exposed or cleaned up due to great expense and laissez faire.

Sewage water (i.e. black water) years ago emanated from just a few private houses flowing it into the sea, but now, with increasing density increase from tourism and businesses, the sewage quantity is awful, and on the horizon is only more construction and tourism that will continue to impact water quality, thus life in the sea.

Fishing for Food Rather than Income

Culebra has become overfished, and most people have shifted into construction in terms of earning income. Fishing for food is another matter and continues unabated. Thus, this Project must focus on the wider community's fishing and tourist sport fishing instead of the handful of proclaimed fulltime fishers. Fisher in Culebra is more someone with a few fish.

Currently in Culebra, it is hard to define any particular group as fishers because there is always some male who is fishing and sharing fish with his family and/or extended family. The preferred fish include *capitan*, *mero*, and red snapper. Preferred denotes a first class; there is also a second class of less preferred fishes.

Culebrenses eat fish approximately three to four times a week. Some is caught, some is bought. A number of people dive three times a day, lobstering and spearfishing. Fish are sold in the street and to restaurants or supermarkets.

For purposes of selling the preferred, highest price fish, there are fish houses in Fajardo and Vieques. Culebra's Fishing Association used to have a fish house that is now considered outdated. The Culebra Association of Fishermen has not invested in maintaining one of its original functions as a processing plant. Now it is mostly a scuba/gas station/hardware store. Paying the lowest prices, they tend to buy up some of the lesser quality, older fish. Hence, those with fish say selling to the Culebra Association of Fishermen is a last recourse.

The Culebra Association of Fishermen believes in the Marine Reserve, having seen the days of large catches disappear. The Culebra Association of Fishermen has been proposing a marine reserve since 1981, for the very reason that there are not a lot of fish left, so why not turn the area into a reserve and get the government to protect it. They want federal money to guard the marine reserve and to make it illegal for fishers to enter the marine reserve.

Hence, the Culebra Association of Fishermen has needed to refocus their business interests away from fishing. They support cage aquaculture in alliance with Snapperfarm, providing the space to Snapperfarm who down the road may sell the Culebra Association of Fishermen its fine-fleshed cage cobia product.

Note that the Culebra Association of Fishermen is perceived by the community as largely an extended family and friends. In a conundrum, Snapperfarm is working closely in conjunction with the Culebra Association of Fishermen. Snapperfarm to give back to community need to widen its activities in terms of community outreach and education.

Snapperfarm

To date, community perceptions of Snapperfarm are totally positive, with people looking forward to training, jobs, and available fish to supplement what they catch. Snapperfarm's plan for an on-island hatchery and for an industrial scale aquaculture farm is embraced at the ideal level. It will require a number of labor positions that most likely will not be of interest to Culebrenses, unless the salary and status is perceived as high.

Some youth say they would not risk their life for Snapperfarm diving to depth three times a day. Either nitrox diving technology or multiple shifts of divers would make diving jobs safer given that the cage bottoms currently sit at 90'. Merit and pay might also attract trained youth. And, Carlos teaches dive courses for youth in the summer, and will be teaching 10 kids in summer 2003.

Snapperfarm initially promised that 80% of its labor force would become Culebrense, a figure that now gives them pause. Since living and working on Culebra, this seems unlikely. But, they are refocusing their energy into education which can contribute to the community, shifting local ideals and practices. Both Snapperfarm and the Turtle Project aim to train local youth in conservation and marine management in Spanish**.** Besides the schools, there are at least two informal groups involved in education on island to be included.

One is the Educational Association of Culebra, a NGO working directly with about 26 welfare families, and the other are the two nuns who are working with pre-adolescent kids after school. The nuns would be open to environmental studies/aquaculture hands-on experiences for their children during their two-week summer period. Tati would like to be included in the loop via Teresa at US Fish and Wildlife who recognizes her community influence. The poorest families perhaps could be coached and incorporated in some way.

Scale for Future Snapperfarm Growth

Snapperfarm has leased rights to an area of water. Some people wonder about the maximum density in term of future cage development to conserve water and product quality in that leased area. Three cages was the estimated development for the current water space and water depth. Careful studies of the area need to asses water quality to maintain the local ecosystem. Ecological studies based on the finding of the present leased area need to be carefully analyzed before entering into new leasing agreements. Marketing and harvesting opens new opportunities for local involvement in areas of packing, transport, and shipping to local and foreign markets.

Suggested Topics to Investigated for Dr. Janet Bonilla, UPRM

We hope Dr. Bonilla will be funded to carry out a questionnaire and fieldwork for the local community at large, beyond the few men identifying themselves as fishers and those who are outright members of the Culebra Association of Fishermen. Fishing, as on many islands worldwide, is often only one of multiple occupations. On Culebra at this point in history, few people would cite full-time fishing as their occupation. This is important to understand, given that many households still rely upon extended family members fishing for subsistence sharing the fish, and perhaps also generating a bit of income or covering costs via sales to local restaurants, supermarket, or to fish houses in Fajardo. It is critical not to discount or dismiss the fishing effort from this part-time fishery —

from youth to retirees— who will not outright identify themselves as fishermen. Yet, their fishing provides desired fish to the diet and is part of the informal economy of Culebra. As such, it must be considered when weighing cultural conservation with resource management of the island. This activity would interact with future MPAs in a way not yet examined.

MPA

Perceptions and knowledge of a new marine protected area (MPA), and how it is introduced will be interesting to follow on Culebra. Again, if it is seen as biologically logical and economically beneficial by locals and for locals, it stands a chance of being honored. What role can the Culebra Association of Fishermen play in its acceptance? Snapperfarm?

Fishing Effort

Questions in order to frame this more general and accurate understanding of fishing effort and its social importance on Culebra would include understanding the following:

- Does anyone in their family own boats
- Do they ever get fish from the person who owns the boat
- What boats are in the family and who uses them
- Who owns and is responsible for boat's maintenance
- Where are they kept
- Actually go visit the boats and see their condition/ engines/ocean-going capability, safety
- Actually meet those who know how to fish and who go out to sea to see gear for fishing/ask about local knowledge of ecosystem, see if target species, multiple species, bi-catch)
- Ask then go with who and where people fish from shore, either swimming out or wading out, or casting from shore
- Does the family have a freezer; actually look in the freezer as ethnography
- How many times a week does the family eat fish
- When they do eat fish
- What's the source of their fish
- Do they buy it or fish it themselves
- Do they buy from store or is there reciprocity/trade of goods or services/family unity and gift-giving. Etc. among family members around fish

Social Framework

Place this more focused Culebra fisheries material within context of basic Culebra social organization obtained from new life and work histories, or utilizing others' research (e.g. excellent work by Manuel Valdés Pizzini and David Griffith

(*Fishers at Work, Workers at Sea.* 2002) on Puerto Rican fishers within context of the broader labor economy). An historical overview can also be gleaned from the history of Culebra by Carlo C. Feliciano.

- How do they define family/ how extended and where living - what are their ideals of family obligations
- Where were parents from; where did they live
    - Where did family members grow up
    - How many brothers and sisters; and where do they live
    - Where do they work if off Culebra/are there any remittances sent back or those who return with savings who provide capital for fishing gear or who retire and fish

Vieques and Culebra in the Balance of Labor

Material on neighboring Vieques will grow in importance as cobia aquaculture catches on and proves profitable.

How does Vieques' labor already interact with the social economy of Culebra? For example, Vieques teenage workers are being ferried over to the medical tubing factory (a transport service recently started specifically for the factory) for menial jobs that Culebra youth and others disdain. Therefore, would Culebra youth and others be interested in jobs offered by Snapperfarm in the future if the jobs were menial?

A study of Culebra youth employment and out-migration could provide information on the types of employment Snapperfarm could realistically offer that would attract locals. Residents who are not locals joke that to lure labor, they will need to offer a cool image titles, uniforms and beepers.

Interestingly, there is a feeling by non-local residents, shared by some retired locals who have returned from work elsewhere that locals are reliant on a "welfare" mentality held over from the old Navy handout days. Some local feel that the US government still wishes to keep them dependent on the government, and the mainland for almost all goods and services, healthcare and pharmacies being a major example of local frustration.

Besides the promise of Snapperfarm, only real estate is being developed on Culebra. This development is currently a font of desirable local jobs outside government offices. Construction jobs are a major source of income for locals as well as illegal migrant islanders. The best positions go to locals in terms of working on the plum projects and attaining the more highly paid skilled posts. Mainland PR and US investors, having gotten the island rezoned for smaller lots, are rapidly building second homes and vacation spots.

Snapperfarm is still too small and young to do more than promise work down the road when there are harvests, a hatchery, and more cages in place. Their business strategy is to maximize harvests by becoming as mechanized and high tech as possible, from cage cleaning devises to automatic feeding shoots and harvesting tubes. This is not labor intensive but capital intensive, and makes profitability sense. Scale is necessary to match the high priced market demand that they will be generating. They will require skilled people who to date are not available locally. The most educated youth have needed to seek professional jobs off-island, unless they take social work and municipal type employment on Culebra.

In any case, one has to ask in the long run if Vieques youth will be the real source of aquaculture development's largely unskilled labor force in Culebra, despite Snapperfarm's good intentions and commitment to provide local jobs to the community once established.

Realistically, how would increase Vieques youth presence in Culebra effect the island. An increased social relation is probably the obvious outcome. Vieques youth who see opportunities on a less populated island could easily settle down, intermarry, increases the Culebra population and thus informal fishing effort and pressure on the system of shared communal lands.

Vieques, itself, could offer other environmentally appropriate cage farm sites, but the social side of establishing aquaculture business on Vieques could be more intricate than on Culebra, and thus the original site selection on Culebra.

One would need to understand how Vieques' far larger population than Culebra's is still reliant on fisheries for food and cash.

More, Vieques must be considered a potential source of marine antagonism and conflict once Snapperfarm has expanded and established cage aquaculture for cobia in waters previously utilized in common by all fishers. Snapperfarm could face hostility in waters they now lease. Their rights might be informally contested, with increased theft, threats of poaching, and desire/frustration among Vieques fishers in particular. Recall that these waters have been traditionally shared without marine tenure or concession rights, or leasing by individuals or companies.

One would want to verify the following initial leads on employment pressures and Vieques generated fishing effort:

(1) 100 fishing boats in Vieques, divided into four groups
(2) Vieques' conch and lobster factory employs 200 workers
(3) Vieques fishers fish in St Thomas, St Croix, and Culebra, and sell a lot on the Big Island
(4) these fishers already respect nothing (e.g. MPA, reserves)

(5) Vieques has terrible unemployment
(6) Vieques had a bra factory that closed one year ago and lost a critical approximate 1000 jobs
(7) with the Navy pulling out of Vieques in mid 2003, they lost another 500 jobs

Turtle Tourism

As far as Turtle tourism as another way to find youth employment, one would verify if:

(1) Vieques and Fajardo people still eat turtle meat, and eggs as aphrodisiac still dug by Culebra men
(2) Vieques/Culebra adults have less respect for turtles than kids who are learning turtle conservation-friendly practices at a young age in island schools

Coralations and US Fish and Wildlife doubt that the current scientific method of drilling into the turtle shell to tag the leatherbacks is wise. The consensus is that local DNER acts too rough with the turtles. What is the science on this? This needs to be mediated as does access to the beach via DNER permits.

The Turtle Project's goal is to combine turtle ecotourism with turtle science. It would be interesting to compare this with any less eco-focused turtle tourism happening outside of Coralation's jurisdiction

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Social Component Report: Perceptions by Local Fishing Community

Objective of social component

The objectives are to obtain a picture of the different perceptions, attitudes, and behaviors held by the residents of Culebra regarding the introduction of a fishing innovation (open-ocean cage aquaculture) 3 km south of Culebra. A researcher of the Center for Applied Social Research (CISA) at the UPRM had the primary responsibility for conduct the social component of the project.

Achievements

January to March 2003. Dr. Bonilla reviewed the existing written materials regarding the social features of Culebra and reviewed literature on similar studies

in other parts of the world. Also, she submitted to the UPR-Mayagüez Committee for the Protection of Human Subject in Research (IRB) a Consent Form for their approval. On March, Dr. Bonilla and Jessica Rodríguez, a research assistant, visited Culebra and identified the fishing community, as well as several community leaders as key informants for the project. Twenty (20) fishermen were identified among the general community of Culebra. According to the USA 2003, census Culebra has 1,700 inhabitants. The following fishermen constituted the entire sample of the fishing community (Tomasito Ayala, Víctor Amaro, Ranthy Amaro, Geraldo Bonano, Abimael Cruz, Elmes De la Paz, Aquilio Feliciano, Samuel Hernández, Tito Jiménez, Héctor Pérez, Gamalier Rohlsen, Ricardo Rahlsen-Hijo, Elías Ortiz, Manolo Rivera, Luis Rodríguez, Anastasio "Taso" Soto, Israel Soto, Flores Soto, Máximo Soto, and Adan Feliciano). Three key informants were interviewed during that occasion. They agreed that their names could be revealed for research purposes. The three key informants were Mrs. Lourdes Feliciano (Representative of the Fishing Association in Culebra), Mr. Anastasio Soto (ex-mayor of Culebra, fisherman since his childhood, and ex-president of the Fishing Association for Culebra), and Mr. Aquilo Feliciano, (also an ex-mayor for Culebra, fisherman and ex-president of the Fishing Association in Culebra). The three key informants agreed with the introduction of the new cage culture industry into Culebra. They have been collaborating with Snapperfarm in the project and represent the position of the Administration of the Fishing Association in Culebra.

January to July 2003. The interview instrument was developed to obtain information concerning perceptions, attitudes, and behaviors held by the residents of Culebra regarding the introduction of a fishing innovation (offshore cage aquaculture practice). Each participant interviewed signed a consent form (in English, Appendix 3; in Spanish, Appendix 4). There are two versions of the instrument: fishing community version and general community version. The interview instrument (Appendix 5) has four parts: (1) socio-demographic information; (2) description of the fishermen work; (3) knowledge and perception about the aquaculture project in Culebra and aquaculture in general, and (4) attitudes toward the implementation of this technique in Culebra as well as in other places. On *April of 2003* a meeting was conducted among members of the social component of the project in UPRM and in RSMAS (Drs. Daniel Benetti, Sara Meltzoff, and Janet Bonilla). In this meeting Dr. Bonilla gave feedback of her visit to Culebra to Drs. Benetti and Meltzoff and they offered Dr. Bonilla feedback about the interview instrument.

During *May and June of 2003,* Dr. Bonilla worked on the final version of the interview instruments, with feedback from personnel of the Sea Grant Program at UPRM.

August to December 2003. Dr. Bonilla and two research assistants (one psychology major and one sociology major) visited Culebra for three days and conducted intensive interviews with community leaders of Culebra as key

informants (n=2), fishermen (n=4), and members of the general community of Culebra (n=14). The interviews to the general community served as a pilot study to evaluate the instrument.

The interviews were conducted individually. The version of the interview conducted for the fishermen took an average of one and half hours, while the interview for members of the general community took an average of 45 minutes. Interviews conducted with key informants took almost two-hours. Data gathered includes socio-demographic information; description of the fishermen's work; knowledge and perception concerning the aquaculture project in Culebra; and aquaculture in general and attitudes toward the implementation of this technique in Culebra as well as in other places.

Results of the Pilot Study

Members of the general community interviewed reported that they did not have sufficient information about the aquaculture project. In general, they reported positive attitudes regarding learning more about this project. However, until they learned more, they could not say anything positive or negative about these methods in relation to the environment or to the economy of Culebra.

Four members of the general community interviewed reported knowing little about the aquaculture project in Culebra (they call the project as "the cages work"). They would like to obtain more information about the project in many areas: nature of the project, implications for Culebra in areas such as economy, affects to the environment, the quality of the fish in the cages, skills, and knowledge needed to manage this method, the cost, and the impact to fishermen (with employment by the company as one of their questions).

Twenty (20) fishermen were identified among the general community of Culebra; of these, 4 were successfully interviewed. The average age for these fishermen was 36 years and all indicated that they completed a high school degree. Also all of them have lived their entire life in Culebra and were half-time fishermen. The four fishermen reported using several methods of fishing, but most frequently used nets ("mallas") and fish traps ("nasa" or "trampa"). Fishermen reported that they primary try to sell fish or other seafood to restaurants in Culebra and Fajardo. Next, they would sell or use the seafood in their own homes and finally, they would sell the seafood to the Fishing Association in Culebra. This data is consistent with the perception of the two key informants interviewed who understand that fishermen (also those in the Association) do not sell their better fish or seafood to the Fishing Association in Culebra.

The four fishermen know about the project of aquaculture conducted in Culebra as well as where the Snapperfarm operation is located in town. However, they reported knowing only general, but not specific information (e.g.,

"I heard about the cages and I know where the cages are located; also I see the younger men working with the cages… But I do not know how the cages work"). However, the four fishermen reported that they were open to receiving information about the cages and the project in general. Also, they reported that the Fishing Association in Culebra only talks positively concerning the cage operation and they feel a little worried about this aspect. Also, they reported that they are really concerned about the "competition" from the cage industry and how it will affect their livelihood as fishermen.

Mr. Anastasio Soto and Mr. Aquilo Feliciano were interviewed a second time. These two key informants agreed with the introduction of the cage agriculture techniques in Culebra. They have extensive knowledge concerning the cage techniques (general and technical knowledge). They have been collaborating with Snapperfarm during the project and represent the Administration of the Fishing Association in Culebra. They understand that the future economy of Culebra Island, if positive, will benefit from the aquaculture technology.

January to December 2004. During the summer, Dr. Bonilla and two research assistants visited Culebra for two days and conducted intensive interviews with community leaders serving as key informants (n=2), and members of the general community of Culebra (n=27). Interviews were scheduled with a sample of fishermen. Four months later, Dr. Bonilla and two undergraduate research assistants (each were psychology majors) visited Culebra for three days and conducted 35 additional intensive interviews with members of the general community of Culebra.

Socio-demographic characteristics and description of the fishing activity

A total of 62 members of the general community of Culebra, with a mean age of 56 (standard deviation "SD"= 17.9), participated in this study. The questionnaire of the study was administrated as an interview (71%) and self-report (29%) format.

Sixty one percent (n=38) of the sample were women and thirty-nine percent (n=24) were men. A high percentage were married (52%, n = 32) and 86% (n =53) had children. The majority of participants were employed, primarily in Culebra, for the public (15%) agencies, for private (20%) entities, or owned their business (20%). Participants' educational level varied from elementary school (16%, n=10) to university schooling (38%, n=23). Seventy-seven percent (n=48) of the participants lived with their relatives in their own house. The average family household was 2.48 (SD=1.82). More than half of all the participants (52%) have lived their entire lives in Culebra, while the other half has also lived in places such as in other municipalities in Puerto Rico, the United States, the Virgin Islands, and Europe.

Most of the participants informed that the do not receive any economic governmental help (79%, n=46), although the mean per capita income in Puerto Rico is $11,279 (González 2005).

Most of the participants reported they do not receive any economic governmental aid (79%, n=46). The activities conducted most frequently by members of the general community of Culebra participating in the study were fishing (34%, n=21), followed by agriculture (13%, n=8), and construction (10%, n=6). Most of the participants who reported participating in fishing conduct the activity between one and three days per week, primarily during the morning and using hook and line ("cordel") to catch fish for their family.

Knowledge and attitudes concerning the aquaculture project in Culebra and aquaculture knowledge in general

Participants were asked to describe their general knowledge about the *aquaculture project in Culebra and aquaculture in general* using a three point Likert scale (nothing-somewhat-a lot). A total of 55% of the participants (n=31) indicated that they known nothing about the aquaculture project conducted in Culebra, while 27% (n=15) reported to somewhat understand the industry. Only 18% (n=10) of the participants reported knowing a lot about the project. Of the participants reporting, 45% (n=27) reported knowing nothing about the Snapperfarm Company while 45% (n=27) reported to have some knowledge. Only ten (10%, n=10) percent of the participant reported knowing a lot about the Snapperfarm Company.

Furthermore, those who reported somewhat understanding the project or had received information from Snapperfarm, typical responses were: "there are some cages located in Culebra to raise fish and other seafood"; "Originally, the project was started by American people who began to raise snapper and now are raising and selling cobia in the Island". The following misconceptions were identified among these participants: "they are raising the fishes to throw them into the sea in order to increase the number of fishes to the fishing activity"; "the cobia is not compatible with the other species in the Island and that will be a great problem, particularly to fishermen", "the project will alter too much the areas where the cages are located, so fishermen will not fish in that place any more". However, according with administrative personnel of the Fishing Association in Culebra, the areas where the cages are located never have been adequate for fishing and the fishermen in Culebra usually do not fish in those places. Indeed, the environment where the cages are located has change positively because red lobster and other seafood are living there now. These participants reported to know about the project primarily by less formal sources: informal conversations with fishermen, announcement of the cobia as part of the menu in some Culebra restaurants, samples of cobia offered by the Association of Fishing in Culebra, or informal conversation with Snapperfarm personnel while they are buying in

stores at Culebra. They also reported receiving information through direct and formal sources such as through radio programs.

Those who reported knowing a lot about the project and Snapperfarm reported that the aquaculture project in Culebra “consisted of an experiment conducted during the last five years by an American Company [Snapperfarm] that introduced two cages located between Vieques and Culebra to raise fishes”; “Originally the project began to raise snapper and now are raising cobia”; “The cobia are in cages and are being fed until they have an adequate size for marketing”. “There was not a lot of knowledge about the cobia in Culebra before the project and now is sold a lot in restaurants and in the fish market”; “Although, some people claim that cobia is too expensive, it has a good market because of its flavor, quality, and innovation”. “The cages are visited several times to feed the fish and to maintain the environment close to it”; “Although, the principal people involved in the maintenance of the cages are from the United States, there are also Culebra residents employed in the project (two or three)”. Misconceptions were not identified among the information given by people who reported knowing a lot about the project. These participants reported to know about the project by direct, and formal or indirect contact, and by less formal sources such as employees of the Snapperfarm Company because they are part of the team that adopted the project in Culebra or are working in restaurants or hotels where they meet the Snapperfarm personnel, or they work at restaurants where cobia is sold or work with the Fishing Association in Culebra.

Participants also were asked to describe their knowledge about specific aspects of the *aquaculture project in Culebra* using a dichotomous scale (yes or no) and open questions. The participants reported to have less specific knowledge than general about the aquaculture project in Culebra. The area in which participants reported to have more knowledge were related to the impact of the project in the economy (35%, n=22) and in the community life (31%, n=18). Participants reported to have less knowledge about the disadvantages of the cages, if any (27%), and the impact on fishing (24%) in Culebra, as well as on the fishermen (24%). Also, participants reported not to have knowledge about the skills associated with maintenance of the cages (10%), the cost of the cages (1%) and the cost of the fish production (7%).

Although knowledge is considered an important criterion to develop attitudes, most of the participants, even those without information, reported agreeing with the implementation of the aquaculture project in Culebra. They sustained that if people with knowledge support the program, it should be good for Culebra. Other participants reported that they could not express their opinion (because they were neutral) regarding the project because they did not have information about it. Also, a great enthusiasm was observed by participants regarding the following question: “how much would you like to learn about the project?” Ninety four percent of the participants reported that they would like to learn more, in many cases a lot more, about the project.

In summary, there is a significant percent (55%) of the members of the general community of Culebra that participated in this study that did not have general or specific knowledge about the aquaculture project in this municipality. Indeed, the participants who reported having some general knowledge about the aquaculture project did not have specific information about the project (advantages or disadvantages in relation to the impact on economy, fishing, fishermen, or community life). These results suggest the need to continue to provide information to the community to increase their knowledge that can later support their attitudes toward the aquaculture methodology. It is important to involve Culebra residents in the social and economic changes regarding aquaculture techniques. The agreements that have allowed the implementation of the aquaculture project in Culebra are related to knowledge and attitudes of those who have promoted and supported the aquaculture techniques. Therefore, an informative program should be developed, taking into consideration the socio-demographic characteristic of the Culebra population as well their emphasis on social relationships. The social component researcher and the assistants have observed the importance of human relationships as part as the informal or formal orientation process with people living in Culebra. The positive attitude observed among the participants toward the project is a key element in the implementation of a program to inform people living in Culebra concerning information about the aquaculture project.

More knowledge was observed among those Culebra residents who worked or were related with the Fishing Association of Culebra, the entity that actively has participated in the implementation of the project on the Island. Among those less related with the Association or with governmental agencies such as the tourism office, less information about the project was observed.

Public policies, laws, and socioeconomic factors

INTRODUCTION

Rationale for open-ocean aquaculture

Puerto Rico as Island has suitable locations to establish open-ocean aquaculture operations; however, suitable culture units have not been available until recently. Due to few enterprises of this nature and the recent interest on this new technology, the regulatory and permit requirements are not clear for Puerto Rico (or even for the US mainland) on how to stimulate the growth of an open-ocean cage culture industry while simultaneously protecting the environment. Even in cases concerning aquaculture, most laws are only related to inshore or terrestrial farming. Because culturists will be sharing the same ocean resource, laws should be designed to encourage sustainable marine aquaculture management techniques.

The principal reasons for the likely expansion of aquaculture into the open-ocean are to avoid conflicts with other human uses of the sea surface, water column, and seabed; to avoid regulation under state laws; to have access to high water quality; and to minimize regulatory compliance burdens (Goldburg et al. 1996). Limiting factors for expansion into the open-ocean environment include difficulty and costs of engineering and building facilities able to withstand severe storm conditions, high cost of operating facilities in the harsh offshore environment, and absence of a clear and environmentally protective federal regulatory framework. These factors have apparently made it difficult for developers to attract sufficient investment capital to construct and operate open-ocean aquaculture facilities.

This section discusses socioeconomic factors and how they relate to the development of a suitable open-ocean aquaculture industry. It also analyzes existing public policies important to future entrepreneurs and government legislators concerning the development of an open-ocean aquaculture industry. The major federal laws applying to aquaculture are presented. Environmental laws and regulations are intricate, so an index of the relevant Puerto Rican agencies and their laws and regulations is appended (Appendix 6).

Socioeconomic aspects in Puerto Rico

To support a new marine aquaculture industry, it is important to consider the socioeconomic aspects of those segments of the population that may be affected by the new business. These factors can later be incorporated into legislation that considers both the needs of the public and the needs of the industry. Successful integration of regulations will ameliorate negative interactions between user groups and should actually be mutually beneficial in many cases. Particularly important user groups are the local traditional and recreational fishing industries.

Like many other Caribbean islands or nations, Puerto Rico is becoming increasingly dependent on coastal recreation and tourism (Valdes-Pizzini et al. 1991). Fisheries is considered a marginal economic activity in the Caribbean, especially in poor sectors where it is an informal part-time activity or an “accidental occupation” along populated coastlines (Valdes-Pizzini 1990). Marine recreational fishing is generally believed to encompass leisure activities fully supported by private enterprises and capital, and is basically composed of sport fishermen representing the upper segments of the socioeconomic ladder. However, research indicates that marine recreational fishing is also composed of members of the lower and middle economic segments. This combination of recreational fishing populations creates a demand for infrastructure, information, and services that are often satisfied by local businesses, municipalities, or the government. Marine recreational fishing means jobs and business opportunities for coastal communities in Puerto Rico.

From the beginning of Puerto Rican history, fishing has always played an important role in local traditions. The fishing industry is open to all fishermen,

regardless of their education (Cruz-Torres 1985). Fishermen often follow the trade of their relatives who were fishermen in the past. Fifty percent of the fishermen relied exclusively on fishing for their primary income. Others were involved in activities such as mechanics, agriculture, boat construction, or carpentry. The fishermen confront the hostile ocean environment, but feel frustrated because they cannot satisfy their economic needs. The fishermen are also discouraged because they feel that the government does not support their activities. They are concerned about environmental pollution, especially because they feel it affects their fishing. Their small boats are not adequate to exploit the distant offshore areas, so the fishermen always return the same day to their community. The fishermen offer their products within the community, often to others with freezer facilities or to restaurants. They recognize the advantage of cooperative ventures, so they formed Fishermen's Associations which help them combine forces to improve their efficiency. Due to internal conflicts, many fishing association are disorganized or has disbanded. In spite of the difficulties encountered in their work, most recommended that young people consider fishing as a profession. Many consider luck to be the main factor in catching fish, although others recognize that experience and an inclination to take risks are other important factors.

Gutiérrez-Sánchez (1985a,b) provided information concerning 292 fishermen and 15 fishing localities throughout Puerto Rico. The average fisherman was more than 40 years old with less than 10 years of schooling, had relatives who were fishermen, but were not necessarily full-time fishermen. About half had previously worked in agriculture and about 60 percent had previously worked on the U.S. mainland. They claimed to invest four or more days a week in fishing over widely varying distances and individual effort ranked as a high indicator of success.

An open-ocean aquaculture industry may be attractive to fishermen who have the infrastructure (boats, motors) and experience (knowledge of the ocean, skill with handling fish, and awareness of the harsh conditions). However, Brass et al. (1991) pointed out that Haitian fishermen work irregular schedules, often taking off time on a whim. In contrast, fish farming requires a steady work commitment. There are also differences in work styles and economic structure between fishermen and marine aquaculturists. Lack of deferred gratification orientation and related spending patterns could inhibit capture fishermen from becoming fish farmers. Long range production planning, contracts, etc., would be new to many fishermen. However, the fishermen, either through individual initiatives or through local fishermen’s associations, could be contracted by the owner of a marine aquaculture operation to manage offshore cage systems or could be trained to organize their own business.

Snapperfarm, Inc., is culturing fish in open-ocean cages near the island of Culebra, Puerto Rico. The Culebra Association of Fishermen has a memorandum of understanding with Snapperfarm, with the latter agreeing to employ 80% of locals during the day-to-day operation of the project, to employ a

representative of the Association as security chief, and to conduct educational seminars to the Culebra community four times per year. The Association agrees to support Snapperfarm's activities. The relationship may also have other benefits including offering a steady income to the fishermen and may indirectly lead to fewer episodes of poaching since the fishermen are likely to protect the cage system when it is serving as a source of income. The arrangement may stimulate the fishermen to enter into activities related to supporting the offshore industry or to start their own marine aquaculture operations. Regardless of the socioeconomic organization, another important regulatory concern is the immediate or long-term impact on the environment.

Concepts related to environmental regulation

Because cages are essentially ecologically open systems, wastes are released into the surrounding environment (Chen et al. 2000) and it is generally accepted that the major impacts result from the deposition of uneaten food and feces on the sea bottom. Waste loadings beneath the cages may produce changes in sediment chemistry and physical characteristics leading to a shift in the macrobenthic faunal diversity and biomass. Wastes from intensive aquaculture systems primarily consist of uneaten food, metabolic waste (feces and urine), chemical wastes, and feral animals (Chen et al. 2000). Release of uneaten feed with subsequent accumulation in the sediment often results in ecological issues, including interactions with the food web, perturbations on local wildlife, habitat destruction, and alteration of the biodiversity of the area. Many chemicals used in the aquaculture industry have not been evaluated in relation to their effects on the marine environment. Thus, chemicals must be evaluated for their persistence, including accumulation of residues in non-cultured organisms and the toxicity to non-target species. Antibiotics and antifouling agents (Goldburg et al. 1996) also need to be studied. Each of the environmental factors needs to be addressed by federal or local laws, or among the aquaculturists. Otherwise the industry can generate the undesirable situation where they pollute themselves along with the marine environment.

Environmental laws use several methods to establish regulations. Controls may specify the quantity of contamination that an installation discharges to the environment. The controls can be based on technology to decrease the release of contaminants on the environment. Regulations may impose standards or limits based on the maximum control of contamination that a technology can achieve or on limits to achieve a level of protection. Most controls are based on the latter type. If specific standards are not established, incentives may be offered to reduce pollution. An industry would "purchase" the right to pollute to a certain degree in a given region. Other regulations require industries to inform the public of contaminants released to the environment. Industries want to avoid negative reactions from the government and the public that could damage their reputation

or affect sales. The Emergency Planning and Community Right-to-Know Act require some industries to publish the quantities of discharged dangerous substances. Economic considerations for establishing regulations may be based on cost-benefit analyses or other cost related factors. Ethical considerations may involve obligations to mankind or the environment.

Federal and international jurisdiction

Federal agencies have recently revived their interest in aquaculture. They recognize that even restored and sustainable wild stock fisheries will not support a growing domestic and international demand for seafood (Matlock and Rhodes 1998). New aquaculture policies facilitate the permit approval process while promoting responsible industry development. They advocate identifying suitable aquaculture areas having minimum conflict among users and minimum negative environmental impacts. The policies also address technological development and financial assistance to businesses.

The current framework of federal laws protecting the environment from the potential impact of open-ocean aquaculture has been pieced together during the last few decades (Goldburg et al. 1996). This situation has led to *ad hoc* applications of federal environmental laws to the few open-ocean aquaculture projects applying for federal approvals. Goldburg et al. (1996) provides a summary of governmental regulations and policies for aquaculture. Several federal agencies have asserted authority over open-ocean aquaculture using existing federal laws, including the Army Corps of Engineers under the Rivers and Harbors Act of 1899 and the Outer Continental Shelf Lands Act; the Environmental Protection Agency following the Clean Water and the Ocean Dumping Acts; the National Marine Fisheries Service under the Magnuson-Stevens Fishery Conservation and Management Act and the Marine Mammal Protection Act; and the Department of Agriculture under the National Aquaculture Act (Goldburg et al. 1996). None of these laws were written with aquaculture in mind, thus creating uncertainty concerning which agencies have jurisdiction over open-ocean aquaculture.

The Rivers and Harbors Act of 1899 and the Outer Continental Shelf Lands Act of the Army Corps of Engineers (ACOE). Historically the ACOE has cited the Rivers and Harbors Act of 1899, as extended by the Outer Continental Shelf Lands Act, to require permits for open-ocean aquaculture facilities. Interpreting the statutory authority broadly, it requires permits for the building or placement of any structure in U.S. territorial waters that may obstruct navigation, including wharves, piers, booms, and jetties. The Outer Continental Shelf Lands Act Amendments of 1978 extended their authority into the Exclusive Economic Zone (EEZ), an offshore federal zone lying beyond state waters that generally extend from 5.6 to 370 km from shore. The EEZ has the following definition:

> Exclusive Economic Zone – that area adjacent to the United States of America which except for areas outside this zone modified to accommodate international borders, covers all waters from the jurisdictional maritime limit of each state, territory, or coastal possession up to a line where each of its points is two hundred nautical miles from the baseline from which is measured the territorial sea of the United States, pursuant to Executive Order 5030 of the United States of America.

This has given ACOE the jurisdiction to regulate installations and other devices permanently or temporarily attached to the seabed. Most open-ocean aquaculture operations would fall under this jurisdiction because the structure would likely be attached to the seabed floor.

The ACOE is authorized to consider navigational impacts and many other factors affecting the public interest. This broad interpretation has resulted in the ACOE considering a broad range of potential environmental and other impacts before issuing or denying permits to open-ocean aquaculture facilities. These include impacts on water and sediment quality; effects of the facility or structure on recreation, fish, and other wildlife; pollution; economic factors; safety; aesthetics; and navigation. The ACOE could decide whether an aquaculture project is in the public interest, after weighing environmental and other factors.

Clean Water Act and Open Ocean Dumping Act of the Environmental Protection Agency (EPA). The EPA has jurisdiction under the Clean Water Act requiring point source pollution discharge permits for aquaculture projects in the open ocean, thus providing protection for the marine environment (Goldburg et al. 1996). However, the law is weak concerning open-ocean aquaculture projects, especially concerning discharge permits under the National Pollutant Discharge Elimination System (NPDES). The Clean Water Act authorizes discharge of point source pollution in navigable waters for all states within 4.8 km of the coastline or any point source pollution other than a vessel or floating craft. Many of the laws refer to land-based aquaculture, so ambiguities exist for open-ocean aquaculture facilities. In general, EPA asserts authority for aquaculture activities in navigable waters in the open-ocean, as long as they are point sources of pollution.

The Ocean Dumping Act (also called the Marine Protection, Research & Sanctuaries Act) provides authority for EPA to regulate the dumping of material into the ocean in the outer continental shelf (Goldburg et al. 1966). The definition of dumping exempts the deposit of oyster shells, or similar materials.

Magnuson-Stevens Fishery Conservation and Management Act and the Marine Mammal Protection Act of the National Marine Fisheries Service (NMFS). In anticipation of research and industrial investment in aquaculture, the National Marine Fisheries Service (NMFS) is preparing guidelines in the form of a Code of Conduct for Responsible Aquaculture in the U.S. Exclusive Economic Zone

(EEZ). NMFS is inviting all stakeholders with an interest in responsible aquaculture to help formulate the national Code. The objective is to determine key elements and then identify guiding principles and standards. The stakeholders represent all local, regional, or national organizations, whether government or non-government, and all persons concerned with the management and conservation of offshore water resources, those engaged in processing and marketing of aquatic products, and other users of the offshore environment in relation to aquaculture. NMFS defines responsible aquaculture as the use of any aquaculture system and practice for the production of seafood or other marketable products that, from the best scientific information available, are compatible with the environment. The Code of Conduct for Responsible Aquaculture is a set of principles and standards applicable to the use of aquaculture technologies, including rearing, processing, and selling the products; research; and, their integration with other industries sharing the same resources, including the coastal zone.

The Magnuson Act grants authority to the National Marine Fisheries Service through the Secretary of Commerce to regulate fisheries and federal waters within the EEZ to conserve, restore, and protect the nation's wild fishery (Goldburg et al. 1996). Based on the act's broad definition of fishing, it applies to facilities culturing species that the NMFS currently regulates. The salmon aquaculture industry has an exemption to culture salmon in the Northeast United States.

The Marine Mammal Protection Act provides protection for marine mammals, including whales, porpoises, seals, and sea lions (Goldburg et al. 1996). This act is defined very broadly to include even the disturbance or temporary restraint of a protected marine mammal. Open-ocean aquaculture facilities causing accidental fatalities to marine mammals or that kill mammals preying on their cultured organism would be subject to this act.

National Environmental Policy Act. This act applies to any federal action that might significantly affect the quality of the human environment (Goldburg et al. 1996). It requires permitting agencies must identify potential significant environmental impacts and attempts to minimize or avoid those impacts while exploring alternatives that may be less harmful to the environment. Lead federal agencies must evaluate each environmental impact statement (EIS) before granting a permit. Smaller projects may only need to prepare an environmental assessment (EA) involving fewer analyses. Where there is a conflict to decide which of one or more agencies would be the lead federal agency, this act requires the agencies reach an agreement to select the lead agency.

National Aquaculture Act of the Department of Agriculture. In 1980, Congress passed the National Aquaculture Act to demonstrate support for the growth of the aquaculture industry, especially to support its economic development (Goldburg et al. 1996). The goal was to augment fisheries products to assist the

United States in meeting its future food needs and contribute to efficient utilization of the world's resources. The Department of Agriculture serves as the central source to encourage and coordinate the aquaculture industry, and to monitor and assess the industry. The Department of Agriculture identifies "regulatory constraints" to the growth of the industry and works with the Joint Subcommittee on Aquaculture, an interagency body, to coordinate and offer recommendations to improve the national aquaculture policy. The Secretary of Agriculture serves as the permanent chair of the Subcommittee, which includes the Secretaries of Commerce, Interior, Energy, Health and Human Services, and the EPA Administrator.

Local jurisdiction

Licenses, permits, and regulations should provide for the growth of a new open-ocean aquaculture industry while protecting the environment. Issues not addressed in current laws need to be carefully crafted to ensure sustainable aquaculture development with little negative environmental and social impact. Permits or licenses must provide the right for the marine aquaculturists to maintain the culture organisms offshore for extended periods. Otherwise, other ocean users (i.e., navigation, commercial fish harvest, recreational boating and fishing, national defense, and mineral mining) will impinge upon marine aquaculture (Curran 1997). So "marine tenure" or long-term leasing options (Corbin and Young 1997; De Alessi 1997, 1998) will become an important issue for development. Availability of investment capital will be essential for growth in the industry. Liability issues arise in cases of abandonment of culture operations, especially concerning the responsibility for removal of cages, long lines, etc.

Public concern over the use of public waters is an issue that will continue to be debated. However, historical evidence suggests that leased areas may serve to stabilize the indiscriminate use of public waters. The precedent for marine tenure exists in the Gulf of Mexico, where oil and gas leases have been granted for decades and near-shore regulations exist for oyster cultivation. Because many entities will be sharing the same resource (ocean water) with other marine aquaculture enterprises, laws should be designed to encourage sustainable management techniques. Marine aquaculturists assigned leased areas will need to cooperate among themselves.

Any legislature assigning leased areas to marine aquaculturists should ensure environmental stability. The Puerto Rican Constitution establishes efficient conservation of natural resources as a public policy, including the use of these resources for maximum development and use for the general benefits of the community. This is especially important for Puerto Rico, an island with few resources.

Because there are US Federal Laws and Puerto Rican local laws, concurrent jurisdiction may cover the same matters. A system of internal rules has been developed between the federal and local agencies. Appendix 6 lists the agencies involved in environmental regulations. Local laws cannot violate federal statutes. Local laws can be more restrictive or can regulate situations not contemplated in federal regulations. Although both federal and local agencies may have jurisdiction concerning a matter, usually the local agency will intervene with supervision from the corresponding federal agency. Control is delegated to the local agency without the federal agency losing control to intervene whenever it deems necessary or to remove the case from the local agency.

The Puerto Rico Environmental Quality Board (Junta de Calidad Ambiental). EQB works with the US Environmental Protection Agency to regulate activities that can pollute the environment, to oversee that regulations are met, and impose sanctions. These regulations may be designated by the EPA and are followed by the Board, but the Board can also establish its own regulations (López-Feliciano 1999).

The Puerto Rico Department of Natural and Environmental Resources (Departamento de Recursos Naturales y Ambientales). DNER was formed in 1972 to administer the conservation of natural resources conforming to the directives established by the Constitution, the Puerto Rico Environmental Quality Board, the Organic Law of the Department of Natural Resources and other special laws. Permits for fishing (DNER 2004) include organisms used for aquaculture in the following:

All persons dedicated full- or part-time to the capture, importation, exportation, and possession in captivity of aquatic or semi-aquatic organisms for purposes of scientific investigation, education, exhibition, aquaculture, marketing, and possession of aquarium or ornamental organisms, must solicit one or more, according to the requirements. The capture and possession of aquarium or ornamental organisms for the purpose of personal enjoyment without economic ends will not require a permit.

The Secretary can limit the number of special permits issued for any of the ends already described. These permits have a maximum term of 60 days to evaluate the application upon submission of the duly completed solicitation.

The following requirements apply for utilizing a captured species for aquaculture (DNER 2004):

- An executive summary including the proposed work, objectives, activities, methods, biology of the species, species' life cycle, number of individuals, facilities, and the destiny of the species will accompany the application. If there are amendments to the proposal, an executive summary to this affect should be submitted.

- A resume of the applicant. In the case of a student approval of his major professor is required. In the case of university students, a cooperative agreement should exist between the university institution and the Department prior to the issuance of the permit.

- Copy of a nautical chart that shows the areas where the capture is proposed.

- Approval of the Department of Agriculture for dedication to the activity.

- If the applicant is not the owner of the farm or property that will serve as access to the proposed site, a notarized document from the owner should be submitted authorizing the same.

The following requirements apply for utilizing importation of species for aquaculture (DNER 2004):

- Veterinary certification or health certificate emitted by a recognized profession in this specialty in the place of origin where it is certified that the fish are free of disease and parasites.
- Origin of the species (number of the permit of the person who captured the specimens), copy of a purchase receipt, or sworn declaration including the date of acquisition and the place of origin.
- Approval of the Department of Agriculture for dedication to the activity.

The following prices are established for each DNER permit application (DNER 2004): capture for aquaculture not for profit, $25.00; capture for aquaculture for profit, $100.00; importation for aquaculture not for profit, $25.00; importation for aquaculture for profit, $25.00; exportation of aquaculture species not profit, $25.00.

Law Title III, Article 13, General Regulations for Aquaculture in oceanic waters has been considered by the Puerto Rican Legislature, but has not been approved. If approved, the proposed lead agency for submitting proposed projects would be the Department of Natural and Environmental Resources. This law would consider bottom characteristics, hydrologic data (velocity and direction of currents, temperature, and dissolved oxygen concentration), proximity to significant habitats, and applicable data from previous studies. Appendix 6 includes a list of the federal and local agencies that have jurisdiction over environmental issues, many of which would apply to open-ocean aquaculture. Only through decisive action will commercial open-ocean aquaculture be demonstrated and eventually become successful (Corbin and Young 1997). This includes proper consideration by the legislative authorities that include in-depth analyses of the effects of the new industry on the socioeconomic structure and

the environment. All decisions should be based on supporting a sustainable industry that minimizes its impact on the environment.

Liability issues

Liability issues are discussed in general in the Appendix 6. Bond Programs are sometimes implemented to address the abandonment liability issues resulting from open-ocean leases (Kruse 1998). The program may include removal of the structure, safety concerns, and potential risk to the environment.

Esthetic issues in tourist or scenic areas

Thus far, “visual esthetic pollution” has not been an important issue in Puerto Rico. However, submergible cages will, in any case, ameliorate these issues. Blue Flag, a campaign run by an independent non-profit organization entitled the Foundation for Environmental Education, is an exclusive eco-label awarded to more than 2900 beaches and marinas in 29 countries across Europe, South Africa, and the Caribbean. Blue Flag works towards sustainable development at beaches/marinas through strict criteria dealing with water quality, environmental education and information, environmental management, and safety and other services. Criteria include water quality, environmental education and information, environmental management, safety, and services. Culebra is currently being evaluated for the Blue Flag program.

Protocol for passage of hurricanes

Introduction

Tropical cyclones, hurricanes, and typhoons are the regional names for what is essentially one and the same phenomenon. Depressions in the tropics which develop into storms are called tropical cyclones in the southwest Indian Ocean, in the Bay of Bengal and Arabian sea, in parts of the south Pacific and along the northern coasts of Australia; these storms are called typhoons in the northwest Pacific and are known as hurricanes in the Caribbean, in the southeast of the United States of America and in Central America. In the Philippines they are called baguios.

Hurricanes constitute one of the most destructive natural disasters that affect many countries around the world, causing tremendous loss of lives and property. The impact of tropical hurricanes is greatest over the coastal areas which bear the brunt of the strong surface winds, and flooding from rainfall at the time of landfall. Wind blows with lethal ferocity, and the ocean develops devastation surge, inundating vast areas of coastline.

Although difficult to quantify, the frequency and severity of extreme weather events seems to have increased over the past decade, and has some support by projected global climate models. Instability in the climate system must be considered as one possible cause of these events and, therefore, the likelihood of even more unsettled and extreme weather in the future is a legitimate concern. The aquaculture industry can be dramatically affected by natural disasters, resulting in damage and losses. Because natural disasters are unpredictable and temporary in nature, they present short-term management problems that can be devastating if proper preparation is not contemplated. Preparedness against hurricanes should consider measurement for the open-ocean and shore-based operations, as well as the activities to be conducted before and after a hurricane has passed.

In the past, coastal aquaculture operations have suffered from natural disasters such as hurricanes because many coastal processes, such as sediment transport, storm surges, waves, and coastal erosion are likely to have a larger effect than the rise in mean high water levels.

Because aquaculture is so heavily dependent on reliable natural resources like water, the possibility of major catastrophes to aquaculture during natural disasters should also be contemplated. Aquaculturists should properly prepare for natural disasters. Many of the suggestions in this section will be site specific, but should be particularly valuable for open-ocean operations located in the hurricane belt.

Open-Ocean Cages

Disastrous loss due to the passage of a hurricane is always a major risk in open-ocean aquaculture operations. The development of stronger cage systems to withstand most hurricanes should be placed as a top priority. Submerged cages currently exist which can be maneuvered, including submerging the cages to minimize the impact of strong waves and currents caused by hurricanes. As a result of independent testing at the University of New Hampshire, MIT (Massachusetts Institute of Technology) and at Ocean Spar/Net Systems, our engineers have increased the maximum current that the submergible Sea Station can safely withstand by 45%. The previous maximum current of 62 cm/second has now been raised to 90 cm/second (personal communication, Langley Gace, Ocean Spar).

However, some hurricanes generate currents with water velocities greater than the cages which can withstand currents of 90 cm/sec. For instance, the passage of Hurricane Georges in 1998 generated currents up to 150 cm/sec at a depth of 34 m in the Mona Passage, Puerto Rico. However, in Hawaii, a hurricane passed over an open-ocean aquaculture operation and did not cause damage to the cages or to the fish. Thus, hurricane damage to an aquaculture operation is still unpredictable. However, some precautionary measurements should be taken by the aquaculturist to avoid significant losses which may also impact the environment. Open-ocean aquaculture operations should be prepared for

emergencies which include protecting the fish and the cage when the site lies within the predicted path of hurricanes. The following factors should be considered before installing an open-ocean aquaculture operation should be:

Location: >2 km from the coast, located in open-ocean conditions on the continental shelf in waters deep enough for floating (gravity cages) at the surface of the water or at depths ranging from 24 to 46 m for submerged cages. (Depths shallower than 24 m are not suitable for the Ocean Spar Sea Station 3000 m3 cages; depths greater than 46 m are too deep for safe diving for divers to check the anchor connections.)

Environment: average waves < 5 m, normally 1-2 m oceanic swells or waves, Verify the type of bottom at the site; sandy oligotrophic areas at least 1 km from reefs is recommended; currents velocity enough to carry away waste (>10 cm/sec), but not so strong to influence diver safety (therefore mean current values of < 30 cm/sec).

Access to the cage site by boat: usually > 80 % of the time when climatic and ocean conditions permit access; an alternative is the possibility of locating submerged cages close enough to the shore to pump the feed to the cages in areas with open-ocean conditions with suitable depths. These areas should be scrutinized for their distribution of wastes from the cages so wastes do not affect coastal or reef environments.

Operation: the site should be located close enough to shore to be feasible to reach it once or twice daily for feeding and routine maintenance; sites located too far from the shore, say > 15 km, result in lost time and increased fuel usage. Future sites may place someone on site, similar to oil rigs. At present, the industry is not mature enough to warrant someone permanently on site. Remote operations could consider remote monitoring and automatic feeding to decrease the number of trips to the cage site.

Mooring and anchoring system: anchoring should be suitable to the site. For instance, Snapperfarm decided to utilize 1360 km Danforth anchors to secure the cages. The mooring should be inspected routinely and shackles, etc., should be changed if they are eroded or corroded. These procedures are especially important during the hurricane season. Mooring should be set for all likely wind velocity and directions. The path of historic hurricane or storm passage over an area is important. For instance a study of 19 hurricanes passing over the Culebra Snapperfarm site during the last 100 years indicated most of the hurricanes passed in a southeast to northwest direction. Snapperfarm decided to place an extra anchor mooring on the southeast side of each cage.
Open-ocean operations should consider making contingency plans involving activities to protect the entire operation before and after the passage of a hurricane.

Preparation related to storms and hurricanes

- Make a detailed hurricane contingency plan
- Send to qualified authorities for review, including the cage dealer, the US Coast Guard, and the local governmental lead-permitting agency. Review and revise the plan, annually, especially to determine if new technology has been developed related to the plan.
- Install a beacon on each cage in case the cages are broken loose from their mooring. The US Coast Guard and US Corps of Engineers are especially concerned with navigational hazards; if a cage is breaks loose, inform them immediately.
- If submerged cages will be raised and/or moved to another site, inform the US Coast Guard and the US Corps of Engineers. Possible scenarios for re-locating cages should be reviewed by these agencies before they are moved.
- Make sure your contingency plans include a time-line of activities should a storm or hurricane enter the region and plan for sufficient time built to complete the activities safely before the storm hits.
- Post the contingency plan for your employees.
- Prepare alternative plans.
- Storm insurance should include disaster relief. Farmers should sign-up with government and/or private insurance companies. Both the U.S. Department of Agriculture (USDA) Farm Service Agency and private insurers have risk insurance for aquaculture industries affected by natural disasters (http://disaster.fsa.usda.gov/fsa.asp).
- Monitor continuously official alert systems and hurricane forecast for the area (maximum wind speeds, surge, possible trajectory and direction of movement, time predictions for landfall, location of the eye of the storm, width of the storm, storm speed, predicted height of tides.
- Have a plan for listen to daily long-range tropical weather forecasts.
- Plan to finish work at least 6 hours in advance of hazardous conditions.
- Have a detailed mooring chart indicating size, anchor location, chain size, and chain length.
- Maintain communication equipment in optimum condition during hurricane season
- If the cage site is in the path of powerful hurricane, the cages could be moved temporarily to deeper water areas to reduce the effect of winds, currents, and wave action.
- If the cultured organisms are moved to a safer place, ensure that the location fulfills water quality requirements to maintain them in good condition.
- Ensure that the selected site is out of the forecasted trajectory (or that the cages can be safely lowered and later retrieved from deeper water).
- Precautionary measures include cleaning biofouling from the surface of the cages (biweekly during the hurricane season which lasts about 5

months) to reduce drag and allow unrestricted current flow through the cages
- The aquaculture operation should consider installing beacons on each cage to locate them in case they are moved or lost
- Evaluate oceanographic data based on past hurricane events. For instance, establishing if passed hurricane has generated powerful underwater currents in the area.
- If possible, cultured animals could be harvested before the storm's arrival.
- To avoid animal loss, ensure the cage's net is intact and has not deteriorated from aging or from maintenance procedures such as cleaning
- Remove equipment which is easily transportable and any non-critical equipment to secure areas
- Inspect all exposed equipment on a regular basis, especially during hurricane season
- If possible, add additional mooring systems
- Train personnel to coordinate and carry out tasks before and after the hurricane
- The contingency plan should consider mitigating procedures such as disposing of dead fish or rehabilitating affected areas.
- Include financial considerations in the contingency plan
- Identify weak areas that are under stress (status of spar and steel rim, mooring system, nets, buoyancy valves, ballast system, and feeding system)
- Maintain a fuel reserve for all boats and vehicles
- Fill fuel tanks for all vehicles previous to the storm's arrival
- All emergency backup equipment should have a regular maintenance schedule and tested regularly, including maintaining the equipment with fuel and lubrication.
- Post appropriate information (locale, telephone numbers, etc.) for local emergency relief organizations
- Solicit information from the cage dealer concerning specific advice for handling the cage during emergency procedures, including safety information
- If cages are moved to secure areas, practice the procedure before an emergency arises.
- Determine main and alternate routes to safety
- Ensure equipment and transportation to immediately check cages after the emergency

<u>Things to do during the passage of hurricane:</u>

- Keep calm
- Keep informed of the hurricane development and trajectory
- Keep informed of the areas affected by the hurricane

- Stay in a safe place until the authorities indicate it is safe to travel or to launch a boat
- Keep constant contact with key farm personnel, especially those who will check the status of the cages after the emergency
- Follow the forecast and reports for rainfall, its time of onset, duration, and the amount expected.
- Be prepared to function with no electricity, gas, or tap water

Things to do after a storm or hurricane has left the area:

- Keep calm
- Continue to monitor the meteorological conditions
- Follow protocols to contact key personnel
- Inspect shore-based facilities and cages once the respective authorities indicate it is safe to travel.
- Repair any damage to the cages if they are affected (netting, anchors, mooring ropes and chains, feeding system, buoyancy, etc.) as well damage to boats and land-based infrastructure.
- Replace lost equipment or tools.
- Determine fish health, apply prophylactic treatment if needed, and remove dead animals from the cages as soon as possible. Dead animals may represent a serious and hazardous situation for human health and the environment.
- The aquaculture company should include contingency plans to handle massive fish mortalities. The US Federal Emergency Management Agency (FEMA) and the Department of Health can offer specific instructions and assistance. Tuna Canneries handle large amounts of fish carcasses, so they may offer suggestions for carcass disposal.
- Continue monitoring animal health in each cage until the fish appear normal and are feeding.

Shore-based facilities

The potential damage to shore-based facilities is serious. The destructive power of a tropical storm is characterized by strong winds, flooding and storm surges. In some situations, land facilities may suffer more than open-ocean submerged cages. A disaster prevention and preparedness system must include contingency plans to for shore-based facilities.

Protection against strong winds

Winds of a tropical hurricane are often strong and gusty and may persist for many hours, even for a day or two, and may damage the physical infrastructure, including flooding, electrical failures, and mortality of land-based animals such as brood-stock.

Contingency plans for shore-based facilities include:

- Strengthening shore-based infrastructure to resist strong winds, including using cables to tie down the roof or other structures and covering windows with shutters. The structure itself should be anchored firmly to its foundation. Structural defects in a building may eventually be revealed by gale force winds.
- Constructing facilities capable of withstanding wind speeds of at least 120 km per hour.
- Windows should be opened on the lee side of hurricane force winds to permit the equalization of air pressures; suction or pull of the wind is often greater than its direct force.

Protection against floods

In flood prone areas, protection against flood includes preventive measures in the land-based facilities, construction of dikes, embankments, temporary reservoirs, etc. Following building codes is essential to strengthen facilities. Preparation should include the following:

- Proper anchorage to prevent buildings floating away from the foundations.
- Insure building structures and another infrastructure susceptible to flooding.
- Locate in areas with sufficient elevation above flood prone areas.
- Refer to US Corps of Engineers flood charts (25, 50, 100-year flood zone, etc.) to determine the likelihood of significant flood damage based on meteorological data and past occurrences.
- Elimination of use of materials which deteriorate when exposed to water.
- Prohibition of equipment installation (e.g. electrical equipment, chemical materials, boilers) at levels exposed to flooding conditions.
- Construction of land-based facilities with flood-proofing designs, considering factors such as speed of water flow, rate of rise and fall of flood water, flood depth and duration, debris load, and wave action.
- Prepare a place above the flood plain to store perishable supplies such as feed, business records, customer receipts, etc.
- Collect data and make profiles of tidal cycles, and current, wind, and air speeds for the shore-based facility location to determine if your site is different from the norm.
- Construct drain channel in areas with high potential of flood

Protection against hurricane surges

Hurricane surges can reach several meters above mean sea level. This often translates to significant distances of surge inland due to run-up, resulting in large inundated areas. The main meteorological factors governing a storm surge are the wind field in the tropical hurricane and the sea-level pressure at the center which in the more vigorous tropical hurricane may be 100 mb lower than the

pressure in the area surrounding the storm. In general, most severe storm surges are associated with a large pressure differences inside and outside the storm and with an extensive area of very strong winds which also affect the swell and wave height. Other factors on which hydrographic advice and data are required are related to tidal factors influenced by coastal topography. For instance, funnel shaped embayments such as the Bay of Fundy generate extreme tidal surges up to 10 m. High storm surges result from a combination of strong winds, high spring tides, and a gently sloping ocean floor. Bays and other inlets along the coast are particularly vulnerable to storm surges. Some measurements that can be taken for protection of shore-based facilities of an open-ocean aquaculture operation against the hurricane surge are:

- Confining building to higher elevations or by building on concrete pillars embedded in the ground so that the "ground floor" of the structure is above the highest water levels to be expected.
- Coastal embankments susceptible to storm surges should be designed specifically to withstand the expected storm-surge water heights and forces, the combined action of wind and waves, and overtopping from the storm surge water.

From this examination of the onset of hurricanes and its potential impact on the open-ocean aquaculture industry, contingency plans should include proper actions before, during, and after the disaster. Even though modern submergible cages can be raised or lowered, companies need to practice this procedure to develop protocols that are efficient and safe for possibly moving cages from the path of a storm. However, reality will probably dictate that open-ocean submerged cage operations will be less affected than shore-based operations during a hurricane. Thus far, cages have survived unscathed after the passage of hurricanes.

Environmental sampling protocols and costs to the industry

Readers may assume that taking open-ocean environmental samples would be routine and inexpensive. This topic has generated discussion among the public and private sector. To date, no environmental sampling protocol has been developed. Discussions relating to future standardization of sampling are included in Appendix 7. The paper is entitled "Standardized environmental monitoring of open-ocean cage sites: basic considerations" and has been submitted for publication in World Aquaculture. The authors plan to submit other articles related to this topic which includes information from Governmental committees that are also discussing these issues. Once standardized protocols are in place for each region, cost estimates can be made for the industry. Government agencies should discuss each sampling protocol fully because over-sampling could be expensive for the industry while under-sampling could lead to environmental perturbation.

Because open-ocean cage aquaculture benefits from large volumes of water and strong water currents passing through the site, the industry differs significantly

from coastal aquaculture where nutrients are more likely to accumulate and cause eutrophication. Wastes from most open-ocean sites are distributed over large areas, making it difficult to determine the impact. So far, water and sediment quality monitoring for nutrients in open-ocean conditions, including for nitrogen and phosphorus, have indicated little impact. However, even small increases in nutrients such as phosphorus and nitrogen can stimulate primary productivity. Accumulation of organic matter in the sediment is usually not severe several hundred meters distance from the cages; thus, the influence will probably be minimal. Accumulation of organic matter and changes in the flora and fauna are important indicators of environmental status. Dredge samples may be suitable in soft sediment, but may be problematic in areas with sand and/or rubble where core samplers could be used. Benthic samples should be monitored under and around the farm site and at a “control” station some distance from the site, but not located immediately up- or down-current of the prevalent conditions at the site.

Best management practices recommended as a result of this project

As part of the goals for this project, best management practices for tropical open-ocean submerged-cage aquaculture have been developed. These should be updated and available to the general public.

Preparation related to storms and hurricanes

- Make a detailed hurricane contingency plan
- Send to qualified authorities for review, including the cage dealer, the US Coast Guard, and the local governmental lead-permitting agency. Review and revise the plan, annually, especially to determine if new technology has been developed related to the plan.
- Install a beacon on each cage in case the cages are broken loose from their mooring. The US Coast Guard and US Corps of Engineers are especially concerned with navigational hazards; if a cage is breaks loose, inform them immediately.
- If submerged cages will be raised and/or moved to another site, inform the US Coast Guard and the US Corps of Engineers. Possible scenarios for re-locating cages should be reviewed by these agencies before they are moved.
- Make sure your contingency plans include a time-line of activities in case a storm or hurricane enters the region and plan for sufficient time built to complete the activities safely before the storm hits.
- Post the contingency plan for your employees.
- Prepare alternative plans.
- Storm insurance should include disaster relief. Farmers should sign-up with government and/or private insurance companies. Both the U.S. Department of Agriculture (USDA) Farm Service Agency and private insurers have risk insurance for aquaculture industries affected by natural disasters (http://disaster.fsa.usda.gov/fsa.asp).

- Monitor continuously official alert systems and hurricane forecast for the area (maximum wind speeds, surge, possible trajectory and direction of movement, time predictions for landfall, location of the eye of the storm, width of the storm, storm speed, predicted height of tides.
- Have a plan for listen to daily long-range tropical weather forecasts.
- Plan to finish work at least 6 hours in advance of hazardous conditions.
- Have a detailed mooring chart indicating size, anchor location, chain size, and chain length.
- Maintain communication equipment in optimum condition during hurricane season
- If the cage site is in the path of powerful hurricane, the cages could be moved temporarily to deeper water areas to reduce the effect of winds, currents, and wave action.
- If the cultured organisms are moved to a safer place, ensure that the location fulfills water quality requirements to maintain them in good condition.
- Ensure that the selected site is out of the forecasted trajectory (or that the cages can be safely lowered and later retrieved from deeper water).
- Precautionary measures include cleaning biofouling from the surface of the cages (biweekly during the hurricane season which lasts about 5 months) to reduce drag and allow unrestricted current flow through the cages
- Evaluate oceanographic data based on past hurricane events. For instance, establishing if passed hurricane has generated powerful underwater currents in the area.
- If possible, cultured animals could be harvested before the storm's arrival.
- To avoid animal loss, ensure the cage's net is intact and has not deteriorated from aging or from maintenance procedures such as cleaning
- Remove equipment which is easily transportable and any non-critical equipment to secure areas
- Inspect all exposed equipment on a regular basis, especially during hurricane season
- If possible, add additional mooring systems
- Train personnel to coordinate and carry out tasks before and after the hurricane
- The contingency plan should consider mitigating procedures such as disposing of dead fish or rehabilitating affected areas.
- Identify weak areas that are under stress (status of spar and steel rim, mooring system, nets, buoyancy valves, ballast system, and feeding system)
- Maintain a fuel reserve for all boats and vehicles
- Fill fuel tanks for all vehicles previous to the storm's arrival
- All emergency backup equipment should have a regular maintenance schedule and tested regularly, including maintaining the equipment with fuel and lubrication.

- Post appropriate information (locale, telephone numbers, etc.) for local emergency relief organizations
- Solicit information from the cage dealer concerning specific advice for handling the cage during emergency procedures, including safety information
- Determine main and alternate routes to safety
- Ensure equipment and transportation to immediately check cages after the emergency
- Repair any damage to the cages if they are affected (netting, anchors, mooring ropes and chains, feeding system, buoyancy, etc.) as well damage to boats and land-based infrastructure.
- Determine fish health, apply prophylactic treatment if needed, and remove dead animals from the cages as soon as possible. Dead animals may represent a serious and hazardous situation for human health and the environment.
- The aquaculture company should include contingency plans to handle massive fish mortalities. The US Federal Emergency Management Agency (FEMA) and the Department of Health can offer specific instructions and assistance. Tuna Canneries handle large amounts of fish carcasses, so they may offer suggestions for carcass disposal.
- Continue monitoring animal health in each cage until the fish appear normal and are feeding.

Feeds and feeding

- Feeds should be selected to provide sustainable culture conditions, including evaluating environmental concerns. For instance, low fishmeal diets with perhaps soymeal or cottonseed meal should replace as much fishmeal as possible. Apparently, some fishmeal is needed for palatability; fish grow faster if the consume more feed.
- Feeds must include all the essential ingredients for rapid growth, be water stable to prevent leaching of feed nutrients, and be highly digestible.
- Instead of seeking highly technical solutions to solve environmental problems because of increased feeding rates and wastes released, the aquaculturists have to provide an excellent quality feed with appropriate feeding rates and feeding strategies.
- Avoid overfeeding. Make visual observation of feed wastes beneath the cages after adjusting feeding tables
- Monitor fish behavior during feeding to avoid overfeeding
- Minimize small feed particles (fines)
- Adjust feed-pellet size to fish size
- If possible use automatic feeders to feed the cages, especially during bad weather conditions
- Use appropriate stocking rates for the species cultured and to the size of the cage

- Practice remedial measures such as allowing the bottom to lie fallow (by moving the cages). Have alternative site pre-selected to expedite moving the cages in case of detection of organic enrichment in the sediments

Water and sediment quality

- Focus on the more relevant water and sediment quality variables
- Because water quality does not seem to be severely affected, sediment should be the focus for most monitoring, especially for those variables which serves as indicators of organic enrichment (organic matter, organic carbon, total nitrogen, hydrogen sulfide, macroinvertebrate community) or ecosystem degradation (impact on the surrounding flora and fauna)
- Relate water and sediments and quality variables with the currents patterns of the area
- From a practical aquaculture perspective, nutrient discharge would likely be more concentrated a few hours following a feeding period, especially during slack tide. Therefore, water sampling procedures should focus on changes or accumulation of any pollutants over time, not daily changes. Daily changes could be useful for modeling purposes where data would be correlated to current patterns to better understand nutrient dynamics at the site.
- Benthic samples should be monitored under and around the farm site and at a “control” station some distance from the site, but not located immediately up- or down-current of the prevalent conditions at the site.
- Consider the use of standard sediments traps to monitor accumulation of pollutants
- Standardized monitoring could begin at the same hour to facilitate comparisons with other variables.
- One goal should be to assess the nearest sensitive areas or potential points influenced by the operation.

Cleaning cages

- Cages should be cleaned regularly to minimize drag during hurricane season and provide adequate interchange of water through the cages.
- Although debate continues concerning organic matter released during the cleaning process, companies should at least screen the biofouling material for its potential as a natural product (pharmaceutical, industrial use such as agar). The debate stems from increased organic matter to the environment which is composed of marine organisms that are subject to being broken off from any substrate during energetic conditions versus the increased costs of collecting material (algae, bryozoans, crustaceans, tunicates, etc.) from the cage netting.

Cages influencing the environment

- Siting and site selection criteria, which precede environmental monitoring should be deeply emphasized. Before permits are issued, governments should establish zones not suitable for open-ocean aquaculture.
- Cage must be oriented to provide optimum flow parallel with the predominate current transport.
- Avoid sites near scenic viewpoints, fishing grounds, areas with significant navigation, and sensitive environmental areas (such as coral reefs and seagrass beds)
- Select areas with moderate water currents to disperse wastes
- Cages should be cleaned regularly to minimize drag during hurricane season and provide adequate interchange of water through the cages.
- Miscellaneous monitoring could entail effects of cleaning cages, adding antibiotics, treating fish for parasites, or harvesting. While these latter items may be important environmentally, they should be treated on a case-by-case basis.
- Increase depth beneath caged fish (to allow waste dispersion over larger bottom areas)
- Chemical treatments to the fish (for diseases or parasites) should be performed by removing the cultured fish or placing a bag under the cultured fish and replacing the treatment water. Treatment water should be disposed of in a proper facility. To date, these latter procedures are not developed within the industry; thus, medicated feeds are frequently utilized. Future consideration should include stocking “cleaner” fish compatible with the culture species.

Conclusions

Open-ocean aquaculture has been hindered because of the energetic oceanic environment, lack of suitable equipment, fingerling fish, and unclear policies and regulations concerning this nascent industry. However, based on cutting-edge technology developed in the US, a New York based company, Snapperfarm, Inc. has successfully grown two fish species in cages located 3 km southwest of Culebra, Puerto Rico. Snapperfarm worked for four years to write a business plan, obtain experimental permits from the Puerto Rico Department of Natural and Environmental Resources, assemble two submerged Ocean Spar Sea Station™ cages, and deploy them in 90-feet of water at the Culebra site. Reviews of monitoring strategies and methods revealed the need for standardized approaches, which are flexible enough to cover the wide range of environments in which fish farms are located (Cochrane et al 1994; Codling et al. 1995; and Alston et al. 2004). Snapperfarm’s success has sparked the initiation of two other farms planning to install 16 more cages within two years. Growth of R. canadum (cobia) to 6 kg in one year has been the primary success factor driving this new industry with little environmental impact.

This project is the first Caribbean-based, large-scale environmental evaluation of the effects of a submerged open-ocean submerged cage operation. Because the possibilities were so numerous to determine the environmental effects of the operation, we used a “shotgun” approach to select the most important water and sediment quality variables and their effects on the local environment. Because nitrogen and phosphorus are important in eutrophication, they were selected as the primary nutrients monitored in the water and sediment column. Quantities of nitrogen and phosphorus provided some basis for predicting environmental loading from allochthonous nutrients (from outside the system). The study indicated of little net accumulation of contaminants (nitrogen or phosphorus) near the cage operation and no detectable release of wastes to the downstream environment was encountered. Even though macroinvertebrates are excellent indicators of environmental perturbation, the only effects on the macroinvertebrate population were directly beneath the cages. It is important to note that the cages shaded the sandy bottom, possibly also having an effect on benthic macroinvertebrate abundance.

Light reaches the bottom at the cage site even though much light has been filtered from the water. Any algae growing at these depths may be affected from shading beneath the cages. Thus, the habitat for algae and, consequently, benthic macroinvertebrates may be significantly different beneath the cages compared to the “un-shaded” benthic sediments. Macroinvertebrate populations are dynamic; populations can vary drastically within a few meters. Even though relatively uniform substrates were found at the control site (grain size, bottom depth, light, etc.), the uniformity does not mean populations are necessarily homogeneous. By utilizing a variety of parameters such as species diversity, evenness, etc., the populations can be evaluated utilizing different criteria. Because the shading effect and increase of nutrients contribute to a “different” environment compared areas distant from underneath the cages, more work needs to be done to determine the relative effects of shading and of increased nutrients deposited beneath the cages. An additional factor is the presence of wild fish congregating beneath the cages; some may perturb the benthic area beneath the cages (through feeding activities, etc.).

On a positive note, the study also determined that the cages served as fish aggregation devices (FADs) and aggregate natural fish biomass near the cages. Along with continued monitoring of nutrient loading in future studies, the positive or negative effects of the submerged cages serving as FADs should be evaluated for their contribution to otherwise depauperate open-water sandy-bottomed habitats. Costa-Pierce and Bridger (2002) indicate cage aquaculture facilities provide habitats and nursery areas for juvenile and adult wild fish, and numerous invertebrates and algal species essential to sustaining healthy marine ecosystems and wild fish stocks. Some aquaculture operations create, enhance, and maintain productive marine ecosystems, habitats, and water quality in a long-term, sustainable manner.

The most notable findings in this study were:

- No overall statistical differences for ammonia-N, nitrite-N, nitrate-N, or phosphate concentrations in the water column.

- No statistical differences for organic matter or organic nitrogen in the sediments when comparing sampling stations near the cages versus the control site. This indicates that sampling stations near the cages were similar to background levels.

- Temporal seasonal differences for organic matter or organic nitrogen variations were encountered uniformly at the cage site and control site. This implies that, for the variables monitored, the cages culture did not exceed the capacity of the system to cope with induced perturbation.

- No evidence of anaerobic sediments beneath the cages.

- No difference in macroinvertebrate abundance 40 m from the cage site when compared to the control site.

- Significantly higher abundance of benthic macroinvertebrates at the control compared to the bottom center of the cages. This indicates effects were localized beneath the cages. It is important to note that the cages themselves shade the ocean bottom, possibly also having an effect on benthic macroinvertebrate abundance.

- No temporal differences in benthic macroinvertebrate Shannon species diversity indices or species evenness indices.

- High diversity and abundance of fish at the cage site with six orders, 23 families and 40 species. These data indicate the cage site acted as a FAD structure and could have ecological importance since the cages could act as nursery structures for some species, having a positive effect on the redistribution of juveniles and adults and contribution to local fisheries. More research is needed to determine the latter supposition.

- Thirty-one species have commercial importance, representing 43% of total numbers of fish censused.

- Dissolved oxygen, turbidity, water temperature and chlorophyll-a concentration were suitable for aquaculture and not detrimental to the environment.

- Water temperature varied only by 3-4 C throughout the year.

- Percent coverage of biofouling for each cage was statistically similar with mean coverage above 50%

- No differences were encountered for biofouling percentage coverage of downstream versus upstream samples or for un-shaded samples versus shaded samples

The flow regime observed during this brief monitoring event was characterized by

- Predominantly along-isobath flow along the axis 300° ↔ 120° true.

- Strong semidiurnal (two cycles per day), and weaker diurnal (one cycle per day), tidal components with maximum amplitudes of 20-30 cm/sec.

- Diurnal inequality of the tidal currents much weaker that that of the surface tide.

- Mean, or low frequency, northwestward flow with a record mean towards 300° true at 8-10 cm/sec.

- Northwestward flow (towards 300°-320° true) occurs during the flooding tide (as the sea surface elevation is increasing) whereas the ebbing tide coincides with southeastward flow (120°-140° true).

- Peak flow lags the tidal peak by about three hours (approximately a quarter of a semidiurnal cycle).

- Tidal ellipses elongated along bottom contours to the point of nearly a straight line so that changes in direction occur very quickly, there is little transport towards land and the velocity vectors are observed to swing back and forth across the open-ocean hemisphere.

- Quasi-periodic 5-day to weekly components in the low-frequency signal.

Implementation of sustainable open-ocean cage culture production will provide opportunities to increase economic development in Puerto Rico and the Caribbean. Coastal communities relying on traditional fishery resources will have additional opportunities to culture fisheries products or to provide services to the open-ocean cage industry. Provision of a sustainable open-ocean industry will minimize the long-term impact on the environment and maximize the potential economic impact. This work provides important information to evaluate, control, and maximize the benefits related to the open-ocean cage culture industry. The information helps to identify positive and negative effects of open-ocean cage culture in terms of environmentally related aspects. Fishermen may be attracted to investing in open-ocean enterprises or may be interested in combining fishing

with aquaculture, especially since the fishermen share the same resources and have nautical gear and palpable skills.

Even though the results of this study indicate little environmental effect, the fact that feed is added to an open-ocean condition implies potential for eutrophication, especially as the industry expands. Because of the tremendous amounts of water flowing through the cages, monitoring nutrient additions to the water column will probably be fruitless; thus, focus should shift to effects on the biota in the benthos under and near the cages. The attraction of reef and pelagic fish to a cage site potentially increases the wild-catch fishery resource. Appendix 8 has publications and presentations related to offshore project.

Recommendations for the industry

Sustainable aquaculture implies a minimum impact on the environment. Because any industry, but particularly the open-aquaculture industry, is complex, the most important issues need to be the focus of the culture system. Aquaculturists face a multitude of issues, including public perception of the project, socio-economic and environmental factors, protecting his investment from hurricanes and concerns to compete on a world market. Thus, it may be easy to loose sight of the main issues. Hence, our team suggests the following topics in addition to the Best Management Practices for the industry, as guides for planning and management (as modified from FAO 2001):

- Focus in sustainable development, using the precautionary approach where the polluter is not allowed to continue his operation
- Integrate the operation with other sector activities or plans, perhaps with ecosystem based management plans
- Involve a wide-range of the public; and include frequent educational and informative opportunities
- Make a thorough assessment of the costs and benefits of aquaculture in a specific area and comparative assessment of costs and benefits of aquaculture relative to other resource uses. Include environmental costs such as utilizing fishmeal in feeds.
- Assess the environmental capacity of any operation to be installed
- Use governmental incentives rather than regulation where possible
- Emphasize controlling the effects of the operation, instead of the scale of activity
- Make frequent evaluations of the operation and be prepared to adapt or modify the management to ensure sustainable aquaculture
- Foster effective and responsible institutions and representative organizations which promote sustainable aquaculture

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Appendix 1

Oceanographic Considerations For Offshore Aquaculture on the Puerto Rico-US Virgin Islands Platform

The following is an excerpt from:

Capella, J., D.E. Alston, A. Cabarcas-Núñez, H. Quintero-Fonseca, R. Cortés-Maldonado. 2003. Oceanographic considerations for offshore aquaculture on the Puerto Rico - U.S. Virgin Islands Platform. Pages 247-262 in C. Bridger, editor. Ocean Open Aquaculture IV June 17-20, 2001, St. Andrews, New Brunswick, Canada. Mississippi-Alabama Sea Grant Consortium, Ocean Springs, Mississippi, USA.

Abstract

Caribbean waters are stratified with currents moving in different directions. The structure and composition of the Caribbean Surface Water exhibit a well-defined seasonal pattern. In the northeastern Caribbean Sea, the depth of the thermocline reaches a maximum of 100 m in the spring (January-March) and a minimum of 25 m in the fall (September-October). Density, temperature, and salinity follow the same seasonal patterns with temperatures and salinities ranging from 26 to 30°C and from 34 to 36.3, respectively. The large range in offshore surface salinities is due to the northwards advection-mixing of South American riverine outflow in the eastern Caribbean Sea, especially from the Orinoco River. The seasonal surface salinity range is therefore narrower northwards into the North Atlantic. The meridional distribution of the zonal wind stress generates a circulation cell in the Caribbean Sea where surface waters (enriched by upwelling and by the Orinoco loading) are advected northwards into the region, especially during the fall season. Eastward geostrophic flow is limited to near surface waters, while deeper flow is generally westward. The northeastern Caribbean receives part of the wind-stress of the large-scale, climatological, southwestward transport. Therefore, the circulation pattern of the wind-driven surface waters around the Puerto Rico-United States Virgin Islands-British Virgin Islands (PR-USVI-BVI) shelf is a west-southwest direction. The convergence of these two distinct, Caribbean and North Atlantic, dynamical regimes defines the region as a boundary zone. Superimposed on the mean circulation, tidal currents are the dominant component of the offshore currents. Due to the highly stratified nature of Caribbean waters current speeds drop quickly with depth below the mixed layer. Tidal sea surface elevations around Puerto Rico are about 30-40 cm above and below mean low water. Thus, the stable warm temperatures and salinities should be ideal for offshore aquaculture enterprises. However, the region is subject to hurricanes. During the passage of Hurricane Georges in 1998, currents reached nearly 150 cm/sec at a depth of 34 m.

Introduction

As an island, Puerto Rico should benefit from its ideal location of being surrounded by the oceanic waters of the Atlantic Ocean and the Caribbean Sea. However, from a production standpoint, Puerto Rico produces less than 5% of its seafood. Because of the island is small and congested with 3.9 million inhabitants, the terrestrial environment has been heavily impacted. Large tracts of land are difficult to obtain for marine aquaculture purposes, leaving room only for intensive marine aquaculture operations. Terrestrial marine aquaculture operations have to be managed carefully to minimize the impact on the environment.

Fisheries operations in Puerto Rico have exceeded maximum sustainable yield due to ocean pollution, over-fishing, and destruction of suitable habitat for native species. The 1979 landings in Puerto Rico were 3,278 MT of fish and shellfish, respectively (Matos-Caraballo 1998). Landings in the 1980s decreased consistently. Reported landings from 1994 -1997 ranged from 1,227 to 1,727 MT of fish and shellfish, respectively. Several fish and shellfish species that fishermen formerly discarded are now easily sold (Matos-Caraballo 1998), probably due to the decrease of traditional species. Over fishing is also revealed from catch per unit of effort data (CPUE). For 1979-82, the CPUE per trip was 55.8 kg; during 1997, it was 32.7 kg. A successful offshore aquaculture industry could alleviate some of the seafood demand from the wild fisheries.

Puerto Rico has an excellent climate for offshore aquaculture with year-round optimum conditions for culturing tropical aquatic species. The high metabolic rate of the cultured organisms will lead to increased growth rates thus reducing the time for the animals to reach commercial size. This paper will describe the oceanographic and meteorological conditions on the Puerto Rico-United States Virgin Islands-British Virgin Islands (PR-USVI-BVI) shelf.

Location

Puerto Rico, the easternmost island of the Greater Antilles, is located in the northeastern Caribbean Sea and is part of a volcanic island platform that includes Puerto Rico and the Virgin Islands (Fig. 74). Puerto Rico and the Virgin Islands are part of the Caribbean Island Arc that was born along the leading edge of the Caribbean Plate from the subduction of the North American Plate. These islands are located on top of a ridge that overlooks great depths in the North Atlantic to the north and in the Caribbean Sea to the south.

The Island is bordered by approximately 501 km of coastline. The north coast, which is wider and receives most of the river drainage, is typical limestone-hill karst country. Along most of the north coast, the ocean's bottom slopes steadily northward into the Puerto Rico Trench, with depths of over 10,000 m found 100

km from shore; an insular shelf is basically non-existent along this stretch of coastline. An irregular insular shelf, three to eight km wide, borders the south and west-southwest coastlines and drops abruptly to deep water offshore. Land surface topography, the fresh-water budget, wave and current energies, sediment types and sediment influx, and bottom features control large variations in the character of the marine coastal habitats around the Island. The north and northwest insular shelf environments are a different marine ecosystem from the west, south and east shelves (Morelock et al. 2000).

Regional Currents and Circulation

Caribbean waters are well stratified with depth which means that at different depths the fluid is moving in different directions, according to the sources and sinks for each water mass. In the ocean around of Puerto Rico (and this varies within the Caribbean) we find the Caribbean Surface Water, the local mixed-layer, whose lower boundary is known as the seasonal thermocline (technically it is the pycnocline but these two boundaries approximately coincide in depth); Subtropic Underwater to about 180 m; Sargasso Sea Water to about 325 m; Tropical Atlantic Central Water to just over 700 m; Antarctic Intermediate Water to 900 m; and North Atlantic Deep Water reaching the bottom. The island passages do not allow any Atlantic bottom water to enter the Caribbean.

The structure and composition of the Caribbean Surface Water, that in which most human activity occurs, exhibit a well-defined seasonal pattern. In the northeastern Caribbean Sea the depth of the thermocline reaches a maximum of close to 100 m in the spring (January-March) and a minimum in the order of 25 m in the fall (September-October). Density, temperature, and salinity follow the same seasonal pattern with temperatures ranging from 26 to 30°C and salinities from 36.3 to 34. The range in offshore surface salinities is due to the northwards advection-mixing of South American riverine outflow in the eastern Caribbean Sea, especially from the Orinoco River; the seasonal surface salinity range is therefore narrower northwards into the North Atlantic. While the Orinoco effect creates a seasonal north-south surface salinity gradient in the eastern Caribbean, the Amazon River outflow becomes entrained in pools or eddies that, after a circuitous trajectory through the Tropical Atlantic, arrive at the Windward Islands as pools of green (high chlorophyll content, low salinity) water and enter the Caribbean from the east.

There are no named current systems in our vicinity that is not characterized by persistent extreme surface currents. The main axis of the Caribbean Current flows south of Puerto Rico, from the southeastern Antillean passages, through roughly the north-south center of the Caribbean Basin, west of Jamaica, and out through the Yucatan Channel. Maps of the mean seasonal surface circulation in the Caribbean Sea are found in Wust's (1967) atlas, in the Pilot Charts, and in the body of oceanographic literature for the region (a good review up to the early eighties can be found in Kinder, et al. 1985).

In the North Atlantic, the curl of the wind stress induces a large-scale Sverdrup transport towards the south that is then compensated by the intense northwards flowing Gulf Stream along the east coast of the U.S. The northeastern Caribbean receives part of this large-scale, climatological, southwestward transport; therefore, the mean circulation pattern of the wind-driven surface waters around the PR-USVI-BVI shelf is in a west-southwest direction, joining the general western flow of the Caribbean towards Yucatan Strait. The convergence of these two distinct, Caribbean and North Atlantic, dynamical regimes defines our region as a boundary zone, with the northern edge of the green Orinoco plume sometimes referred by local researchers as the Caribbean Front.

Coastal Currents

Coastal current around PR-USVI are mainly tidally and wind driven. The narrow and shallow shelf (Fig. 74) is in most places directly exposed to the open ocean, especially along the north coast. With the exception of bays and lagoons, coastal flows are steered by the coastline-shelf topography and are therefore east-west along the north and south coasts. Typical peak tidal speeds of 10-20 cm/sec have been observed at numerous sites in the region; the mean vector velocity is usually less than 5 cm/sec. The typical pattern is that of oscillatory currents parallel to the coastline. In spite of the diurnal-semidiurnal regimes around Puerto Rico (see Tides), the tidal currents around the island are mainly semidiurnal (two cycles per day). The local wind stress, dominated by the easterly Trade Winds, pushes surface waters towards the west, the same direction as the large-scale offshore mean flow. However, during times of weak easterly winds, near bottom waters are commonly observed to flow towards the west. This behavior is known to occur along the north and south coasts of PR and has been attributed to 1) a reverse pressure gradient resulting from the action of the mean flow on the abrupt island topography, and/or 2) a mean eastward external geostrophic transport.

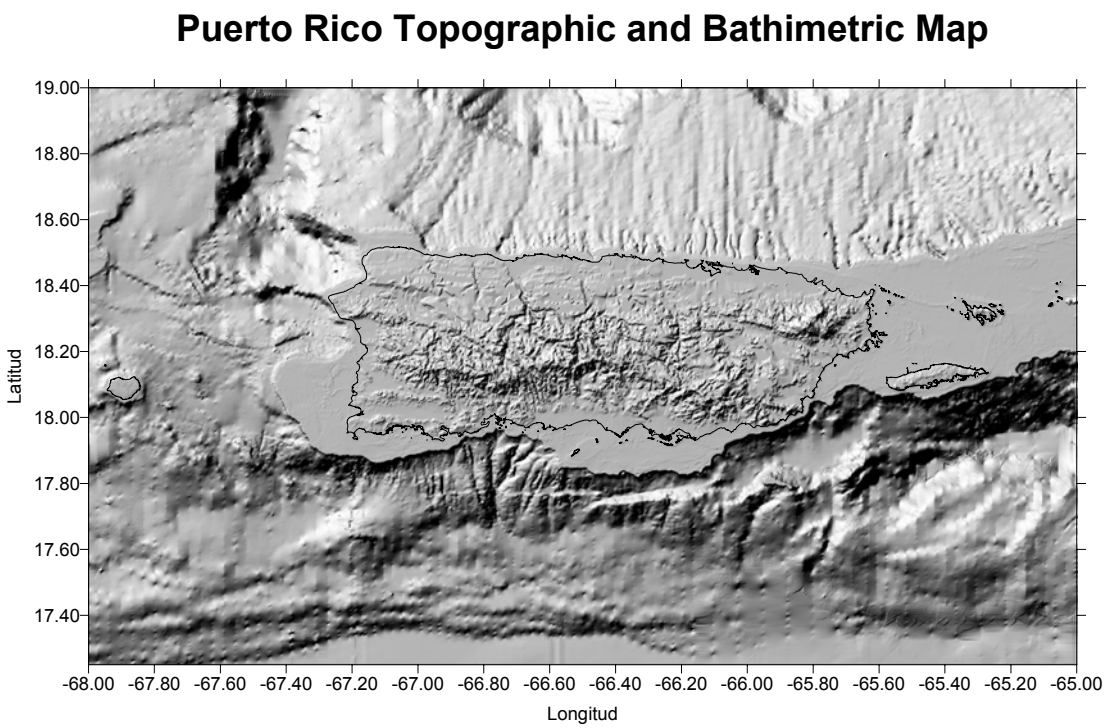

Figure 74. Puerto Rico topographic and bathimetric map.

Surface and Internal Tides

Tides throughout the northeastern Caribbean Sea exhibit a complex behavior. Along the south coasts of PR and Vieques the tide is principally diurnal (one cycle per day; i.e., 24-h period) while the tide along the north and west coasts of PR is semidiurnal (two cycles per day; i.e., 12-h period) (Kjerfe,1981). This is further complicated as we approach Vieques due to the presence of the semidiurnal (M2) anticlockwise rotating amphidromic system, centered south of St. Croix.

Tidal sea surface elevations around Puerto Rico are about 30-40 cm above and below mean low water. Maximum yearly tides occur when a lunar perigee coincides with a new or full moon; this alignment usually occurs twice a year and evolves from year to year in response to lunar orbital characteristics. Coastal tidal currents generally lag the phase of the predicted surface tide by a quarter of a cycle (3 hours for the semidiurnal tide).

Vertical oscillations in the water column driven by the barotropic tide, known as internal tides, are observed to extend from the seasonal thermocline to the maximum observed depth. The amplitudes of these tidal oscillations are inversely proportional to the stability of the water column, resulting in a general increase in amplitude with increasing depth. Associated with the patterns of astronomical forcing of the internal tides is the excitation of large-amplitude coastal seiches along the south coast of Puerto Rico. Low amplitude seiches occur continuously

as this is a fundamental mode of coastal oscillation, however, under the right astronomical forcing and vertical stratification conditions these can reach amplitudes of the same order as the astronomical tide (Teixeira and Capella 2000).

In summary, most of the coastal and oceanic waters surrounding Puerto Rico should be ideal for offshore aquaculture enterprises. Even though there is little insular shelf on the north coast of Puerto Rico, an irregular insular shelf, three to eight km wide, borders the south and west-southwest coastlines. Optimal growth conditions for fish culture exist with stable temperatures and salinities ranging from 26 to 30°C and from 34 to 36.3, respectively. Tidal sea surface elevations around Puerto Rico are about 30-40 cm above and below mean low water. However, Puerto Rico lies along hurricane tracks, with similar hits as many of the coastal Southeastern States. During the passage of Hurricane Georges on September 22, 1998, currents of 150 cm/sec were measured at a depth of 34 m in western Mona Passage. Thus, aquaculturists would have to plan for an occasional catastrophic event by employing offshore gear designed to avoid or withstand the impact of hurricane generated waves and currents. Current plans are to use submerged cages that will avoid destructive surface waves.

Acknowledgments

Data presented in this article were obtained during research initiatives sponsored by the Office of Naval Research, the Government of Puerto Rico, the University of Puerto Rico, and the Puerto Rico Sea Grant College Program.

Appendix 2

Current meter report

The first current meter report documented the second in a series of current meter monitoring events conducted in the vicinity of the Snapperfarm, Inc. corresponding to the period from April 10, 2003 to June 20, 2003 and is described as event 1. Ocean Spar Technologies, Inc, designers of the marine aquaculture cages, conducted the first deployment as event 1 (see the Culebra 1 Deployment Report from May 30, 2002 to June 6, 2002) as part of the cage placement and mooring protocol (Table 10). This was the first deployment by the University of Puerto Rico at Mayagüez, Department of Marine Sciences (UPRM-DMS) group at the control site. This report intends to describe the S4 velocity and temperature data and to provide some basic context for its interpretation.

The flow regime observed during this brief monitoring event was characterized by

- predominantly along-isobath flow along the axis 300-320° ↔ 120-140° true;
- strong semidiurnal (two cycles per day), and weaker diurnal (one cycle per day), tidal components with amplitudes of 20-30 cm/sec;
- mean, or low-frequency, northwestward flow with a record mean towards 300° true at 8 cm/sec;
- quasi-periodic 5-day to weekly component in the low-frequency signal;
- northwestward flow (towards 300°-320° true) occurs during the flooding tide (as the sea surface elevation is increasing) whereas the ebbing tide coincides with southeastward flow (120°-140° true);
- peak flow lags the tidal peak by about three hours (approximately a quarter of a semidiurnal cycle);
- the tidal ellipses are elongated along bottom contours to the point of nearly a straight line so that changes in direction occur very quickly, there is very little transport towards land and the velocity vectors are observed to swing back and forth across the open-ocean hemisphere.

The record maximum value of 47 cm/sec (91.3% of a knot) occurred on April 16 at 16:25. Typical daily high speeds were reflected in the 90th percentile, are in the order of 30 cm/sec (~60% of a knot). The mean magnitude of the flow is

represented by the scalar mean speed, 15.2 cm/sec, and by the 50th percentile speed, 13.0 cm/sec.

Lunar perigee (Moon closest to Earth) and zyzygy (full or new moon) coincided during April 15 and lunar declination was not far from 18°. Tidal currents often reach bi-annual maximal during, or a few days after, these astronomical events known as King Tides. Note that the maximum record speed was observed on April 16 and keep this relationship in mind in the subsequent discussion. For the representation of the 2-D velocity vector data, a natural, bottom-aligned, coordinate system was chosen. In these coordinates, *v* represents the along-isobath axis with positive/negative *v* pointing towards 300°/120° true, whereas *u* is the cross-isobath axis, with positive/negative *u* towards 30°/210° true. The record-mean *v* (8.4 cm/sec) is two orders of magnitude higher than the corresponding mean *u* (-0.02 cm/sec). Note that the largest amplitude of the tidal *v* component occurs near April 18 with daily values of ~40 cm/sec. The directional distribution of transport per unit area is presented in Fig. 75.

The NOAA software predicted tide at Ensenada Honda, the NOAA tide station closest to the cage site, for the full record period is shown in Fig. 76. This figure is intended to serve as reference in the description of expanded data intervals to follow. Two time periods, from April 11-17 (Figs. 77-79) and from May 22-27 (Figs. 80-81) have been selected for a more detailed view of tidal flow behavior and its variability.

First, in the Culebra 1 Deployment Report, the statement was in contrast to the current data set: The tide at Ensenada Honda precedes the tide at the S4 mooring by about three hours. Due to similar time lags, the NOAA tides at Ensenada Honda are a good predictor for the velocities at the cage site; peak high tide at Ensenada Honda is in phase with northwestward flow at the cage site whereas peak low tide at Ensenada Honda is in phase with southeastward flow." This statement was based on information provided by Ocean Spar regarding the times at which their velocity data were taken; It was applied a 3-hour delay to the data to account for California time.

As shown in Figs. 77 and 80 the peak flow is not in phase with the Ensenada Honda tide. Northwestward flow (towards 300°-320° true) occurs during the flooding tide (as the sea surface elevation is increasing) whereas the ebbing tide coincides with southeastward flow (120°-140° true). Peak flow lags the tidal peak by about three hours (approximately a quarter of a semidiurnal cycle). This leads me to believe that the surface tide at Ensenada Honda is in phase with the surface tide at the cage site. Future monitoring should clarify this inconsistency between the two data sets.

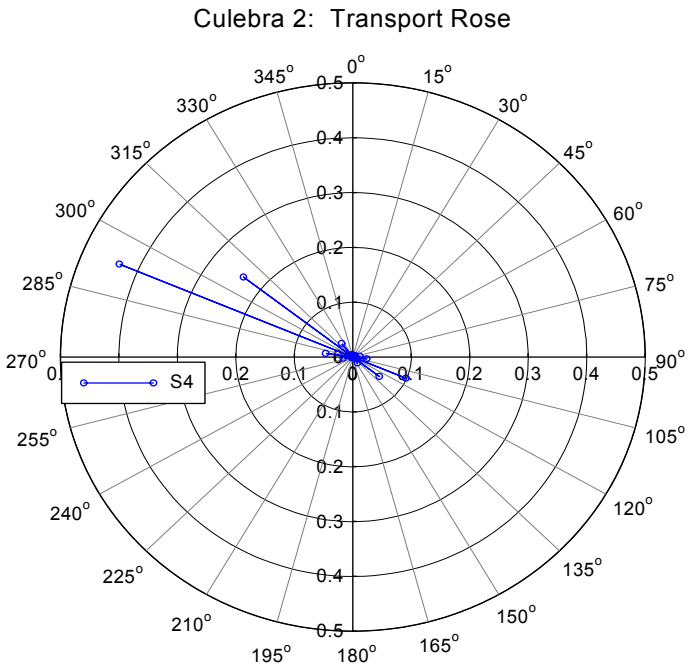

Figure 75. Culebra 2 current transport rose. The length of each vector represents the percentage of total transport that lies in any given 15° bin. Each radial divisions indicates 10% of the total transport

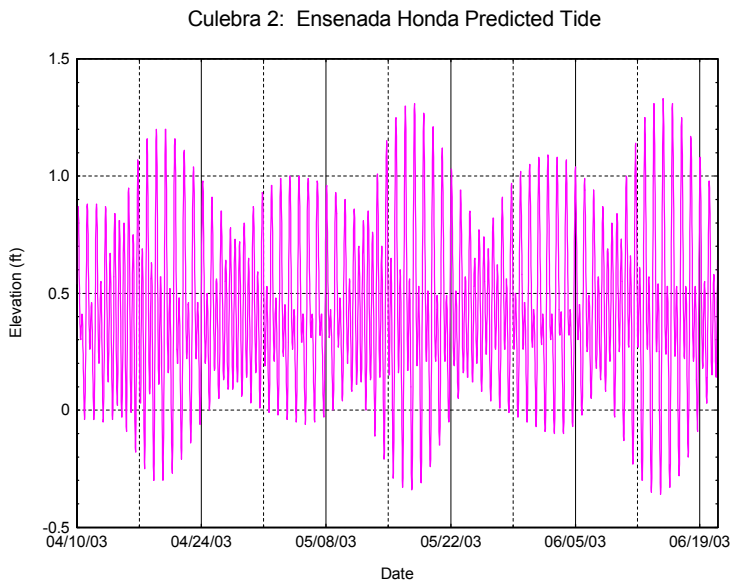

Figure 76. Predicted tide at Ensenada Honda. Tide predicted with Tide and Currents software from Nautical Software, Inc.

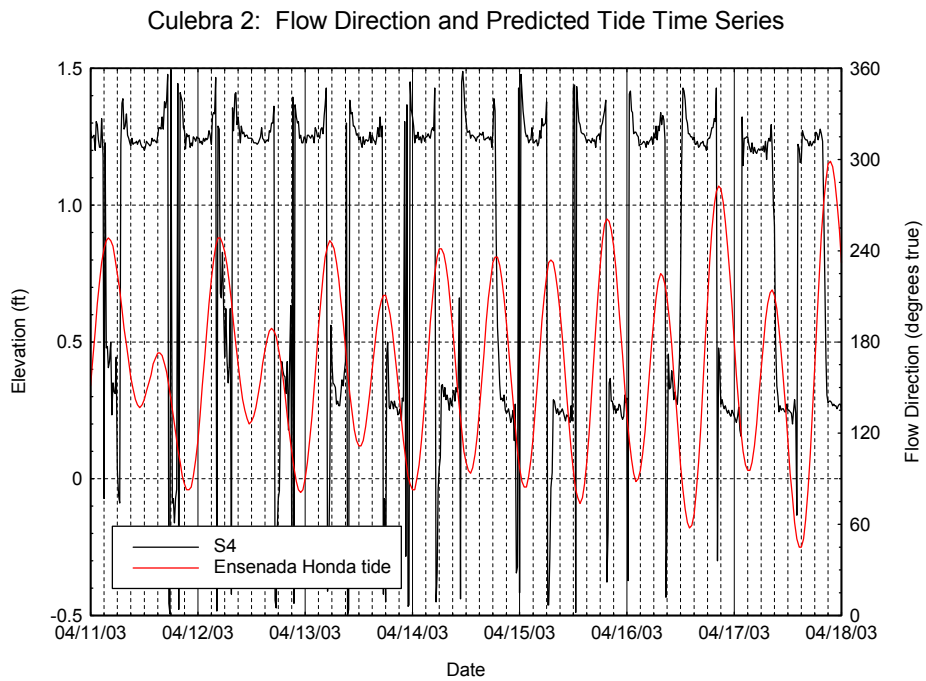

Figure 77. Culebra 2 flow direction from the S4 and the predicted tide at Ensenada Honda. Tide predicted with Tide and Currents software from Nautical Software, Inc.

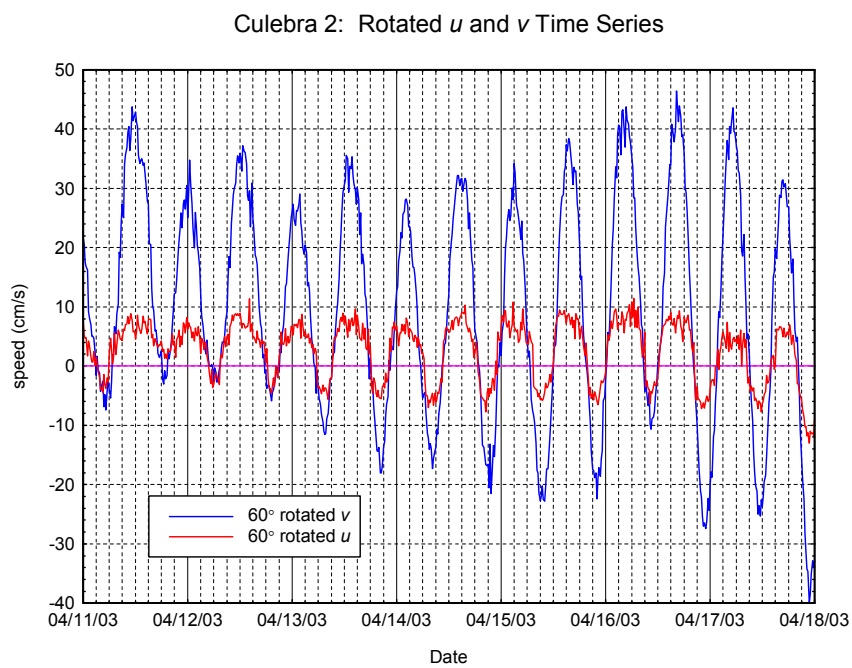

Figure 78. Culebra 2 rotated u and v time series.

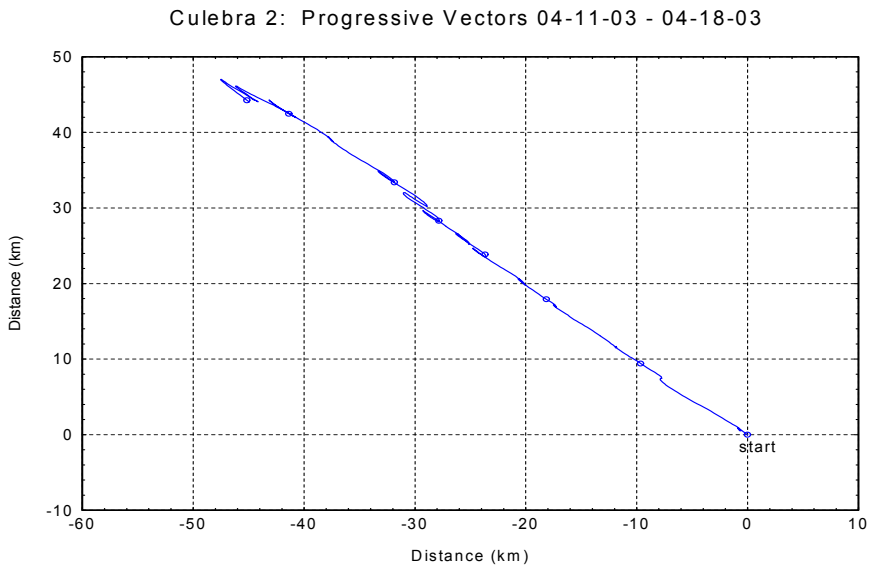

Figure 79. Culebra 2 progressive vector diagram. Markers are spaced on a daily basis.

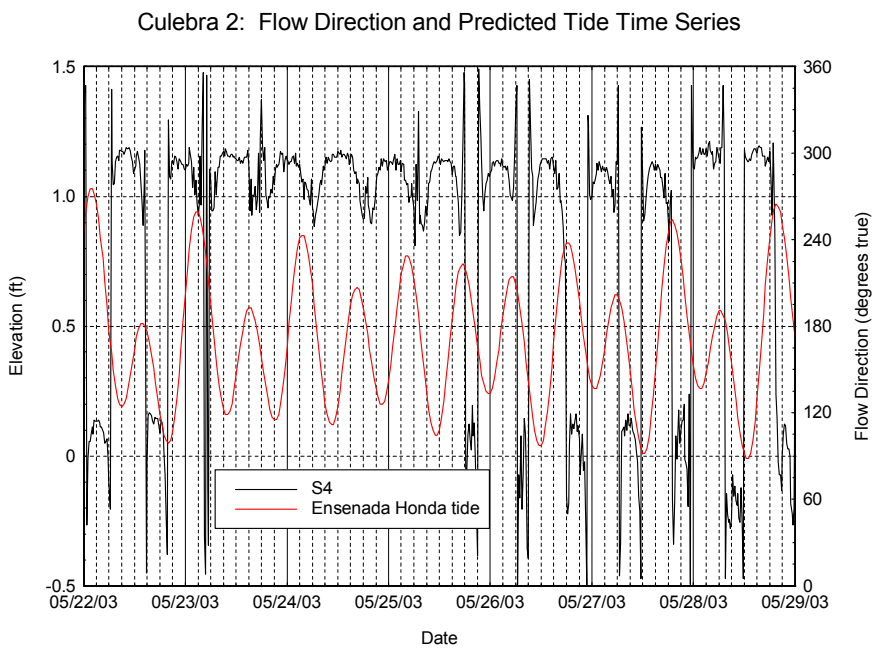

Figure 80. Culebra 2 flow direction from the S4 and the predicted tide at Ensenada Honda. Tide predicted with Tide and Currents software from Nautical Software, Inc.

The dominant semidiurnal and diurnal tidal components in the velocity time series were filtered out (or smoothed out) of the raw time series so the lower frequency components could be observed (Fig. 81). The most prominent features in this figure are the mean *u* and *v* components and the quasi-periodic 5-day to weekly component in the low-frequency signal. The 5-7 day variability in the velocity time series could very well arise from the previously described meteorological forcing.

The mid-depth temperature record at the control site. The record mean temperature was 27.76°C with a minimum of 27.01°C and a maximum of 28.28°C. The typical diurnal temperature range was ~0.2°C. This narrow range of water temperature during a year cycle guarantee that any thermal stress is expected for the organisms cultured and the temperature remain almost at optimal level to reach high growth rates for the organisms cultured.

The three-day period from May 23-25 was unusual in that the flow did not reverse direction and a persistent northwestward current prevailed. One possible explanation for this behavior lies in the large-scale regional mesoscale eddy field that populates the northeast Caribbean Sea. The synchronicity of the mesoscale geostrophic currents north and south of La Sonda de Vieques at the time would promote persistent northward flow into the Atlantic. Anyway, this figure serves to illustrate the large-scale circulation that may influence conditions at the cage site.

The second report documented the two deployments from June 20 to October 8, 2003. Mid-water currents were monitored for one year at the Culebra environmental monitoring control site. This report intends to describe the new velocity and temperature data and to provide some basic context for its interpretation.

Recycling of the S4 current meter was performed on December 5, 2003. However, an internal power failure on October 10 prevented the instrument from recording useful data beyond this date. It was determined that a leaky battery in the battery pack caused the malfunction. The S4 seemed to be in good operating condition despite this failure, the electronics are isolated from the power compartment, so after a thorough cleaning and rebuilding of the battery pack, it was redeployed.

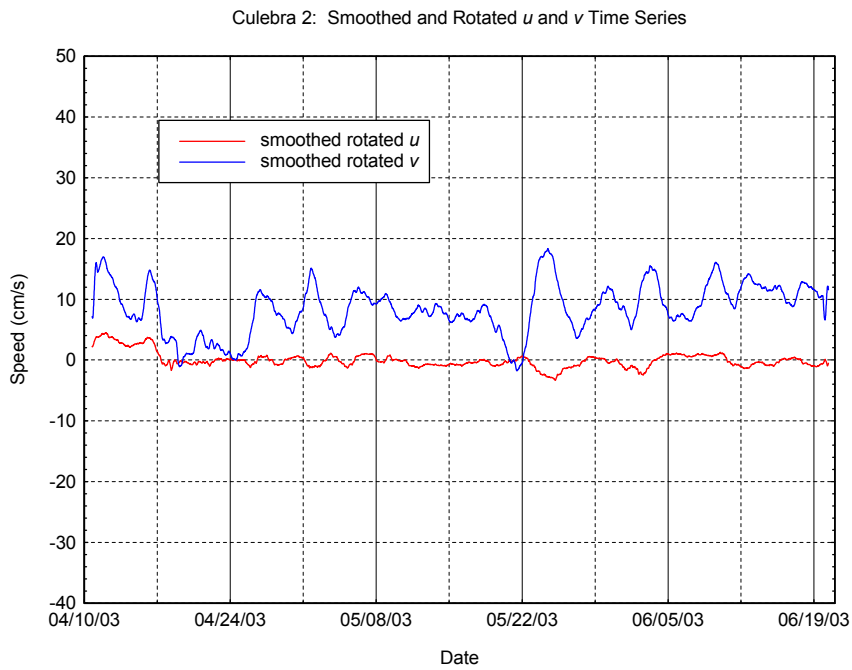

Figure 81. Culebra 2 Smoothed and rotated u and v time series.

The flow regime observed during this monitoring period, C03-C04, does not differ much qualitatively from that observed during April-June; the mean, or resultant, flow direction has remained steady towards the northwest while the degree of flow variability, as represented by the R/S ratios (Resultant/Scalar) and showed a similar stability. However, the resultant, mean and percentile current speeds increased significantly; the mean speed during C04 was ~32% higher than during C02 while the resultant vector was 23% stronger.

The flow regime observed during this brief monitoring event is characterized by

- predominantly along-isobath flow along the axis 300° ↔ 120° true;
- strong semidiurnal (two cycles per day), and weaker diurnal (one cycle per day), tidal components with maximum amplitudes of 20-30 cm/sec;
- the diurnal inequality of the tidal currents is much weaker that that of the surface tide;
- mean, or low-frequency, northwestward flow with a record mean towards 300° true at 8-10 cm/sec;
- northwestward flow (towards 300°-320° true) occurs during the flooding tide (as the sea surface elevation is increasing) whereas the ebbing tide coincides with southeastward flow (120°-140° true);

- peak flow lags the tidal peak by about three hours (approximately a quarter of a semidiurnal cycle);

- the tidal ellipses are elongated along bottom contours to the point of nearly a straight line so that changes in direction occur very quickly, there is little transport towards land and the velocity vectors are observed to swing back and forth across the open-ocean hemisphere;

- quasi-periodic 5-day to weekly components in the low-frequency signal;

The full velocity data are presented in the form of current direction and speed time series in Figs. 79 and 80, respectively, and as *u* (cross-isobath or southwest-northeast) and *v* (along-isobath or northwest-southeast) component time series in Fig. 82. Note that the *u* and *v* components have been rotated so they are aligned (*v*) and perpendicular (*u*) to bottom contours. Due to the large number of velocity data points, these figures are difficult to interpret; however, several important features are distinguishable. The closely spaced oscillations (wiggles) correspond to the dominant semidiurnal oscillations of the velocity vectors.

The NOAA software-predicted tide at Ensenada Honda, the NOAA tide station closest to the cage site, for the full C03 and C04 record periods is shown in Fig. 82. The C03 record maximum value of 56.1 cm/sec (1.1 knot) occurred on June 29 while during C04 a value of **59.6 cm/sec** (1.2 knot) was recorded on September 10. The company, Net Systems / Ocean Spar Technologies (email: Langley Gace email:engineering@oceanspar.com) rates the submergible Sea Station cages as being able to safely withstand currents of 62 cm/sec. A recent (January 21, 2004) email from the Net Systems / Ocean Spar Technologies indicated that they have performed independent testing at the University of New Hampshire, MIT (Massachusetts Institute of Technology) and at their own R&D department. Results of this research have increased the maximum current that Sea Station can safely withstand by 45% to 90 cm/sec.

The along-isobath component *v* (along 300°/120° true) was to be the predominant flow axis. The record-mean *v* (11.1 and 10.2 cm/sec) are one order of magnitude higher than the corresponding mean *u* (-1.0 cm/sec). The full trajectories for such long records do not allow for the resolution of the tidal oscillations at the size scale of the figure and appear as linear tracks towards the northwest.

The dominant semidiurnal and diurnal tidal components in the velocity time series were filtered out (or smoothed out) of the raw time series so the lower frequency components could be observed. The most prominent features in these figures are the mean *u* and *v* components and the quasi-periodic 3-day, 5-day and weekly components in the low-frequency signal. The simple smoothing applied to the time series does not allow for good resolution of the inertial

frequency oscillations (38-39 h periods) forced by the tropical cyclones and could in fact generate false peaks due to aliasing effects. More sophisticated time series analysis is required to extract fully the variability component spectra.

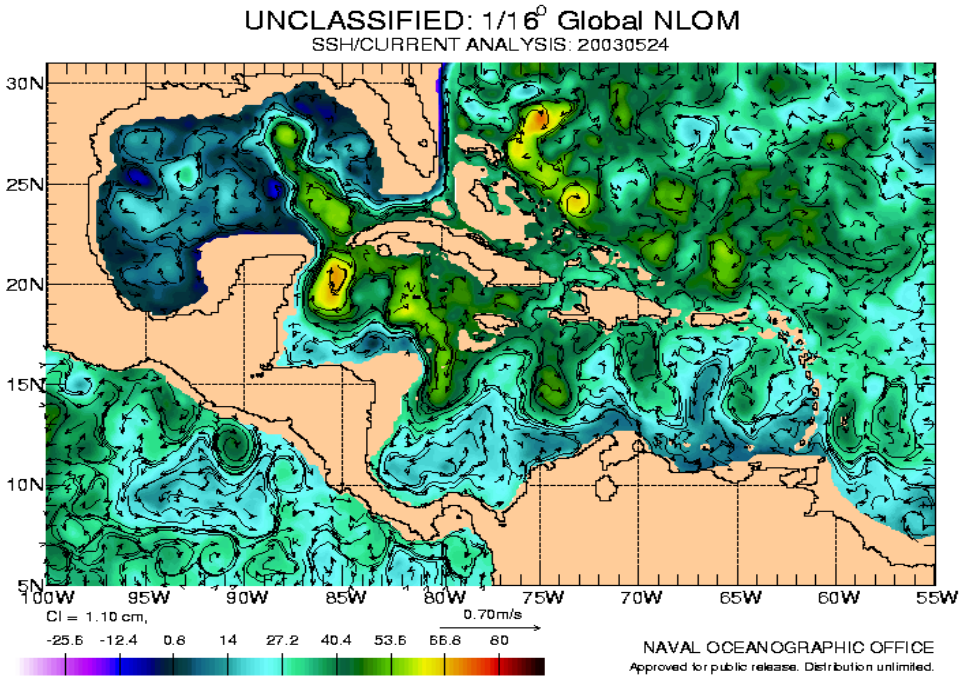

Figure 82. NLOM sea surface height and surface current analysis for May 24, 2003. Image downloaded from www.7320.nrlssc.navy.mil/global_nlom/globalnlom/ias.

The strongest, largest amplitude, low-frequency flow variability appears to be related to the approach of tropical storms or hurricanes from the east. Such is the case during the period from June 28 to July 8 (Tropical Storm Claudette, Plate 1), during August 5-15 (Tropical Depression 9, Plate 2) and during September 2-14 (Hurricane Fabian followed by Hurricane Isabel, Plate 3). A causal relationship between cyclones and flow variability can not be unequivocally established at this stage of the analysis, but the coincidence is remarkable. In the narrative above, the peak velocities in each record fell within these periods.

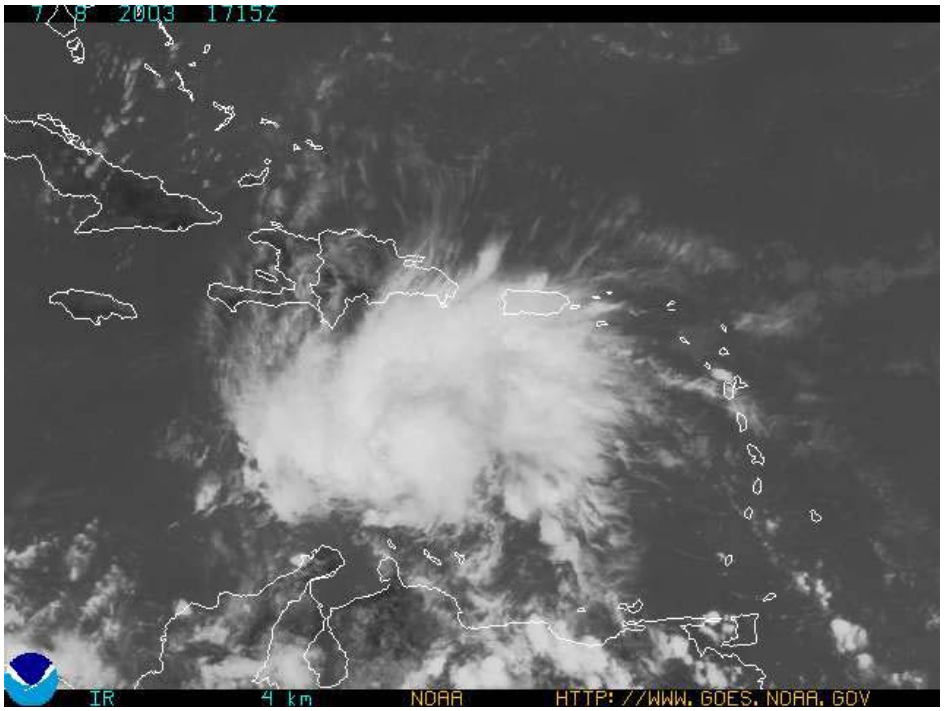

Plate 1. Satellite infrared image of the Eastern Caribbean for July 8, 2003(Tropical Storm Claudette)

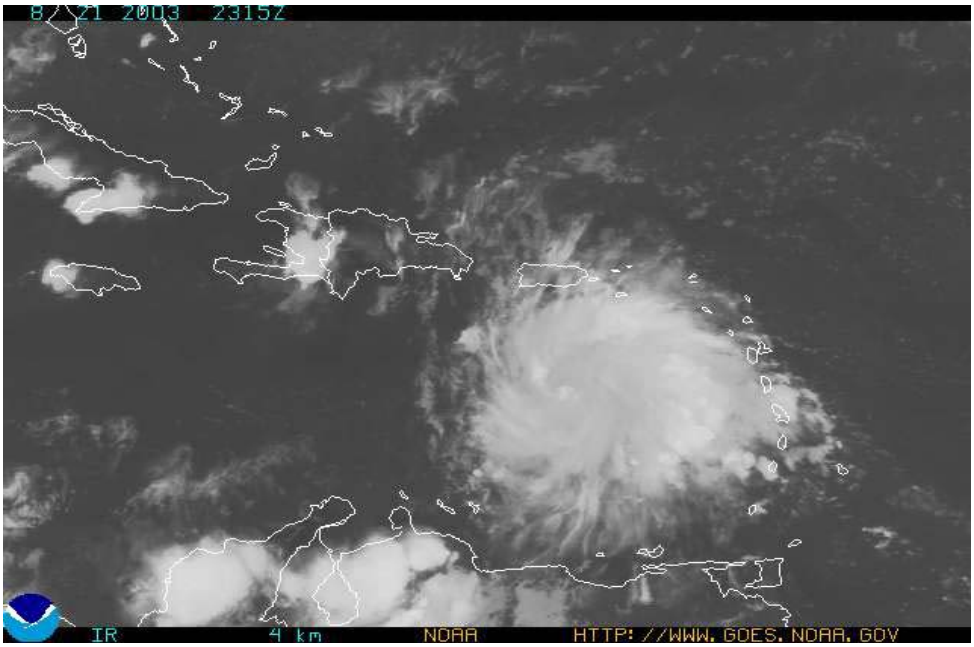

Plate 2. Satellite infrared image of the Eastern Caribbean for August 21, 2003 (Tropical Depression 9)

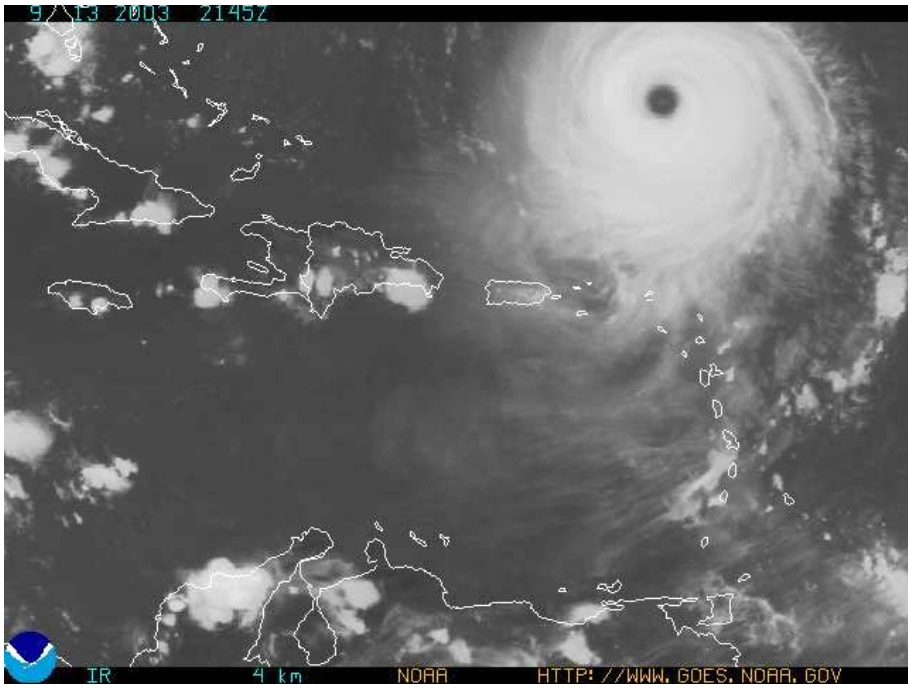

Plate 3. Satellite infrared image of the Eastern Caribbean for September 13, 2003 (Hurricane Fabian followed by Hurricane Isabel)

Appendix 3

Consent Form (English Version)
PARTICIPANT CONSENT FORM
(Interview)

Hello! I am (*give name*), (Investigator) for the Project entitled "Offshore Cage Culture: Environmental Impact and Perceptions by Local Fishing Community" by Drs. Alexis Cabarcas, Dallas Alston, Daniel Benetti, Janet Bonilla, and Sara Meltzoff, University of Puerto Rico, Mayagüez Campus and the University of Miami using funding from the US National Marine Fisheries Service. Among the studies performed, the researchers would like to ascertain perceptions of the Culebra community relating to new technology utilizing open-ocean cage aquaculture and their relations to various aspects, including economic, environmental, and work issues.

We are inviting you to participate in this study. *Your participation will consist* of one interview that with questions concerning your demographic information (i.e., age, sex, civil status, etc.), information related to your fishing activities (if applicable) and your perception relating to open-ocean cage aquaculture in Culebra.

Your participation in this study is free and voluntary meaning that you are free to participate or not. Even though you may sign this consent form, you may change you mind at any time and withdraw your consent. If the latter case is your decision, please indicate this to the person giving the interview.

The information that you provide during the interview is *anonymous and confidential*. This means that the interviews will not indicate names or information that could be related to your name such as social security number, address, or telephone number. Information you provide will be used only for the purposes of the study. Once you complete the interview, the information will be kept in a locked file in the Center of Social Applied Research (CISA for the Spanish abbreviation) of the University of Puerto Rico, Mayagüez Campus. Only personnel that work in this study will have access to the information you provide.

You will *not receive benefits* by participating in this study. You are not expected to suffer physical or psychological injury by participating in this interview. Nevertheless, if any question causes uneasiness, you may indicate you do not wish to respond. If you feel uneasy, immediately indicate to the investigator that you would like to terminate the interview.

Once the study is completed, you will have access to the *results of the report* by November 2003 which will include a compilation of results of the participants of the interview process. This will also assure your information will remain confidential.

If you have any doubts concerning the study, the investigator can clarify them now or at any time you wish. If you are not satisfied with the information offered or if you have any other comments please tell the investigator or contact the following person responsible for the social component of the study:

Dr. Janet Bonilla, Assistant Professor

University of Puerto Rico, Mayagüez Campus
Department of Social Sciences
PO Box 9266
Mayagüez, PR 00981
Tel. 1(787) 832-4040 Ext. 2108, 2109
You may leave a voice message at extension 3839 or 3303

PARTICIPATION CLAUSE

"I have answered all of the questions of this study to my satisfaction. I understand that a copy of this form of consent was given to me. My signature in this form indicates that I, of legal age and resident in Culebra, PR, understand the information presented, and that I am willing to participate voluntarily in the study."

_____

Signature or Initials of the Participant/Date

_____

Signature of the Investigator/Date

_____

Signature of the Social Component Investigator/Date

Appendix 4

Consent form (Spanish Version)

HOJA DE CONSENTIMIENTO DE PARTICIPACIÓN
(Entrevista)

İHola! Yo soy (*se indica el nombre*), (Investigadora) el Proyecto "Offshore Cage Culture: Environmental Impact and Perceptions by Local Fishing Community" que llevan a cabo los profesores Dallas Alston, Daniel Benetti, Janet Bonilla, Alexis Cabarcas y Sara Meltzoff, del Recinto Universitario de Mayagüez y de la Universidad de Miami con fondos del US National Marine Fisheries Service. El estudio tiene entre sus objetivos conocer la percepción de la comunidad culebréense con relación a la tecnología de la acuicultura en jaulas en mar afuera en aspectos variados (ej., economía, ambiente, trabajo, entre otros).

A usted lo/la estamos invitando a participar en este estudio. *Su participación consistirá* en contestar una entrevista que contienen preguntas sobre información demográfica (ej. edad, sexo, estado civil, etc.), información de sus tareas como pescador (sí le aplica) y sobre su conocimiento y percepción en torno a la tecnología acuicultura en jaulas en mar afuera utilizada en Culebra.

Su *participación en el estudio es libre y voluntaria***.** Esto significa que usted está en la libertad de participar o no. Aunque haya firmado la hoja de consentimiento de participación, puede cambiar de opinión y dar por terminada su participación en el estudio. Si esto le ocurre, déjele saber su decisión a la persona que le está llevando a cabo la entrevista.

La información que usted nos ofrezca en la entrevista es *anónima y confidencial*. Esto quiere decir que las entrevistas no llevarán nombre o información que lo/la identifique (ej. número de seguro social, dirección o teléfono). La información que usted nos brinde se utilizará para propósitos del estudio únicamente. Una vez usted complete la entrevista, la información se guardará en un archivo bajo llave en el Centro de Investigación Social Aplicada (CISA) de la Universidad de Puerto Rico en Mayagüez. Sólo personal que trabaja en el estudio tendrá acceso a la información que usted ofrezca.

Usted *no* gozará de *beneficios* por participar en este estudio. Tampoco se anticipa que usted sufra *daños* físicos o psicológicos por participar en el mismo. Sin embargo, sí alguna pregunta le causa incomodidad está en la libertad de no contestarla. Si se siente demasiado incómodo/a dígaselo inmediatamente a la persona que lleva a cabo la entrevista y se dará por terminada su participación en la misma.

Una vez se termine el estudio usted tendrá acceso a un *informe de los resultados*. El mismo estará disponible a partir del mes noviembre del año 2003. El informe incluirá un compilación de los resultados de todos/as los/las participantes del estudio. De esta manera se garantiza la confidencialidad de sus respuestas.

Si usted tiene alguna duda acerca del estudio puede aclararla ahora o en cualquier momento que lo desee. Si no queda satisfecho/a con la información ofrecida y tiene algún comentario o queja sobre el estudio, favor de comunicarlo ahora o contactar a la persona responsable del componente social del estudio:

Dra. Janet Bonilla, Catedrática Auxiliar
Universidad de Puerto Rico, Recinto de Mayagüez
Departamento de Ciencias Sociales PO Box 9266
Mayagüez, PR 00981 USA
Tel. 832-4040 Ext. 2108, 2109
Pede dejar mensaje en las exts. 3839 y 3303

CLÁUSULA DE PARTICIPACIÓN

"Todas las preguntas sobre el estudio me han sido contestadas en forma satisfactoria. Entiendo que se me entregó una copia de esta forma de consentimiento. Mi firma en esta hoja significa que Yo, mayor de edad y residente en Culebra, PR, entiendo la información presentada y que acepto participar en el estudio de manera voluntaria."

_____

Firma o Iniciales del o la Participante/Fecha

_____

Firma de la Asistente de Investigación/Fecha

_____

Firma de Investigadora del Componente Social/Fecha

Appendix 5

Interview for the General Population (English version)

STUDY OF GENERAL KNOWLEDGE AND PERCEPTION OF CULEBRA, PUERTO RICO, FISHERMEN AND GENERAL COMMUNITY IN RELATION TO THE OPEN-OCEAN AQUACULTURE PROJECT

Interview to members of the General Community

Part I: Socio-demographic variables

I will ask to you questions concerning socio-demographic aspects. For each question, you should answer or select the description which most closely describes you.

1. What is your sex?	_____ feminine _____ masculine
2. How old are you?	_____ years
3. What is your civil status?	_____ single _____ married _____ co-inhabiting without being legally married _____ separated (widow, divorced)
4. How many people live in your home? (Include yourself.)	_____ number of people
5. Of these people, how many are relatives of yours?	_____ all _____ only some how many? _____
6. Do you have children?	_____ yes how many? _____ _____ no
7. Have you lived all of your life in Culebra?	_____ yes _____ no in what town, state or country have you lived? _____ how many years have you lived in Culebra? _____
8. Your work is:	____ part-time ____ full-time
9. Your work is?	_____ in a public agency (local or federal government) _____ in a private enterprise indicate enterprise: _____ _____ own business _____ other (specify)

	_____
10. What is you title or position in this work?	_____ (title or position)
11. In what town municipality) do you work?	_____ Culebra _____ another town (indicate which) _____
12. In addition of the work mentioned above, do you work in one of the following activities?	_____ fisheries _____ agriculture _____ construction _____ mechanics _____ electricity _____ other (specify)
13. Do you receive pay from these activities?	_____ yes _____ no
14. Which of the following categories best describes the monthly income of your family?	_____ less than $4,999 _____ $5,000 a $9,999 _____ $10,000 to $14,999 _____ $15,000 to $19,999 _____ $20,000 to $24,999 _____ $25,000 to $34,999 _____ $35,000 to $44,999 _____ $45,000 or more
15. How many people contribute to this income?	_____ number of people
16. Does your family receive some type of governmental economic aid?	_____ yes _____ no
20. Which of the following did you complete?	_____ elementary school _____ intermediate school _____ superior school _____ university _____ none of the previous options _____ I did not attend school

Part II: Description of your work as a fisherman
Now I am going to ask to you questions concerning your work as a fisherman.

21. Why do you fish?	
22. How many days (average) do you fish each week?	_____ days
23. At what time do you go fishing?	_____ hora
24. Which type of fishing do you do mostly?	_____ More frequent
25. What do you do with the capture of fish and seafood?	(indicate all that apply) _____ sell fish to the of Culebra Association of Fishermen _____ sell to a refrigeration service _____ sell to a restaurant _____ sell to a residence _____ sell in the street _____ give catch to friends and relatives _____ process fish into fried products to be sold _____ use for family consumption _____ other (specify): _____

Part III. Knowledge of the methods and the open-ocean cage aquaculture project
Now I will ask to you how much you know about diverse aspects of the open-ocean cage aquaculture project in Culebra, as well as aquaculture in general.

26. Have you heard of the open-ocean aquaculture project here in Culebra? 22. How did you learn about the project?	_____ yes _____ no *(Proceed to the question # 30)* _____

	nothing	something	a lot
28. How much do you know about the project?			
29. Explain to me what you know concerning the project?			
	nothing	something	a lot
30. How much do you know of the company, Snapperfarm, Inc.?			

31. Explain to me what you know concerning Snapperfarm.
32. How did you learn about Snapperfarm?

Do you know...	Yes	No
33. The *advantages of open-ocean cage aquaculture* as a technique to ***produce*** fish or other marine species		

34. Explain what you consider are advantages?		
35. The ***disadvantages or limitations of open-ocean cage aquaculture*** as a technique to **produce** fish or other marine species	Yes	No
36. Explain what you consider are disadvantages?		
37. The impact of *open-ocean cage aquaculture* on Culebra's environment	Yes	No
38. Explain to me what you know concerning the environmental impact		
39. The impact of *open-ocean cage aquaculture* in reference to Culebra's economy	Yes	No
40. Explain to me what you know concerning the economic impact		
41. The impact of open-ocean cage aquaculture on Culebra's fishing	Yes	No
Explain to me the impact on fishing		
42. Impact of open-ocean cage aquaculture on the fishermen of Culebra	Yes	No
43. Explain to me the impact in the Culebra fishermen		
44. The impact of open-ocean cage aquaculture in relation to the Culebra community	Yes	No
45. Tell me what you think.		
46. The skills or knowledge needed to manage open-ocean cage aquaculture	Yes	No
47. What are these skills or knowledge?		
48. The approximate cost of the production of fish or other seafood (shrimps, lobsters) using open-ocean cage aquaculture.	Yes	NO
49. Which would estimate are the cost? Cost of the cages: _____ Other costs: _____ Total cost: _____		

Would you like to know more concerning the Culebra open-ocean aquaculture project.			Yes	No
51. How much it would like to know:	Little	Something	A lot	Everything
Of what aspects in particular would you like to know more?				

Part IV. Attitudes concerning the use of open-ocean aquaculture techniques
Finally, I will ask your opinion on the use of open-ocean aquaculture techniques to produce and harvest fish.

52. Are you in agreement or not with the use of open-ocean cage aquaculture in Culebra to produce fish or other seafood? In agreement _____ Do not agree _____
53. Why are you in _____(agreement or not in agreement)?
54. Are you to favor or against the use of open-ocean cage aquaculture in another place to produce fish or other seafood?
55. Why are you in favor or against?
56. This you disposed to learn skills needed to produce fish or other seafood using this technology? Yes _____ No _____
57. Why?
58. Are you disposed to integrate or to complement your fishing activities with the aquaculture techniques?

Appendix 6

Environmental Laws of Puerto Rico

(Modified from Fiddler González & Rodríguez Environmental Practice Group. 2003. Puerto Rico Environmental Law Handbook, which may be ordered from Government Institutes, 4 Research Place, Rockville, MD 20850 USA; ISBN number: 0-86587-969-9).

Caveat: In compiling this appendix, the principal investigators sought to provide an overview of the laws, the structure of the agencies administering those laws, and the regulations which may affect an open-ocean operation or simply pertaining to water (so, therefore may be not direct relationship with open-ocean aquaculture). Thus, some points are mentioned to illustrate the "terrestrial" focus to which most laws adhere; others offer a glimpse into the general reason for such laws (such as using a resource wisely for the public good).

Introduction

The Commonwealth of Puerto Rico was created in 1952 and organized through the adoption of a constitutional government composed of executive, legislative, and judicial branches. Puerto Rico is a non-incorporated territory of the United States. The Puerto Rico federal Relations act of 1950 defines the relationship between the governments of Puerto Rico and the Unites States. The laws of the Unites states have the same force and effect in Puerto Rico as in the United States, unless the statute expressly establishes it inapplicability to Puerto Rico; or the particular conditions of Puerto Rico make the statute locally inapplicable. The United States Congress has expressly extended the applicability of environmental statutes to Puerto Rico.

Protection of natural resources and the environment is afforded constitutional status in Puerto Rico. The Constitution of Puerto Rico specifically states that "it shall be the public policy of the Commonwealth to conserve, develop, and use its natural resources in the most effective manner possible for the general welfare of the community…"

Environmental Quality Board

The Public Policy Environmental Act (Act No. 9) establishes an environmental public policy in Puerto Rico. It delegates the regulatory authority to implement the environmental public policy to the Environmental Quality Board (EQB). Act No. 9 establishes a public policy, an environmental review requirement, creates EQB, and provides for environmental causes of action, enforcement, and penalties. The public policy and environmental review provisions closely parallel those of the National Environmental Policy Act (NEPA), enacted by the United States Congress. There are six main program areas of EQB, namely: air quality, water quality, land pollution control, scientific assessment (environmental review), environmental emergencies, and complaints.

Environmental Review Documents

The Regulation for the Process of Presentation, Assessment and Procedure of Environmental Documents was promulgated on September 29, 1999 and amended on August 22, 2002. The Regulation allows agencies to exempt, with the consent of EQB, categories of action with no predictable significant impact from having to comply with most of the regulatory requirements of the environmental review process. The approval of a categorical exclusion does not exempt the applicant from complying with other applicable regulations of EQB or any other government agency.

An environmental document is a detailed writing which includes an analysis, evaluation, and discussion of the possible environmental impacts of a proposed action. Environmental documents can be written in Spanish or English; however, if it is written in English, Spanish versions should be available upon request. An Environmental Assessment (EA) is a document prepared by the lead agency in order for EQB to determine if the proposed action will have a possible significant environmental impact. Lead agencies must submit to EQB an EA for any action subject to this Regulation, unless an Environmental Impact Statement is submitted or the action is classified as a categorical exclusion. The EA is subject to a relatively simple procedure. However, the EA must comply with the specific format and content requirements set forth in the Regulation. There is no public notice requirement. There is no regulatory requirement that the EA be circulated among the agencies, but in practice, it is circulated and other agencies are given the opportunity to comment. The lead agency must respond to all comments in an EA supplement. The environmental review process is not complete until EQB certifies that the lead agency has complied with Article 4(C).

The Environmental Impact Statement (EIS) is a detailed document prepared by the lead agency when it is determined the proposed action will have a significant impact on the environment. An EIS is mandatory in the following cases:

- any action that can significantly degrade the environment uses;
- actions that will use a substantial part of the available infrastructure;
- actions that may significantly impact natural resources or values of ecological, recreational, social, cultural, or archaeological importance;
- stages of actions which individually do not require an EIS, but that together might have cumulative significant impact;
- construction of any sanitary landfill; and
- construction of any major air emission source.

The EIS is subject to a formal regulatory procedure. The Regulation establishes specific content and procedural requirements for the EIS. A preliminary EIS must be submitted to EQB and circulated among various agencies for comment. The lead agency issues a public notice in newspapers of general circulation and the

Internet when a preliminary EIS is submitted and is available for review and comments. Upon conclusion of the comment period, the lead agency must submit a final EIS addressing all comments. EQB issues a public notice when a final EIS is submitted and is available for review. EQB has discretion to hold public hearings on an EIS. Act No. 9 imposes on government agencies the responsibility of submitting environmental review documents to EQB, prior to approving any project which may have a significant environmental impact. In such case, the government agency assumes the role of lead agency for the project.

Department of Natural and Environmental Resources

The Department of Natural Resources was created in 1972 as a governmental executive department. Later it was reorganized and renamed the Department of Natural and Environmental Resources (DNER), which is an umbrella agency subdivided into Natural Resources Administration, Energy Affairs Administration, the Mineral Resources Administration, The Advisory committee on Energy, the Advisory Council on Natural and Environmental Resources, and the Solid Waste Management Authority.

DNER is responsible for implementing the operational phase of the public policy and has the authority to regulate the use and conservation of natural resources, such as water, sand gravel, stone, caves, caverns, sinkholes, forests, fish, marine resources, wildlife, and minerals. Of the subdivisions of DNER, the following will most affect open-ocean aquaculture permitting and practices. The Puerto Rico Planning Board is an instrumentality attached to the office of the Governor of Puerto Rico. It is responsible for guiding the integral development of Puerto Rico and regulating land use. The Regulations and Permits Administration (ARPE for its Spanish acronym) is an instrumentality attached to the Planning Board. ARPE is responsible for the operational aspect of public policies and strategies developed by the Planning Board. It has authority to enforce planning laws and regulations, to issue construction and use permits, and to enforce building codes. The Puerto Rico Industrial Development Company (PRIDCO) was created to, among other things, to promote industrial development. PRIDCO plays an important role in the promotion of new and expanded industrial operations. As a promoting agency, PRIDCO can serve as lead agency in industrial projects. The Department of Agriculture is a government executive department created with the purpose of promoting, developing, and regulating agriculture in general. The Department of Agriculture is responsible for the authority to regulate pesticides, insecticides, and fungicides.

Municipal Government Entities

Municipal governments must comply with Act No. 9 and the environmental review process provided in its Article 4(C). The Autonomous Municipalities Act provides municipalities with more authority over their urban, social, and economic

development. Qualifying municipal governments can request the delegation of permit authorities, traditionally exercised by the Planning Board and ARPE, such as the promulgation of regulations for land use and zoning maps, as well as the regulation for lotification, building, and use permits. Municipal governments can also request the delegation of other authorities from other Commonwealth agencies.

Water Pollution Control

Water pollution control regulations address both direct and indirect discharges of pollutants into bodies of water. Direct discharges are point source waste waters and storm waters discharged directly into bodies of water. They are regulated through National Pollution Discharge Elimination System (NPDES) permits, and are subject to technology based effluent limitations established by the Environmental Protection Agency (EPA) and by water quality based effluent limitations established by EQB. Indirect discharges are industrial waste waters discharged through publicly owned treatment works (POTWs), which are primarily designed to handle domestic waste and are often not capable of treating industrial waste waters. Indirect discharges are regulated through discharge permits, and are subject to federal and local pretreatment standards. Pretreatment requirements were established to regulate industrial dischargers who discharge indirectly into bodies of water through POTWs and are thus outside the reach of the NPDES permit system.

EQB's water quality program for direct discharges regulated the discharge of water pollutants into coastal, estuarine, surface, and ground waters as regulated by the Public Policy Environmental Act (Act No. 9), the Water Quality Standards Regulation (Water Regulation), and the federal Clean Water Act (CWA), including the NPDES permit regulations. Act No. 9 grants EQB the authority to establish water quality standards, to promulgate regulations to control the discharge of pollutants into bodies of water, and to receive and administer the delegation of the NPDES permit program.

The Water Quality Standards Regulation was updated by EQB in May 2003. The Water Regulation classifies water bodies in terms of their intended used, maintains general water quality standards for all water bodies and specific standards according to water use classifications, and provides for mixing zones, intermittent stream variances, and an anti-degradation policy. The Water Regulation also establishes a waste load allocation mechanism, temporary exemptions for waste water and drinking water treatment plants, a rule that allows for the site specific standards, and provides for compliance plans. The Water Regulation prohibits water pollution generally, as well as the "point source" discharge of water pollutants in violation of water quality standards. "Point source" is defined as a discernible, confined, and discrete conveyance, including, but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, mobile homes, mobile cafeterias, or any other vehicle,

concentrated animal feeding operation, vessel, or floating craft, from which pollutants may be discharged.

A water pollutant is any substance which may cause “pollution.” The regulatory definition of the term “pollution” includes, but is not limited to, the following pollutants: dredged spoil, solid waste, incinerator residue, filter backwash, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, industrial, municipal domestic, animal or agricultural waste, or any substance and/or material including storm water sediments or any substance which may pollute a receiving body of water.

Puerto Rico has not promulgated a local regulation that is equivalent to the federal NPDES permit regulation. Thus, EPA has not delegated the NPDES permit system to EQB. However, EPA and EQB entered into a Water Enforcement Agreement under which terms EQB has primary enforcement responsibility for violations of the Water Regulation. The agreement provides for EPA enforcement in cases of compliance schedules violations, effluent limitations, and other NPDES permit conditions.

Classification of Waters

Pursuant to Section 303 of the CWA, state regulatory agencies must promulgate regulations to classify all water bodies within the state’s jurisdiction according to intended uses, and must establish water quality criteria for the protection of those uses. The Water Regulation classifies waters according to the following use-base classifications:

- Class SA waters are high quality coastal or estuarine waters such as bioluminescent lagoons and bays, whose existing characteristics should not be altered and existing natural phenomena should be preserved. It also includes waters 500 m seaward from the high quality coastal or estuarine waters.
- Class SB waters are coastal and estuarine waters intended for use in primary and secondary contact recreation, and preservation of desirable species. This classification comprises water between the zone subject to the ebb and flow of tides (mean sea level) and 500 m seaward.
- Class SC waters are coastal waters for indirect human contact such as fishing and boating, and for propagation and preservation of desirable species. This classification comprises water between the zone subject to the ebb and flow of tides (mean sea level) and 10.3 nautical miles seaward.
- Class SD waters are surface waters designated as a source of public water supply and for propagation and preservation of desirable species, as well as for primary and secondary contact recreation. Except for those classified SE, all surface waters are classified SD.

- Class SE waters are surface waters and wetlands of exceptional ecological value, whose existing characteristics should not be altered, and existing natural phenomena should be preserved.
- Class SG1 waters are ground waters which serve or may serve as a source for drinking water or agricultural use, including irrigation. It also includes ground waters which flow into waters, which nourish ecological communities of exceptional ecological value.
- Class SG2 waters are ground waters which because of high concentrations of total dissolved solids (in excess of 10,000 mg/L) are not fit for use as a source of drinking water.

Water Quality Standards

Section 303 of the CWA provides for the establishment of water quality criteria, based on numerical or other limitations, on the concentration of specific substances that may exist in a body of water so that it may be considered safe for its intended use. The federal regulations define the term “water quality standards” as “provisions of State or Federal law which consist of a designated use or uses for the waters of the United States and water quality criteria for such waters based on such uses.” Regulations promulgated by states to comply with this federal requirement are known as water quality standards regulations. The Water Regulation establishes water quality standards for all waters and standards according to use classifications. The former are designated as general water quality standards, while the latter are designated as specific use classification standards.

The general water quality standards require that all waters meet generally accepted aesthetic qualities, and that they do not contain floating debris, scum, or other floating materials in amounts sufficient to be unsightly or deleterious to the existing or designated uses of the water body. The waters of Puerto Rico must be free from color, odor, taste, or turbidity which creates a nuisance to the enjoyment of the existing or designated uses of the water body. The general water quality standards also provide numerical limitation standards that establish the maximum allowable concentrations for certain substances such as heavy metals, organochloride and persistent pesticides, organothiophosphorus and non-persistent pesticides, radioactive materials, temperature, asbestos, non-pesticide organic substances, and carbon tetrachloride. The waters of Puerto Rico must be substantially free from floating non-petroleum oils and greases, as well as from petroleum-derived oils and greases. Solids from waste water sources must not cause sedimentation, or be deleterious to the designated uses of the waters. The allowable level of biochemical oxygen demand (BOD_5) of waste water discharges will be determined on a case-by-case basis depending on the assimilative capacity of the receiving water body, and such determination will ensure compliance with the dissolved oxygen standard application to the receiving water body.

Water Regulation establishes water quality standards for six of the seven classifications of waters:

- Class SA waters shall not be altered except for natural causes and methylene blue reactive substances (MBRS) shall not be present.
- Class SB waters are subject to numerical limitations on dissolved oxygen, fecal coliform bacteria, pH, turbidity, sulfates, and surfactants such as MBRS. In addition, the color of these waters must not be altered and they must not contain taste or odor-producing substances in amounts that will interfere with use for primary contact recreation or that will cause any undesirable taste or odor on edible aquatic life.
- Class SC waters are subject to numerical limitations on dissolved oxygen, total and fecal coliform bacteria, pH, turbidity, sulfates, and surfactants such as MBRS. The color of these waters must not be altered, except when it can be proven that such changes are harmless to the biota and aesthetically acceptable. In addition, these waters must not contain taste or odor-producing substances in amounts that will cause undesirable taste or odor on edible aquatic life.
- Class SD waters are subject to numerical limitations on dissolved oxygen, total and fecal coliforms, pH, color, turbidity, total dissolved solids, chlorine, surfactants, sulfates, total ammonia upstream of certain segments, and total phosphorus. In addition, these waters shall not contain taste or odor-producing substances in amounts that will interfere with their use as potable water supplies or that will cause any undesirable taste or order on edible aquatic life, and they must be free of pathogenic organisms.
- Class SE waters shall have no parameter altered except for natural causes. MBRS shall not be present.
- Class SG1 shall not alter the composition, combination, and concentration of dissolved gases, except by natural causes. Likewise, pH, color, turbidity, taste, and odor-producing substances, and total dissolved solids concentrations shall not be altered except by natural causes. In the case of total dissolved solids, the term natural causes does not include salt water intrusion, unless resulting from severe drought conditions. These waters shall contain no fecal coliforms nor surfactants.
- Class SG2 have not specific water quality standards.

The Water Regulation provides that discharges must comply with water quality standards at the monitoring point, before dilution (end of pipe), except when EQB has approved a mixing zone, a waste load allocation, an intermittent stream variance, a compliance plan, or a waste or drinking water treatment plant temporary exemption. EQB acknowledges that for some substances the numerical value of the water quality standard is below the detection limit of the approved analytical method. For these cases, EQB has promulgated a rule that provides that whenever the numerical value of a water quality standard is below the detection limit of the approved analytical method, the detection limit will be

considered to determine compliance with the standard. Compliance with the discharge limitations will be measured on a 24-hr average concentration.

The Water Regulation does not provide a permit mechanism for discharges into the waters of Puerto Rico. Thus, EPA has not delegated to EQB the NPDES permit program. However, EQB plays an active role in the permit process through the Water Quality Certificate (WQC) mechanism, the mixing zone rule, and the intermittent streams variance rule. The WQC specifically provides that the water quality standards will become water quality certificate limitations unless the proposed discharge qualifies for and obtains a mixing zone, a waste load allocation, an intermittent stream variance, a compliance form, or a waste water or drinking water treatment plant temporary exemption. Public notice is required either to approve or to deny a WQC application. The mixing zone rule allows taking into account dilution of the discharge in the receiving waters to meet the water quality standards. A mixing zone is a tri-dimensional space in a receiving body of water, where a discharge is diluted with surrounding waters. EQB has developed mixing zone and bioassay guidelines which describe procedures, methods, techniques, and organisms to be used to calculate dilution, perform bioassay, collect field data, and establish the natural background concentration values. A mixing zone can be authorized for a period not to exceed five years, but in no case the period will exceed the NPDES permit expiration.

Waste Load Allocation

The Water Regulation allows for the allocation of the waste assimilative capacity of a receiving body of water among various dischargers, whenever a segment of the body of water is not meeting or may not meet the water quality standards after the implementation of technology-based effluent limitations. Whenever EQB determines that an allocation of the receiving water's assimilative capacity if necessary, it will request each point source to submit an application for a Waste Load Allocation (WLA) within 60 days unless an extension of time is granted.

Hazardous Waste

A solid waste is a hazardous waste if it exhibits any of these characteristics: ignitability, corrosivity, reactivity, or toxicity as these are defined in the Hazardous Waste Regulation. EQB may also identify other characteristics if it is determined that they may cause or contribute to a substantial hazard to human health or to the environment. Hazardous waste generated by a small quantity generator may be partially or fully excluded from regulation if it generates no more than 200 kg of hazardous waste in a calendar month and does not accumulate more than 1000 kg of waste at any given time; or if it generates not more than one kg of acute hazardous waste in a calendar month or no ore than 100 kg of any residue of contaminated soil, waste, or other debris resulting from the clean-up of an acute hazardous waste spill or on any land or water. Some hazardous waste recyclable materials are partially exempted, subject to certain conditions. Among

those exempted are the following: industrial ethyl alcohol; used batteries returned to a battery manufacturer for regeneration; used oil that is recycled instead of burned for energy recovery; scrap metal; waste fuel of such waste results from normal petroleum refining, production, and transportation practices. Hazardous waste generators are required to characterize their waste. Each facility must develop and submit to EQB for approval a written contingency plan as part of the facility operations plan which must minimize hazards to human health or to the environment.

Solid waste is any garbage, refuse, residue, sludge, or any other discarded material, including solid, semi-solid, liquids or containers with liquid or gas materials generated by industry, commerce, mining, agricultural operations or household activities. Solid waste exclude the following materials: domestic sewage, permitted industrial wastewater discharges, irrigation return flows, and special nuclear sources or by-product material as defined by the Atomic Energy Act of 1954, as amended.

Water Resources

The Act for Conservation, Development and Use of the Water Resources of Puerto Rico (Law of Waters) declares that all waters of Puerto Rico are property and patrimony of the Commonwealth of Puerto Rico, and are to be administered and protected by the Government, through the DNER. The Waters Regulation establishes the procedure and the requirement for the recognition and registration of water rights acquired under prior legislation. Claims of water rights are subject to a reasonable and beneficial use test. Domestic, agricultural, commercial, industrial, and recreational uses are considered to be beneficial. Reasonable use is achieved when, among other considerations, water is used efficiently and without exceeding the amount that would be normally considered adequate for the existing or proposed use. The franchise is an authorization to use a specific quantity of water, not a right over a particular source. A franchise application must be filed by the property owner or a person duly authorized by the owner. The Waters Regulation appears to limit franchises to the owner or duly authorized tenant. However, the Law of Waters allows applications from any interested party. Domestic consumption has priority over other uses when the volume of available water is insufficient. The optimum use criteria takes into account the public benefit of the water use, including water quality and proposed use; compatibility with available resources; future plans; possible interference with existing water rights and franchises; the impact on the environment, public health and safety, and socio-economic impact. The franchise holder must obtain and maintain, through the effective period of the franchise, a public liability insurance to cover damages to the water resource. DNER and the Commonwealth of Puerto Rico must be insured parties with the amount of insurance coverage established on a case-by-case basis following the guidelines established in the Waters Regulation. Franchises are subject to a fee payment of 1/5 of a cent for each gallon of freshwater extracted; a fee of $150.00, plus $0.20

per million gallon authorized, must be paid for the use of saltish or seawater. Agriculture relative activities are exempted from a fee payment. Fee payments must be made to DNER on a monthly basis. Franchises can be granted for a maximum of ten years and renewed if a renewal permit is filed at least 90 days prior to its expiration date. Franchises are transferable subject to the Secretary's approval.

The Secretary of DNER may, after holding public hearings, designate Critical Areas to implement special rules that may be needed for the conservation and use of a water resource. An area may be designated as critical in the case of foreseeable water supply scarcity, or when water quality conditions require special management techniques to protect the body of water or public health. The Secretary may implement the following management techniques, among others:

- establish priorities for the consumption of water;
- suspend the granting of new franchises and permits;
- require users to implement special conservation measures for the extraction and use of water; and
- impose special reporting requirements.

Upon recommendation from DNER's Secretary, the Governor can declare an emergency when there is a scarcity of the water supply, when such scarcity is foreseen; or when water quality conditions could affect public health.

Fish and Marine Resources

The Fisheries Act was enacted to regulate the activities that affect the fishing resources within the territorial limits of the Commonwealth of Puerto Rico. The statute declares that all aquatic and semi aquatic organisms found in public waters are of public domain. The DNER Secretary has authority to, among other things: establish limitations and regulatory requirements on fishing activities; implement a license and register system for commercial fishing vessels; perform studies to promote the breeding of species; and implement mechanisms to promote the conservation and protection of fish and marine resources. The Secretary has issued regulations establishing limitations, requirements, and prohibitions on general fishing activities. Regulations have also been promulgated to restrict lobster fishing and to control the extraction, transportation, and sale of coral resources for commercial or scientific purposes.

The Puerto Rico Commonwealth Wildlife Act was enacted to, among other things, promote the effective conservation and management of wildlife fauna. The term "wildlife fauna" includes native or adapted species in wild state that breed naturally, and migratory species which settle in Puerto Rico during any season of the year. The Secretary has issued regulations establishing license requirements and limitations on hunting activities and hunting seasons, as well

as mechanisms for the conservation and management of wildlife. Species have been designated by type: game species for hunting; harmful species; and exotic species, and established requirements for their import, possession, purchase, and sale. A regulation has also been promulgated for the designation, protection, and conservation of threatened and endangered fish, wildlife, animals, and plants. “Threatened species” are those in which the majority of or all known populations, are undergoing a decline because of excessive exploitation, extensive habitat destruction, or other environmental disturbances. Also included are species whose populations have not undergone a drastic reduction, and whose ultimate survival is still not guaranteed, as well as species whose populations are still abundant but are in danger because of gravely adverse factors that operate throughout the entire habitat. Endangered species are those whose numbers are reduced to a critical level, or whose habitats have experienced such a drastic reduction that they are considered in immediate danger of extinction. The threatened and endangered species that have been designated include, among others: the golden coquí, the Mona iguana, the green sea turtle, the Puerto Rican boa, the sharp-skinned hawk, the Puerto Rican parrot, the peregrine falcon, the masked duck, the brown pelican, the Caribbean monk seal, and the West Indian manatee.

Concurrently with the designation of threatened or endangered species, the Secretary may designate the critical habitat of the species. The critical habitat of a threatened or endangered species is a specific area within the geographical range where the species was present at the time of its designation, where the physical and biological factors necessary for the conservation of the species exist, and where special management considerations or protection may be necessary. Specific areas outside the geographical range of the species, at the time of its designation, must also be included, if it is determined that these areas are essential for the conservation of the species.

Conservation Easements

The Puerto Rico Conservation Easements Act provides for the creation of conservation easements on properties recognized for their natural, archeological, cultural, historical, or agricultural value. The Act provides tax incentives for the corporations and individuals who donate an easement right to either the government or to a designated nonprofit entity. Conservation easements can only be constituted on properties registered with DNER’s Natural Patrimony Program, or on properties considered important for the conservation of the environment by a bona fide nonprofit entity. Conservation easements shall be constituted in perpetuity.

Zoning Regulations

The Planning Board has promulgated the Zoning Regulation of Puerto Rico which established the general zoning regulatory requirements to guide and

control the use and development of private and public lands. The Zoning Regulation provides specific zoning classifications or districts for agricultural lands, forest areas, highly valuable ecologic areas (such as wetlands, river basins, caverns, and sinkholes), and areas for the conservation of archaeological and historical resources, including establishing a Zoning Regulation of Coastal Zones and to Provide Access to the Beaches and Coasts of Puerto Rico.

Wetlands

Wetlands are areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and mangroves. Activities in wetlands are regulated by the Rivers and Harbors Act of 1899 and the Federal Water Pollution Control Act (CWA) and the regulations promulgated by the US Army Corps of Engineers (the Corps) and the Environmental Protection Agency (EPA). The Fish and Wildlife Service (F&WS) also has jurisdiction over wetlands, pursuant to the Emergency Wetlands Resource Act of 1986 and the Endangered Species Act.

Navigable Waters

The Rivers and Harbors Act requires a permit for the construction of structures, excavation, filling, or conducting any other activity that may obstruct navigable waters. Section 404 of the CWA authorizes EPA to monitor the Corps' permitting procedures, and grants EPA veto power to override the Corps' determinations, whenever EPA's Administrator determines that the discharge will have an unacceptable adverse effect on municipal water supplies, shellfish beds and fishery areas, wildlife, or recreational areas. This veto power extends to the Corps' jurisdictional determinations, its specification of possible disposal sites, and any Corps' decision to authorize dredge and fill permits. A WQC must be obtained from or waived by EQB and a determination of consistency with the Puerto Rico Coastal Management Program (CMP) must be obtained from the Planning Board. The WQC must certify that the discharge will comply with local water quality standards and effluent limitations. Activities that affect land and water uses in the coastal zone must be conducted in a manner consistent with the CMP. Activities outside of the coastal zone are subject to this requirement if such activities have spillover effects over a coastal zone. Puerto Rico's coastal zone extends inwards 1,000 m from the shoreline and can extend farther inland to include important natural ecosystems.

Coastal zones are regulated by federal and state statutes and regulations including the federal Coastal Zone Management Act (CSMA), Puerto Rico Coastal Management Program (CMP), Puerto Rico Planning Board Organic Act, and DNER's Organic Act. Congress enacted the Coastal Zone Management Act to promote the preservation, protection, development, restoration and

enhancement of the coastal zones' resources, and to assist the states in developing and implementing coastal zone management programs for the protection of natural resources, including wetlands, floodplains, estuaries, beaches, dunes, barrier islands, coral reefs, and fish and wildlife within the coastal zone. The Puerto Rico Coastal Management Program designates "coastal zone" to include the coastal strip which extends 1000 m inland from the shoreline, and the territorial sea which extends seaward three nautical miles from all land areas (including offshore islands and cays under the Commonwealth's jurisdiction, such as the islands of Culebra, Vieques, and Mona). The CMP extends the coastal zone of Puerto Rico inland to include important natural ecosystems. Activities that impact the coastal zone and require a federal permit or license are subject to a CMP consistency determination requirement. The following activities are specifically identified in the CMP as activities that impact the coastal zone:

- Sand extraction from dunes;
- Construction of roads in the coastal watershed;
- Discharge of waste in the coastal watershed;
- Activities that affect or alter surface run-off waters in the coastal watershed;
- Planning, construction, modification, or removal of public works, facilities, or structures located within the coastal zone;
- Acquisition and use of land or water resources located within the coastal zone;
- Dredge fill, development, construction, or discharge of waste in coastal waters.

The Planning Board has authority, under its Organic Act, to regulate coastal zones. The Board promulgated the Zoning Regulation and the Coastal Zone Regulation, both of which an impact on coastal zones. The Zoning Regulation establishes a series of design requirements for projects to be developed within the coastal zone. This regulation mandates public access to beaches and establishes minimum requirements to be observed between buildings and the maritime terrestrial zone. The Coastal Zone Regulation provides regulatory controls over construction, demolition, or alteration of structures, subdivision of parcels, development, and any other activity proposed for a coastal zone.

DNER has authority under its Organic Act to regulate coastal zones. DNER promulgated the Regulation for the Use, Vigilance, Conservation and Administration of Territorial Waters, Submerged Lands, and the Maritime Zone. DNER's regulation restricts the types of activities to be carried out in the coastal maritime zone. The regulation establishes permit requirements for dredging activities, construction of submerged utility lines, marinas and fishing areas, and for conducting beach festivals.

Pesticide control

The Pesticide Act of Puerto Rico prohibits the introduction, distribution, and sale of adulterated or mislabeled pesticides, or any pesticide that is not registered with the Department of Agriculture of Puerto Rico. The Secretary of Agriculture has the authority to promulgate regulations: set criteria for the labeling, registration, packaging, distribution, sale, use, and classification of pesticides; and inspect the establishments where pesticides are manufactured, mixed, or packaged.

Private Rights and Remedies

The cornerstone of the law of damages in Puerto Rico is the broad and encompassing Article 1802 of the Civil Code, which states that "[a] person who by act or omission causes damage to another through fault or negligence shall be obliged to repair the damage so done. Concurrent imprudence of the party aggrieved does not exempt from liability, but entails a reduction of the indemnity. Three requirements must be met to have a cause of action: the damages suffered must be real; a causal relation exists between the damages and the act or omission of another person; and that said act or omission is negligent or wrongful. The doctrine of strict liability, also known as absolute, objective, or no-fault liability, is based on public policy and societal concerns over distributive justice where any person who knowingly engages in inherently dangerous activities, that pose a great public risk, must bear any detrimental consequences which may stem therefrom, regardless of the precautions taken, or the diligence exercised. Fault or negligence are irrelevant; once damages and causation are established, the defendant responds irrespectively of whether he was prudent or careful.

Article 22 of the Act for Conservation, Development and Use of the Water Resources of Puerto Rico (Law of Waters) establishes two distinct sources of redress. The first remedy is an action against any person or entity found to be in violation of the Law of Waters or of the regulations promulgated. The second is an extraordinary remedy in the form of mandamus and injunction. A mandamus is a writ directed to a private or municipal corporation, or any of its officers; or to an executive, administrative, or judicial officer; or to an inferior court; ordering the performance of a particular act therein specified which pertains to a public, official, or ministerial duty. Common or public nuisance is anything injurious to health, is indecent or offensive to the senses, or an obstruction to the free use of property, so as to interfere with the comfortable enjoyment of life or property by an entire community or neighborhood, or by any considerable number of persons, or unlawfully obstructs the free passage or use, in the customary manner, of any navigable lake, river, bay, stream, canal or basin, or any public park, square, street or highway is a public nuisance. An injunction is an extraordinary remedy that is characterized by its urgent and summary nature where the petitioner must be confronting imminent and irreparable harm.

Appendix 7

Standardized environmental monitoring of open-ocean cage sites: basic considerations

DRAFT (submitted to World Aquaculture, February 2005)

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As interest increases in marine fish culture in open-ocean environments, more governmental agencies will receive petitions for permits for these operations. The agencies will continue to need information concerning potential environmental influence of open-ocean aquaculture and will seek appropriate environmental monitoring methodology. Other governmental agencies are taking proactive steps in the event applicants propose open-ocean cage aquaculture in their waters. Because every site is different, standardization of the sampling methodology will be difficult, but some common and basic measurements must be considered.

The purpose of this article is to initiate discussions leading to effective monitoring plans to provide information for agencies to make informative decisions. Further, standardized methodology must be identified that is cost-effective and practical while still capable of collecting pertinent data. Anyone should be able to take on-site samples and send them to an appropriate lab. The methodology should be appropriate for a future open-ocean cage aquaculture industry to continue beyond the research and development phase.

Because open-ocean cage aquaculture benefits from large volumes of water and strong water currents passing through the site, the industry differs significantly from coastal aquaculture where nutrients are more likely to accumulate and cause eutrophication. Wastes from most open-ocean sites are distributed over large areas, making it difficult to determine the impact. It is difficult to control discharges--whether from excess feed, fish wastes, medications, or escapement--from cage systems. Because of high dilution rates, information gathered concerning the influence on water quality may be difficult to interpret while operating at experimental levels. So far, water and sediment quality monitoring for nutrients in open-ocean conditions, including for nitrogen and phosphorus, have indicated little impact. However, even small increases in nutrients such as phosphorus and nitrogen can stimulate primary productivity. Little is known concerning nutrient levels influencing primary productivity in the water column near cage operations. Dilution factors are so great that only with low current conditions is there any possibility of significant notable change. That said, agencies will still require some monitoring of the water column, perhaps to

determine the area affected by the cages (as for the United States NPDES, National Pollutant Discharge Elimination System). Oceanographic remote sensing technology could measure primary productivity, but is used for deep oceanic areas; relatively shallow areas at open-ocean cage sites are not suitable because reflectance from the bottom interferes with chlorophyll measurements. Another limitation of oceanographic remote sensing of ocean color is that the spatial resolution (pixel size) is in the order of one kilometer, too coarse for this type of application. This may change as more sophisticated techniques are developed, especially ones which can compensate for reflectance and increase the spatial resolution.

Currents should be considered within any standardized sampling scheme. Currents vary by location and time of day. For safety, sampling methodologies need to minimize risk to divers, including sampling at slack tide, sampling on days with the least current during the monthly lunar phase, or adaptation for boat-side sampling. From a practical aquaculture perspective, nutrient discharge would likely be more concentrated a few hours following a feeding period, especially during slack tide. Therefore, water sampling procedures should focus on changes or accumulation of any pollutants over time, not daily changes. Daily changes could be useful for modeling purposes where data would be correlated to current patterns to better understand nutrient dynamics at the site.

Accumulation of organic matter in the sediment is usually not severe several hundred meters distance from the cages; thus, the influence will probably be minimal. Accumulation of organic matter and changes in the flora and fauna are important indicators of environmental status. Dredge samples may be suitable in soft sediment, but may be problematic in areas with sand and/or rubble where core samplers could be used. Benthic samples should be monitored under and around the farm site and at a “control” station some distance from the site, but not located immediately up- or down-current of the prevalent conditions at the site.

Many of the water quality variables of interest may be monitored automatically using devices taking continuous information for 1-2 months duration. These include currents, dissolved oxygen, temperature, chlorophyll-*a*, total suspended solids, and turbidity. Care must be taken in cases where probes can become fouled over time, especially with chlorophyll-*a* and dissolved oxygen probes. Unfortunately, other *in situ* measurements are neither reliable nor sensitive to minute changes in variables such as ammonia-N, nitrate-N and nitrite concentrations. Thus, laboratory analyses will continue to be important.

The significance of monitoring results will be enhanced if basic oceanographic variables, e.g. currents, tide-phase, wind, sea state, and time and rate of feeding are measured concurrently with water quality parameters. Standardized monitoring could begin at the same hour to facilitate comparisons with other variables. Basic oceanographic techniques should be devised to determine local

current patterns, combined with information concerning nutrients concentrations exiting cages. In the case of multiple neighboring farms, care must be taken to compare to pre-farm ambient levels.

Miscellaneous monitoring could entail effects of cleaning cages, adding antibiotics, treating fish for parasites, or harvesting. While these latter items may be important environmentally, they should be treated on a case-by-case basis.

Open-ocean cages serve as fish aggregating devices (FADs) as demonstrated in recent experiences in Hawaii and Puerto Rico. Thus studies should include the assemblages of native fish attracted to cages and their relation with fisheries. Fish census methodologies are usually for reef or coastal systems; thus, suitable methodologies need to be utilized to determine biomass and population of wild fish near cages. Fish census techniques using video could be correlated to, and complemented by, sonar scanning techniques.

Consequently, planning environmental monitoring programs needs to consider these and other points. As the industry grows, scientists should eventually leave most environmental monitoring to aquaculturists, their impartial consultants, or to governmental agencies. These agencies should continue to provide bureaucratic oversight of the monitoring, which should be routine and comparable among sites. The goal should be to assess sensitive areas or points influenced by the operation. Because water quality does not seem to be severely affected, sediment should be the focus for most monitoring. Scientists would only be involved in evaluating and determining the overall environmental influence by the industry.

Minimizing the influence of open-ocean cage aquaculture

Aquaculture, like agriculture, always results in an unavoidable change to the pre-existing environment. Thus some change near a fish farm is to be expected. Agencies regulating the permitting process need to recognize this and allow for these necessary changes. Environmental impact assessments or statements should demonstrate if the influence is minimal or negligible compared to other food productions systems. Appropriate management practices could be recommended, such as moving the cages to allow a site to lie fallow for some period of time. Siting and site selection criteria, which precede environmental monitoring per se, are crucial components of the permitting process. Before permits are issued, governments should establish zones not suitable for open-ocean aquaculture. Some suggestions for minimizing the environmental influence in open-ocean cage aquaculture include the following:

- avoid sites near scenic viewpoints, fishing grounds, areas with significant navigation, and sensitive environmental areas (such as coral reefs and seagrass beds)
- select areas with moderate water currents to disperse wastes

- use high quality feeds
- avoid overfeeding
- monitor fish behavior during feeding to avoid overfeeding
- minimize small feed particles (fines)
- adjust feed-pellet size to fish size
- increase depth beneath caged fish (to allow waste dispersion over larger bottom areas)

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